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U.S. Department of Commerce
National Institute of Standards and Technology

Office of Applied Economics
Building and Fire Research Laboratory
Gaithersburg, Maryland 20899

Metrics and Tools for Measuring Construction Productivity: Technical and Empirical Considerations

Allison L. Huang, Robert E. Chapman, and David T. Butry

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Dr. Patrick D. Gallagher, Deputy Director

Abstract

Although the construction industry is a major component of the U.S. economy, it has experienced a "perceived" prolonged period of decline in productivity. Due to the critical lack of measurement methods, however, the magnitude of the productivity problem in the construction industry is largely unknown. The measurement problem is exacerbated by the fact that the construction industry is composed of four sectors that differ significantly in the outputs produced, firm size, and use of technology. The four sectors, which taken together define the construction industry, are residential, commercial/institutional, industrial, and infrastructure.

This report describes efforts underway that focus on the measurement of construction productivity at three levels—task, project, and industry—and how such measurements can be developed. This report analyzes the measurement challenges associated with the development of meaningful measures of construction productivity at the task, project, and industry levels and establishes a framework for addressing those challenges. Specifically, this report identifies the metrics, tools, and data needed to move forward in collaboration with key construction industry stakeholders. Once produced, these metrics, tools and data will help construction industry stakeholders make more cost-effective investments in productivity enhancing technologies and improved life-cycle construction processes; they will also provide stakeholders with new measurement and evaluation capabilities. Finally, this report lays the foundation for future research and for establishing key industry collaborations that will enable more meaningful measures of construction productivity to be produced at the task, project, and industry levels.

Keywords

Building economics; construction; economic analysis; information technology; labor productivity; metrics; performance measurement; productivity

Preface

This study was conducted by the Office of Applied Economics in the Building and Fire Research Laboratory at the National Institute of Standards and Technology. This report analyzes the measurement challenges associated with the development of meaningful measures of construction productivity at the task, project, and industry levels and establishes a framework for addressing those challenges. The intended audience is the National Institute of Standards and Technology, as well as, other government agencies that compile and publish construction-related statistics, private sector organizations concerned about the perceived decline in construction productivity, and standards development organizations that produce standards used by the construction industry.

Disclaimer

Certain trade names and company products are mentioned in the text in order to adequately specify the technical procedures and equipment used. In no case does such identification imply recommendation or endorsement by the National Institute of Standards and Technology, nor does it imply that the products are necessarily the best available for the purpose.

Disclaimer Regarding Non-Metrics Units

The policy of the National Institute of Standards and Technology is to use metric units in all of its published materials. Because this report is intended for the U.S. construction industry that uses U.S. customary units, it is more practical and less confusing to use U.S. customary units rather than metric units. Measurement values in this report are therefore stated in U.S. customary units first, followed by the corresponding values in metric units within parentheses.

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Table of Contents

List of Figures

List of Tables

Acronyms and Abbreviations

AAR	Additions, Alterations, and Reconstruction
BEA	Bureau of Economic Analysis
BFRL	Building and Fire Research Laboratory
BIM	Building Information Modeling
BLS	Bureau of Labor Statistics
CERF	Civil Engineering Research Foundation
CES	Current Employment Statistics
CII	Construction Industry Institute
CPS	Current Population Survey
CURT	Construction Users Roundtable
ECI	Employment Cost Index
GDP	Gross Domestic Product
GPS	Global Positioning Satellite
HWS	Hours-at-Work Survey
ICS	Industry Classification System
KLEMS	Capital, Labor, Energy, Materials, and Services
M&R	Maintenance and Repair
NAICS	North American Industry Classification System
NCS	National Compensation Survey
NIPA	National Income and Product Accounts
NIST	National Institute of Standards and Technology
NRC	National Research Council
NSF	National Science Foundation

OAE	Office of Applied Economics
OECD	Organization of Economic Co-Operation and Development
PPI	Producer Price Index
PPMOF	Prefabrication, preassembly, modularization, and offsite fabrication
R&D	Research and Development
RFID	Radio-Frequency Identification
SIC	Standard Industry Classification
SOC	Standard Occupational Classification
TFP	Total Factor Productivity

1 Introduction

1.1 Background

Although the construction industry is a major component of the U.S. economy, it has experienced a "perceived" prolonged period of decline in productivity. Due to the critical lack of measurement methods, however, the magnitude of the productivity problem in the construction industry is largely unknown. Construction productivity is a highly important topic. An analysis of articles published in the American Society of Civil Engineers' Journal of Construction Engineering and Management (JCEM) during 1985-2002 indicates that productivity is a second highest ranked topic, in terms of number of articles.[1] The measurement problem is exacerbated by the fact that the construction industry is composed of four sectors that differ significantly in the outputs produced, firm size, and use of technology. The four sectors, which taken together define the construction industry, are residential, commercial/institutional, industrial, and infrastructure.

To address these challenges, the National Institute of Standards and Technology (NIST) requested that the National Research Council (NRC) appoint an *ad hoc* committee of experts to provide advice for advancing the competitiveness and productivity of the U.S. construction industry. The committee's specific task was to plan and conduct a workshop to identify and prioritize technologies, processes, and deployment activities that have the greatest potential to advance significantly the productivity and competitiveness of the capital facilities sector of the U.S. construction industry over the next 20 years.[2]

To assist the committee in its planning for the workshop, NIST prepared a white paper[3] describing efforts underway that focus on the measurement of construction productivity at three levels: task, project, and industry.[4] The NIST white paper discussed how such

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[1] Osama Abudayyeh, Amber Dibert-De Young, and Edward Jaselskis, "Analysis of Trends in Construction Research: 1985-2002," Journal of Construction Engineering and Management May/June (2004): 433-439.

[2] The capital facilities sector includes commercial/institutional buildings (including high-rise and multifamily residential), industrial, and infrastructure projects. It does not include single-family and low-rise residential projects.

[3] Robert E. Chapman and David T. Butry, *Measuring and Improving the Productivity of the U.S. Construction Industry: Issues, Challenges, and Opportunities*, NIST White Paper (Gaithersburg, MD: National Institute of Standards and Technology May 2008).

[4] Tasks refer to specific construction activities such as concrete placement or structural steel erection. Projects are the collection of tasks required for the construction of a new facility (e.g., the construction of a new commercial office building, bridge, or power plant) or renovation (i.e., additions, alterations, and major replacements) of an existing constructed facility. Industry measures are based on the North

measurements can be developed, how they are related to the use of information and automation technologies and construction processes over the life of the project, and how to build on several ongoing collaborative efforts aimed at improving the efficiency, competitiveness, and innovation of the construction industry.

NIST briefed the NRC committee in July 2008 on the Building and Fire Research Laboratory's overall research program, its Measurement Science for Advanced Infrastructure Delivery goal that focuses on metrics and tools for construction productivity, and the contents of the white paper. Members of the NRC committee discussed on-going productivity-related research with NIST and asked for recommendations of researchers who might be willing to prepare white papers that would be presented as part of a major workshop planned for November 2008. As a result of NIST's input and input from other subject-matter experts, three white papers were commissioned. The three white papers were presented at the November workshop, which was attended by the NRC committee members, several key NIST staff, and approximately 50 additional experts. At the end of the workshop, the participants identified a range of activities that could improve construction productivity. From among these, the committee identified five that could lead to breakthrough improvements in construction efficiency and productivity in 2 to 10 years. These activities are highlighted in the NRC report which states "If implemented throughout the capital facilities sector, these activities could significantly advance construction efficiency and improve the quality, timeliness, cost-effectiveness, and sustainability of construction projects."[5] The five activities, entitled "Opportunities for Breakthrough Improvements," are:

1. Widespread deployment and use of interoperable[6] technology applications, also called Building Information Modeling (BIM);

2. Improved job-site efficiency through more effective interfacing of people, processes, materials, equipment, and information;

3. Greater use of prefabrication, preassembly, modularization, and off-site fabrication techniques and processes;

American Industrial Classification System (NAICS) codes for the construction sector and represent the total portfolio of projects.

[5] National Research Council. *Advancing the Competitiveness and Efficiency of the U.S. Construction Industry*. (Washington, DC: National Academies Press, October 2009).

[6] Interoperability is the ability to manage and communicate electronic data among owners, clients, contractors, and suppliers, and across a project's design, engineering, operations, project management, construction, financial, and legal units.

4. Innovative, widespread use of demonstration installations; and

5. Effective performance measurement to drive efficiency and support innovation.[7]

Although the focus of this report is on effective performance measurement (activity 5), it also provides limited coverage of activities 1 through 4. This is due in part to the treatment of those activities in the NIST white paper and the expansion of that treatment in various sections of this report.

1.2 Purpose

The purpose of this report is to analyze the measurement challenges associated with the development of meaningful measures of construction productivity at the task, project, and industry levels and establish a framework for addressing those challenges. Measuring construction productivity is challenging because on the one hand construction industry stakeholders, such as building owners and managers, want easy answers to complicated questions that are made available through task-level metrics, while, on the other hand, industry leaders, policy makers at the federal and state levels, construction industry researchers/academics, and industry specialists demand complicated data-intensive metrics to assess national and industry-wide trends and challenges facing this critical sector of the U.S. economy. To address these challenges, this report identifies the metrics, tools, and data needed to move forward in collaboration with key construction industry stakeholders. Once produced, these metrics, tools, and data will help construction industry stakeholders make more cost-effective investments in productivity enhancing technologies and improved life-cycle construction processes; they will also provide stakeholders with new measurement and evaluation capabilities.

1.3 Scope and Approach

This report contains four chapters and three appendices in addition to the Introduction. Chapters 2 through 4 are the core components of the report. These chapters lay the foundation for future research and for establishing key industry collaborations that will enable more meaningful measures of construction productivity to be produced at the task, project, and industry levels.

Chapter 2 provides a snapshot of the U.S. construction industry. As such, it provides the context within which the scope and size of the construction productivity measurement problem is defined. The chapter contains three sections. Section 2.1 presents information on the value of construction put in place to show the size of the construction industry and each of its four sectors. The four sectors, which taken together define the

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[7] National Research Council, *Advancing the Competitiveness and Efficiency of the U.S. Construction Industry. Op. cit.*

construction industry, are residential, commercial/institutional, industrial, and infrastructure. Section 2.2 uses information on the construction supply chain to highlight the critical importance of manufactured products (materials, components, and systems). Section 2.3 places special emphasis on the role of research and innovation in the construction industry.

Chapter 3 provides a survey of the literature on productivity and competitiveness. The chapter contains seven sections. Section 3.1 describes the three dimensions of construction productivity—task, project, and industry. Section 3.2 discusses the factors affecting construction productivity. Sections 3.3 through 3.5 describe existing productivity measures and present estimates of construction productivity measures at the task, project, and industry levels, respectively. Section 3.6 discusses the divergence between task-level and industry-level productivity estimates and presents possible explanations for the divergence. Section 3.7 synthesizes a number of conclusions and observations from the literature survey.

Chapter 4 analyzes the challenges and opportunities for using national statistics in construction productivity measurement. The chapter is divided into two sections. Section 4.1 discusses the widely-referenced productivity comparison diagram produced by Paul Teicholz. The discussion focuses on the productivity calculations by Teicholz with particular emphasis on the data challenges associated with construction productivity measurement. Section 4.2 examines the types of data that are available in national statistics and suggests ways in which they would enable the development of meaningful productivity measures for the construction industry.

Chapter 5 concludes with a summary and a discussion of topics for future research.

Appendix A presents a mathematically-oriented discussion of productivity metrics. The metrics described in Appendix A are largely based on the Bureau of Labor Statistics productivity methodology. Both single factor labor productivity and multifactor productivity methodologies are presented and discussed.

Appendix B presents an annotated bibliography on productivity and competitiveness. The annotated bibliography consists of three sections. Section B.1 focuses on documents with particular emphasis on productivity measurement and other related issues in the construction industry. Some of the measurement issues covered are deflators, quality adjustments of output, and the definition of what constitutes the construction industry. Section B.2 focuses on construction data-related documents. Section B.3 focuses on documents that treat the general topic of productivity methods and measurement.

Appendix C identifies sources of construction productivity data and discusses their availability. Appendix C contains two sections. Section C.1 provides a description of data sources that may be relevant to construction productivity measurement. Section C.2

describes classification systems, variables, and availability. The section concludes with a series of tables cross-referencing key sources of data and their availability.

Appendix D is a glossary of terms used in economics and construction.

2 Construction: An Engine for Economic Growth

Construction is an engine of growth for the U.S. economy. Investment in plant and facilities, in the form of construction activity, provides the basis for the production of products and the delivery of services. Investment in infrastructure promotes the smooth flow of goods and services and the movement of individuals. Investment in housing accommodates new households and allows existing households to expand or improve their housing. It is clear that construction activities affect nearly every aspect of the U.S. economy and that the industry is vital to the continued growth of the U.S. economy.

This chapter provides a snapshot of the U.S. construction industry. As such, it provides the context within which the scope and size of the construction productivity measurement problem is defined. The chapter contains three sections. Section 2.1 presents information on the value of construction put in place to show the size of the construction industry and each of its four sectors. The four sectors, which taken together define the construction industry, are residential, commercial/institutional, industrial, and infrastructure. Section 2.2 uses information on the construction supply chain to highlight the critical importance of manufactured products (materials, components, and systems). Section 2.3 places special emphasis on the role of research and innovation in the construction industry.

2.1 Value of Construction Put in Place

This section provides information on a key indicator of construction activity; the value of construction put in place. Data published by the U.S. Bureau of the Census are used to establish the composition of construction expenditures by type of construction/function (e.g., non-residential/office building). These expenditures are then assigned to four key construction industry sectors. The reference document used throughout this section is the Current Construction Reports series C30 publication Value of Construction Put in Place.

The data presented in the C30 report are summarized in Table 2.1. To facilitate comparisons between this report and the C30 report, Table 2.1 uses the same row and column headings as are used in the C30 report. Table 2.1 records annual values in millions of constant 2008 dollars for the years 2002 through 2008.[8]

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[8] Inflation reduces the purchasing power of the dollar over time; deflation increases it. When amounts are stated in actual prices as of the year in which they occur, they are said to be in ***current dollars***. Current dollars are dollars of any one year's purchasing power, inclusive of inflation/deflation. That is, they reflect changes in purchasing power of the dollar from year to year. In contrast, ***constant dollars*** are dollars of uniform purchasing power, exclusive of inflation/deflation. Constant dollars indicate what the same good or service would cost at different times if there were no change in the general price level to change the purchasing power of the dollar. For additional information on conducting economic analyses using either constant dollars or current dollars, see Sieglinde K. Fuller and Stephen R. Petersen, *Life-Cycle Costing*

Reference to Table 2.1 reveals that total construction expenditures in real terms increased gradually from 2002 ($1015 billion) to 2006 ($1247 billion) and then declined in 2007 ($1195 billion) and 2008 ($1072 billion). Table 2.1 is organized to allow for in-depth analyses of the components/subcomponents of total construction expenditures. To facilitate such analyses, the data presented in Table 2.1 are initially divided into two parts: (1) private construction; and (2) public construction.

Private construction contains two major components—residential buildings and non-residential buildings—plus a number of subcomponents. Both the two major components and the subcomponents are shown as headings in the first column of Table 2.1.

The residential buildings component includes new private housing and improvements. New private housing includes new houses and town houses (single family) and apartments and condominiums (multifamily). The value of improvements put in place is a direct measure of the value of residential additions and alterations activities.

The non-residential buildings component includes manufacturing (industrial), office buildings, lodging, and commercial. Also falling under the non-residential buildings component are religious, educational, health care, and public safety.

Rounding out the private construction component are farm non-residential, public utilities, and "all other private." These are generally of a non-residential nature, but are not part of non-residential buildings. Farm non-residential construction includes structures such as barns, storage houses, and fences. Land improvements such as leveling, terracing, ponds, and roads are also a part of this subcomponent. Privately owned public utilities construction is categorized by industry rather than function of the building or structure. This subcomponent includes expenditures made by utilities for telecommunications, railroads, petroleum pipelines, electric light and power, and natural gas. "All other private" includes privately owned streets and bridges, sewer and water facilities, airfields, and similar construction.

For public construction, there are two major components—residential and non-residential. Both the two major components and the various subcomponents are shown as headings in the first column of Table 2.1. The non-residential building component contains subcomponents similar to those for private construction, with educational buildings being the largest subcomponent. Expenditures for the non-building

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Manual for the Federal Energy Management Program. NIST Handbook 135. (Gaithersburg, MD: National Institute of Standards and Technology, 1996).

subcomponents overwhelmingly consist of outlays for highways and streets, with sewer systems being a distant second subcomponent.

Table 2.1 Value of Construction Put in Place in Millions of Constant 2008 Dollars[9]

Type of Construction	Millions of Constant Dollars (2008)						
	2002	2003	2004	2005	2006	2007	2008
Total Construction	1,014,728	1,043,163	1,130,154	1,215,644	1,246,914	1,194,869	1,072,132
Total Private Construction	759,287	790,267	879,195	957,501	974,170	894,697	766,170
Residential	474,763	521,917	607,385	674,571	655,447	512,184	350,078
New Housing Units	357,651	404,502	475,856	530,052	500,665	367,740	229,934
New single family	318,214	363,412	430,329	477,911	444,273	316,902	185,776
New multi-family	39,437	41,090	45,527	52,141	56,392	50,839	44,158
Improvements	117,112	117,415	131,529	144,519	154,782	144,444	120,144
Nonresidential	284,524	268,351	271,811	282,930	318,723	382,513	416,092
Lodging	12,527	11,619	13,657	13,963	18,822	28,536	35,379
Office	42,242	35,781	37,475	41,094	48,785	55,881	57,084
Commercial	70,620	67,288	72,028	73,404	78,355	89,155	81,495
Health Care	26,854	28,337	29,944	31,414	34,192	36,954	39,101
Educational	15,689	15,708	14,476	14,098	14,780	17,332	18,585
Religious	9,975	10,015	9,293	8,505	8,266	7,811	7,097
Public Safety	260	216	329	450	447	618	650
Amusement and Recreation	8,950	9,105	9,611	8,276	9,960	10,584	10,316
Transportation	8,106	7,685	7,797	7,854	9,242	9,355	9,896
Communication	22,002	16,915	17,630	20,776	23,695	28,543	25,496
Power	39,025	39,338	31,184	28,998	33,282	49,184	68,702
Sewage and Waste Disposal	294	325	377	265	326	424	548
Water Supply	475	460	462	359	509	536	696
Manufacturing	27,220	25,080	26,975	32,947	37,471	47,042	60,784
Other	286	476	573	528	591	558	263
Total Public Construction	255,441	252,896	250,958	258,143	272,744	300,172	305,962
Residential	6,300	6,103	6,278	6,182	6,496	7,499	7,330
Nonresidential	249,141	246,792	244,681	251,961	266,248	292,674	298,632
Office	10,750	10,343	10,856	9,356	9,085	11,884	13,222
Commercial	4,203	4,709	4,402	4,033	3,572	3,974	3,447
Health care	5,626	5,982	6,738	6,543	6,895	8,493	8,598
Educational	72,709	71,251	70,152	73,751	75,921	83,142	85,496
Public safety	9,108	8,163	7,671	7,613	7,850	9,975	12,286
Amusement and recreation	11,790	10,608	9,418	8,520	10,367	11,442	11,172
Transportation	22,747	21,228	20,766	19,764	20,623	23,746	24,057
Power	5,022	9,163	9,158	10,099	9,174	12,398	11,457
Highway and street	68,636	66,667	66,442	70,323	76,431	79,176	81,592
Sewage and waste disposal	19,138	19,078	20,058	21,637	24,436	25,403	24,596
Water supply	14,415	14,159	13,922	15,106	15,467	15,869	16,255
Conservation and development	4,208	4,322	4,410	4,765	5,390	5,353	5,350
Other	790	1,120	688	450	1,037	1,818	1,104

Source: Census C30 Report. Individual entries may not sum to totals due to independent rounding.

To get the sector totals, each subcomponent was assigned to a sector and summed. The sector totals and the overall total are recorded in Table 2.2. Reference to the table reveals

[9] Value of construction put in place is reported in current dollars by the Census Bureau. Constant 2008 dollars are obtained using consumer price indices.

that sector totals vary considerably, with residential normally being the largest and industrial the smallest.

Table 2.2 reveals that the commercial/institutional, industrial, and infrastructure sectors grew more or less consistently in real terms over the entire seven-year period. In real terms, expenditures in the commercial sector grew from $301.8 billion in 2002 to $384.4 billion in 2008, an increase of almost 30 %. Real expenditures for two of the four sectors, industrial and infrastructure, were essentially constant between 2002 and 2005 and then increased sharply between 2006 and 2008. Real expenditures for the industrial sector grew from $27.4 billion in 2002 to $61.3 billion in 2008, an increase of almost 125 %. Over the 2002 to 2008 period, real expenditures for infrastructure increased by slightly more than 30 %. Real expenditures for the residential sector exhibited a cyclical pattern that highlights the magnitude of the current housing crisis. Real expenditures for the residential sector first increased sharply, from $481.1 billion in 2002 to $680.8 billion in 2005, declined gradually in 2006 (to $661.9 billion), and then fell precipitously in 2007 (to $519.7 billion) and 2008 (to $357.4 billion).

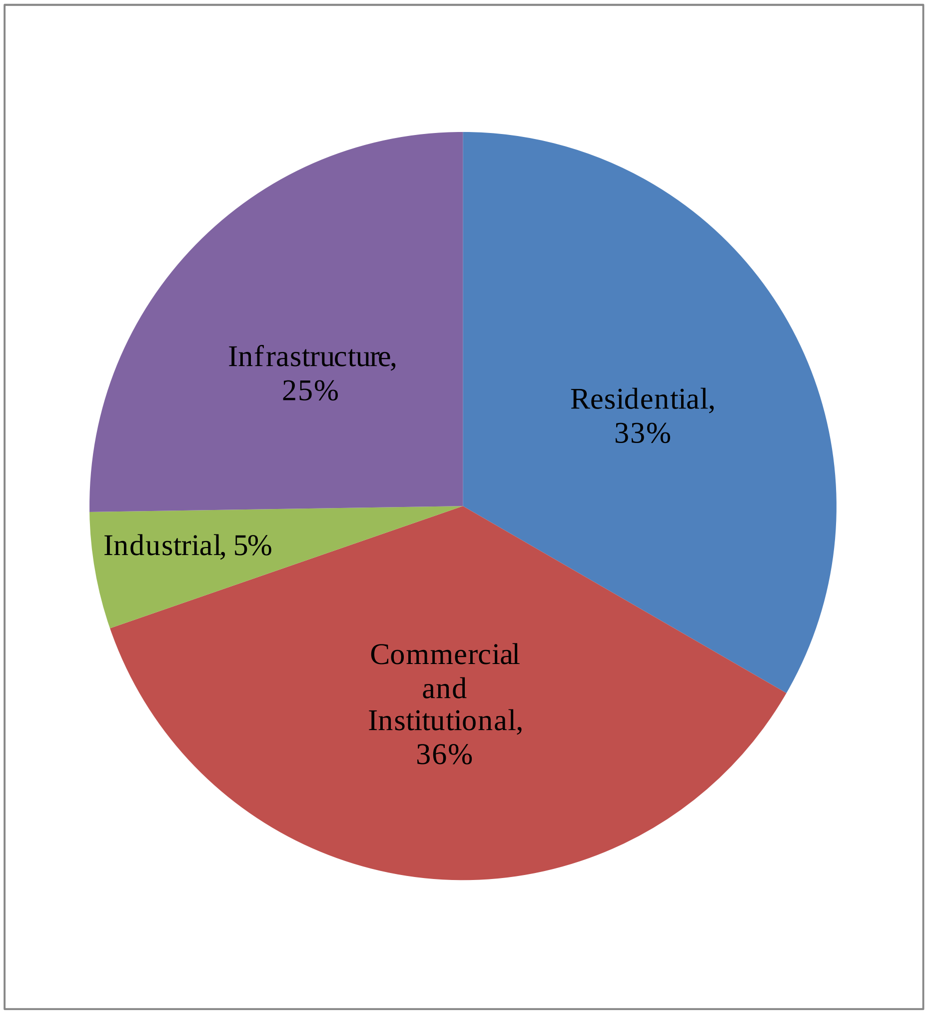
Table 2.2 Value of Construction Put in Place: Sector Totals and Sum Total in Millions of Constant 2008 Dollars

Type of Construction	Millions of Constant Dollars						
	2002	2003	2004	2005	2006	2007	2008
Residential	481,063	528,020	613,663	680,753	661,944	519,684	357,408
Commercial/Institutional	301,784	290,052	296,490	301,233	327,855	377,068	384,394
Manufacturing	27,438	25,167	27,136	33,117	37,913	47,475	61,269
Public Works	204,443	199,924	192,868	200,543	219,204	250,642	269,062
TOTAL	1,014,728	1,043,163	1,130,154	1,215,644	1,246,914	1,194,869	1,072,132

Source: Census C30 Report. Note that due to rounding the values entered in the "Total" row in Table 2.2, differ slightly from the values entered in the "Total Construction" row in Table 2.1.

The data contained in Table 2.2 provide the basis for calculating each sector's relative share of total construction expenditures. Each sector's relative share of total construction expenditures is shown graphically in pie chart form in Figure 2.1. It was constructed using 2008 data from Table 2.2. Figure 2.1 reveals that in 2008 the commercial sector accounted for 36 % of total construction expenditures, followed by the residential sector with 33 % of total construction expenditures. Over the longer term, the commercial/institutional sector's relative share of total construction expenditures is usually exceeded by the residential sector, which normally constitutes about 45 % of the total. However, due to the current housing crisis, their relative shares were reversed. Historically, the commercial sector's relative share tends to exceed the combined total for the industrial and infrastructure sectors.

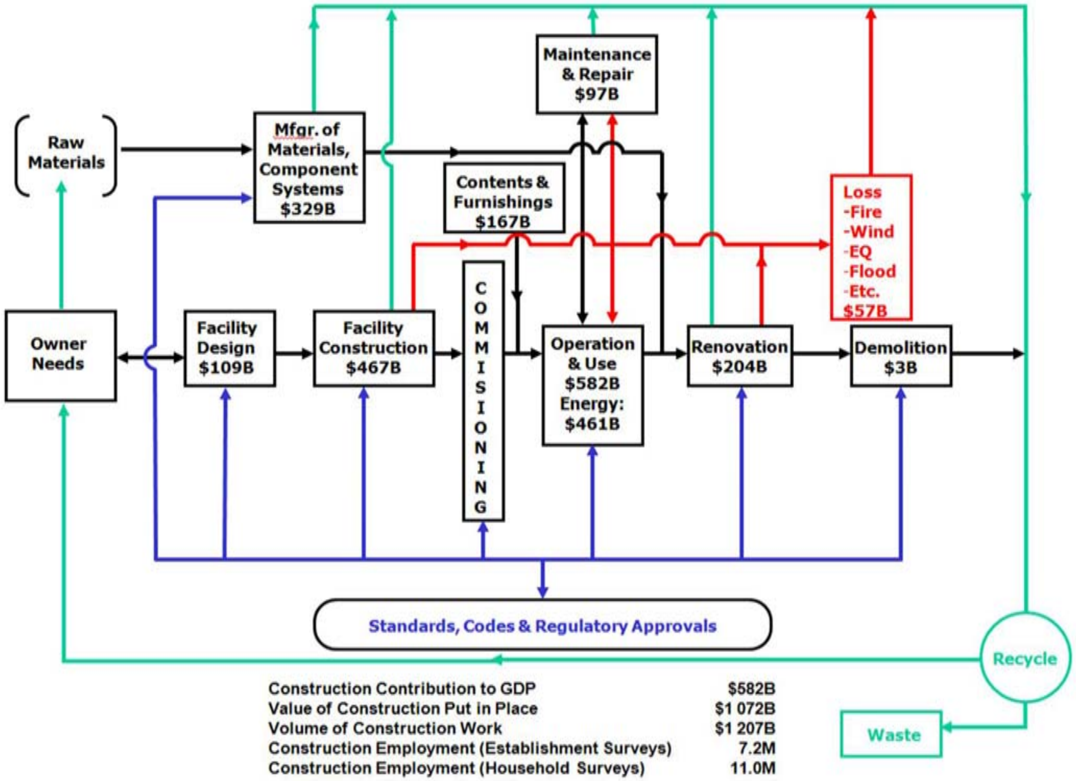
Figure 2.1 2008 Breakdown of $1072 Billion Construction Market



2.2 Overview of the Construction Industry Supply Chain

A total industry supply chain for construction gives a more complete representation of construction work in the United States. Complete data is not gathered on an annual basis; however, there is sufficient data in the 1997 and 2002 Census of the Construction Industry reports to extrapolate construction data that is gathered on an annual basis. Using the Census Bureau's C30 annual figures for construction put in place along with Census data from 1997 and 2002, one can calculate values for five components of the construction industry: facility design; facility construction; renovation; maintenance and repair; and a value for materials, components, supplies, and fuels. Other components of the construction supply chain include contents and furnishings, operation and use, demolition, and losses. Each of these components is labeled in Figure 2.2, which records both the linkages between supply chain components and their estimated values.

Figure 2.2 Impacts of Construction Industry Supply Chain in 2008



In 2008, the construction industry's contribution to gross domestic product (GDP) was $582 billion (see Figure 2.2), or 4.1 % of GDP.[10] In 2008, the value of construction put in place was $1072 billion ($750 billion for new construction, $323 billion for additions, alterations, and reconstruction (AAR).[11] Table 2.2 reveals that the value of construction put in place declined by 6.8 % from 2007 to 2008. This decline was caused by a 34.3 % decline in new residential construction and a 13.6 % decline in residential renovations (see Table 2.1). The total of these two declines resulted in a -28.6 % change in the value of residential construction put in place. The remaining sectors of construction, commercial/institutional, industrial, and infrastructure, grew by 5.9 %, 34.0 %, and 11.5 % respectively. Overall, new construction declined by 9.4 % while renovations declined by 0.2 %.

Maintenance and repair activities are an integral part of the construction industry. Expenditures for maintenance and repair (M&R) amounted to $134 billion in 2008.[12] Thus, the total volume of construction work in 2008—equal to the value of construction put in place plus expenditures for maintenance and repair—was $1207 billion. It is important to note that expenditures for maintenance and repairs declined by 9.4 % from 2007 to 2008.

Approximately 30 % of the volume of construction work—$329 billion—was due to the demand for manufactured products (materials, components, and systems).[13] Note that expenditures for manufactured products are derived as percentages of expenditures for facility design services, new construction, AAR, and M&R. Thus, expenditures on manufactured products are tied to the volume of construction work done. Consequently, these expenditures decreased by 7.1 % from 2007 to 2008.

Figure 2.2 is organized so that expenditures are not double counted. Since expenditures for manufactured products (materials, components, and systems) are derived as percentages of expenditures for facility design services, new construction, AAR, and M&R, the values for the latter items are reduced by the appropriate percentage. Facility design services is also a derived

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[10] Bureau of Economic Analysis, "Gross-Domestic-Product-(GDP)-by-Industry Data." *Industry Economic Accounts* (Washington, DC: Bureau of Economic Analysis), http://www.bea.gov/bea/dn2/gdpbyind_data.htm (accessed July 2009).

[11] United States Census Bureau: Manufacturing and Construction Division, "Annual Value of Construction Put in Place." *Current Construction Report (CCR) C30 (*Washington, DC: United States Census Bureau, July 2009), http://www.census.gov/const/C30/total.pdf (accessed July 2009).

[12] The value for maintenance and repair is calculated by using the ratio of maintenance and repair to new construction put in place from the 1997 census and multiplying it by the current value for new construction put in place.

[13] The value of manufactured products, materials, components, and systems is calculated using ratios from the 2002 census. United States Census Bureau. "2002 Economic Census: Construction Subject Series." *Industry General Summary: 2002*. EC02-23SG-1 (Washington, DC: U.S. Census Bureau, October 2005).

calculation; it is derived based on data from the 2002 Census of the Construction Industry for architectural services, surveying services, and engineering services. The total thus derived for facility design services is allocated according to the percentage shares between the value of new construction and AAR put in place, also from the 2002 Census of the Construction Industry.

Four components recorded in Figure 2.2 are of particular importance in understanding how the double counting of expenditures is avoided; they are: (1) facility design; (2) facility construction; (3) renovation; and (4) maintenance and repair. The value of facility design recorded in Figure 2.2, $109 billion, equals the sum of architectural services ($32.0 billion), surveying services ($5.4 billion), and engineering services ($73.7 billion) for a total of $111.2 billion[14] less manufactured products associated with these services ($2.2 billion). The value for facility construction in Figure 2.2, $467 billion, equals the value of new construction put in place ($749.7 billion) less new construction-related facility design services ($79.7 billion) and new construction-related manufactured products ($202.7 billion). The value for renovation recorded in Figure 2.2, $204 billion, equals the value of AAR ($323.4 billion) less AAR-related facility design services ($31.6 billion) and AAR-related manufactured products ($87.5 billion). The value for maintenance and repair recorded in Figure 2.2, $97 billion, equals M&R expenditures ($133.6 billion) less M&R-related manufactured products ($36.4 billion). Thus, the value of manufactured products (materials, components, and systems) recorded in Figure 2.2, $329 billion, equals the sum of manufactured products associated with: (1) facility design services ($2.2 billion); (2) new construction ($202.7 billion); (3) AAR ($87.5 billion); and (4) M&R ($36.4 billion).

The large value of manufactured products that appear in the construction industry supply chain is noteworthy because any productivity improvements associated with those products is not captured in productivity calculations for the construction industry. Construction activities often involve on-site assembly of manufactured products, which would be captured in part by construction productivity calculations. However, recent trends have emphasized the increased use of pre-assembly and off-site fabrication, particularly for many industrial applications.[15] This trend poses a serious measurement challenge for the industry. Consequently, it is discussed in detail in Chapter 3.

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[14] The value of facility design services is allocated according to the percentage shares between the value of new construction and AAR put in place. Thus, $79.7 billion is for new construction-related facility design services and $31.6 billion is for AAR-related facility design services.

[15] Construction Users Roundtable, “Pre-Assembly Perks: Discover Why Modularization Works,” *The Voice*. (Fall 2007), pp 28-31.

Construction also has a major impact on U.S. employment. In 2008, 11.0 million persons were employed in the construction industry.[16] This translates into 7.6 % of the total U.S. workforce. During the 2007 to 2008 period, the construction industry shed 882 000 jobs representing 7.4 % of all construction jobs, according to the Current Population Survey. This loss was the most severe among all industries in terms of percent lost and number of jobs lost. No other industry exceeded a loss of more than 3 % of employment or more than 400 000 jobs.

The composition of the construction workforce differs from much of the U.S. workforce due to the large number of self-employed workers (sole proprietorships and partnerships). Within the construction industry, there are 1.8 million self-employed workers. In contrast, manufacturing, which employs 15.9 million workers, has only 308 thousand self-employed workers.[17] The large number of self-employed workers both reduces the size of the average firm and increases fragmentation within the construction industry. Table 2.3 shows number of establishments in construction industry by size of establishment.[18] Nonemployers, which are businesses without paid employees that are subject to federal income tax, constitute about 2 million establishments and represents 74.46 % of all establishments in the construction industry. Establishments with 1 to 4 employees constitute another 15.17 % of all establishments. Nonemployers, together with establishments with 1 to 4 employees, represent nearly 90 % of all establishments. Figure 2.3 shows value of construction work and value of business done by size of establishment. Value of construction work is defined as receipts, billings, or sales for construction work. Value of business done is the sum of value of construction work and other business receipts.[19] For nonemployers, only receipts data are available, and this variable is labeled "value of business done" in Figure 2.3. Figure 2.3 shows that value of construction work or value of business done is much more evenly distributed among size categories. Table 2.4 shows percentage and cumulative percentage of value of business done in each size category. Nonemployers and establishments with 1 to 4 employees each perform about 9 % of total value of business done. In other words, establishments with 5 or more employees, which constitute 10 % of all establishments, perform 82 % of total value of business done. The prevalence of self-employed workers and small-sized establishments complicates the adoption of new technologies and practices. Construction employment is affected by both the weather and the business cycle. Thus, year-to-year changes in employment can be substantial, resulting in layoffs and hiring surges. The cyclical nature of construction employment produces shortages in many highly-

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[16] United States Bureau of Labor Statistics, "Household Data: Employed Persons in Nonagricultural Industries by Sex and Class of Worker." *Current Population Survey* (Washington, DC: Bureau of Labor Statistics), http://www.bls.gov/cps/cpsaat16.pdf (accessed July 2009).

[17] *Ibid*.

[18] Nonemployer Statistics.

[19] 2002 Economic Census.

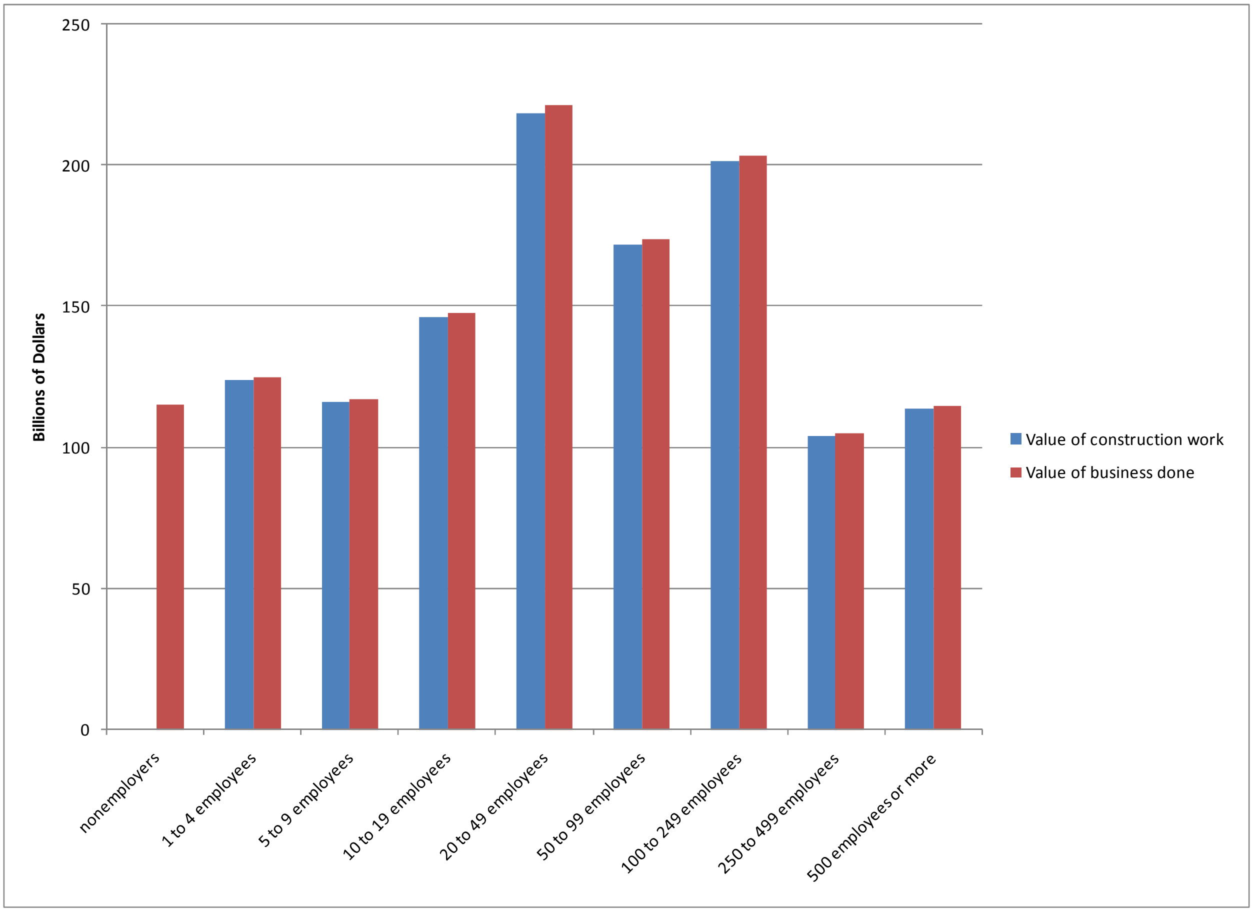
skilled trades. These shortages adversely impact productivity in the construction industry. Finally, declining construction productivity is exacerbated by the influx of unskilled labor from abroad, many of whom find their first employment opportunity in the construction industry.

Table 2.3 Number of Establishments by Size of Establishment in the Construction Industry (2002)

	Number of establishments	Percentage of total number of establishments
nonemployers	2 071 317	74.5 %
1 to 4 employees	421 959	15.2 %
5 to 9 employees	140 498	5.1 %
10 to 19 employees	78 917	2.8 %
20 to 49 employees	46 625	1.7 %
50 to 99 employees	13 649	0.5 %
100 to 249 employees	6640	0.2 %
250 to 499 employees	1434	0.05 %
500 employees or more	585	0.02 %

Source: 2002 Nonemployer Statistics and 2002 Economic Census.

Figure 2.3 Value of Construction Work and Value of Business done by Size of Establishment



Source: 2002 Nonemployer Statistics and 2002 Economic Census.

Table 2.4 Percentage and Cumulative Percentage of Value of Business Done by Size of Establishement

	Percentage of value of business done	Cumulative percentage of value of business done
nonemployers	8.7 %	8.7 %
1 to 4 employees	9.4 %	18.1 %
5 to 9 employees	8.9 %	27.0 %
10 to 19 employees	11.2 %	38.2 %
20 to 49 employees	16.7 %	54.9 %
50 to 99 employees	13.2 %	68.0 %
100 to 249 employees	15.4 %	83.4 %
250 to 499 employees	7.9 %	91.3 %
500 employees or more	8.7 %	100 %

Source: 2002 Nonemployer Statistics and 2002 Economic Census.

2.3 Research and Innovation in the Construction Industry

Given the demonstrated large impact of construction on the nation's macroeconomic objectives, effective construction research becomes critical to the economy. Key drivers for change in construction research are sustainability; competition due to globalization and offshoring; homeland security and disaster resilience; infrastructure renewal; demand for better, faster, and less costly construction; and information technology.

The problem is that the U.S. construction industry invests little in research relative to its significant GDP contribution to the economy. A landmark study co-sponsored by the Civil Engineering Research Foundation (CERF) and the National Science Foundation (NSF) involved a nationwide survey of civil engineering-related research and development (R&D). The study, later published by CERF,[20] is especially noteworthy because it includes R&D associated with each of the key construction industry stakeholders. The CERF study reported that all key construction industry stakeholders combined invested in R&D at a rate that corresponds to only 0.5 % of the value of construction put in place. This translates into approximately $5.4 billion in 2008. A recently published NSF study covering companies performing industrial R&D provides a useful contrast.[21] Private sector R&D investments in manufacturing totaled nearly $167 billion in 2007. Total R&D investments in construction were even surpassed by segments of the manufacturing industry (e.g., $9.8 billion for machinery, a mature segment of the industry).

[20] Civil Engineering Research Foundation, *A Nationwide Survey of Civil Engineering-Related R&D.* CERF Report #93-5006 (Reston, VA: American Society of Civil Engineers, 1994).

[21] http://www.nsf.gov/statistics/infbrief/nsf079316/ (accessed July 2009).

Underinvesting reduces the potential for research-inspired innovations that contribute to substantial national benefits—namely constructed facilities that are more user and environmentally friendly, affordable, productive, and that are easier, faster, and more life-cycle cost effective to build, operate, and maintain. Given the impact of construction spending on the economy's health, and that construction research helps make construction workers more productive and the construction industry more globally competitive and profitable, construction research becomes a critical variable in generating economic growth.

Although the generally accepted perception of the construction industry views innovation as a rare occurrence, in actuality it occurs consistently throughout the industry. Construction innovation offers the potential for significant company, industry, and societal benefits. As the demand rises for increasingly complex facilities, and the traditional sources of skilled labor shrinks, many construction firms are looking for design and technology innovations to improve their products and services and reduce their costs. Owners and clients seek construction innovations to increase the technical feasibility of their proposed projects and improve the performance of the completed facility.

Slaughter's paper on "Models of Construction Innovation" is especially instructive.[22] In that paper, five models of construction innovation are presented as a basis for construction firms to plan and carry out activities to effectively use specific construction innovations. These models are based upon established theories in management and economics but are modified to reflect the special conditions associated with constructed facilities, such as their scale, complexity, durability, and organizational contexts. For the purposes of project incorporation, the five categories of innovation are differentiated with respect to their degree of change from current practices and their links to other components and systems. Based on these models of innovation, firms can evaluate what they must do to implement the innovations. This framework can provide firms with a means through which to reduce the perceived risks of using construction innovations, and thereby somewhat lower the barriers to those innovations throughout the industry.[23]

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[22] E. Sarah Slaughter, "Models of Construction Innovation." *Journal of Construction Engineering and Management*. Vol. 124 (May/June 1998), pp. 226-231.

[23] *Ibid*.

3 Productivity and Competitiveness: A Survey of the Literature

This chapter provides a survey of the literature on productivity and competitiveness. The chapter contains seven sections. Section 3.1 describes the three dimension of construction productivity—task, project, and industry. Section 3.2 discusses the factors affecting construction productivity. Sections 3.3 through 3.5 describe existing productivity measures and present estimates of construction productivity measures at the task, project, and industry levels, respectively. Section 3.6 discusses the divergence between task-level and industry-level productivity estimates and presents possible explanations for the divergence. Section 3.7 synthesizes a number of conclusions and observations from the literature survey.

3.1 Three Dimensions of Construction Productivity: Task, Project, and Industry

The nature of the construction process points to a need for measures of construction productivity at three levels: (1) task; (2) project; and (3) industry. *Tasks* refer to specific construction activities such as concrete placement or structural steel erection. *Projects* are the collection of tasks required for the construction of a new facility (e.g., the construction of a new commercial office building) or renovation (i.e., additions, alterations, and major replacements) of an existing constructed facility. *Industry* measures are based on the North American Industrial Classification System (NAICS) codes for the construction sector and represent the total portfolio of projects.

Producing measures of construction productivity at each level involves the development of both metrics (i.e., the definition of the appropriate measure [parameter] that forms the basis for the calculation) and tools (i.e., the means through which construction industry stakeholders can perform the calculation for the selected metrics). Once produced, these metrics and tools will help construction industry stakeholders make more cost-effective investments in productivity enhancing technologies and life-cycle construction processes; they will also provide stakeholders with new measurement and evaluation capabilities (e.g., enabling them to simulate key elements of the project delivery process).

The basic concept underlying construction industry productivity measures is a comparison of the output of a task, project, or industry with the corresponding factors of production (inputs) required to generate that output.[24] The output and inputs of production thus constitute the basic components of every productivity measure. Typically, productivity measures are formulated as a ratio of output to one or more inputs. If only one of the inputs is used, then the ratio is a single factor productivity measure. A common example of this type of measure is output per labor hour. If all of the inputs are used, then the ratio is a multifactor productivity measure.

[24] Stephen F. Weber and Barbara C. Lippiatt, *Productivity Measurement for the Construction Industry*. NBS Technical Note 1172 (Gaithersburg, MD: National Bureau of Standards, February 1983).

3.2 Factors Affecting Construction Productivity

Much has been published about the factors that affect construction productivity. Although a comprehensive treatment is beyond the scope of this study, several key factors are usually cited in the literature. These factors are: (1) skilled labor availability; (2) technology utilization; (3) offsite fabrication and modularization; and (4) use of industry best practices.

3.2.1 Skilled Labor Availability

One of the greatest challenges facing the construction industry is its ability to attract and retain qualified workers. This is underscored by the fact that shortages of skilled workers continue to plague the construction industry.[25] A 1996 survey by the Business Roundtable, for example, found that over 60 % of its members who responded to the survey reported shortages of skilled labor on construction projects. Furthermore, 75 % indicated that the trend had worsened during the past five years.[26] Nearly 90 % of chemical and petrochemical companies have experienced difficulty in recruiting skilled craft workers.[27] Craft worker shortages appear to be the most severe for electricians, pipefitters, and welders. But the survey results also suggest labor shortages among all other types of craft workers.[28] Most respondents believe this skilled labor shortage is driven more by a shrinking skilled workforce, and less by increasing demand.[29] Many industry practitioners have suggested the shortage of skilled labor is a result of aging construction workforce, with fewer young people entering the industry. Figure 3.1 shows the annual average number of employed persons in the construction industry by age groups from 1994 through 2008. The median age is plotted against the secondary axis for 2000 through 2008 with a clear upward trend.[30] The median age has risen from 38.7 years old in 2000 to 40.3 years old in 2008. Figure 3.2 plots the same data using percentages. The decline of young workers (34 years old or younger) in proportion is evident. Part of the decline in 2008 may be due to the economic downturn, as inexperienced workers, who tend to be younger, tend to be laid off first. Since experienced workers tend to be more productive, as the proportion of experienced workers increases, productivity is likely to increase.

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[25] Construction Industry Institute, *The Shortage of Skilled Craft Workers in the U.S.* RS 182-1 (Austin, TX: Construction Industry Institute, 2003).

[26] The Business Roundtable, *Confronting the Skilled Construction Work Force Shortage—A Blueprint for the Future* (The Business Roundtable, October, 1997).

[27] *Ibid.*

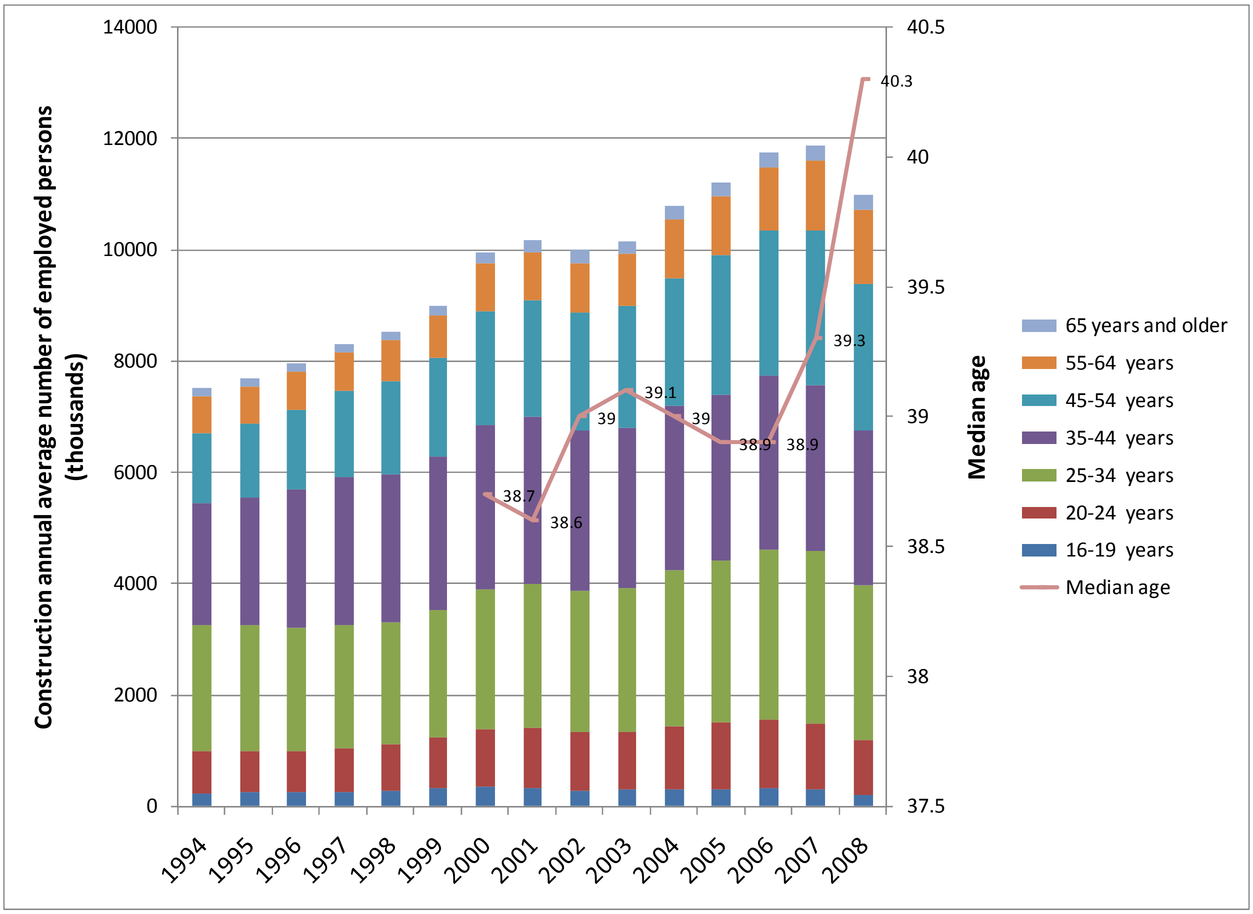
[28] *Ibid.*

[29] *Ibid.*

[30] Current Population Survey is the data source, and median age by industry is not available prior to 2000.

With an aging workforce, one concern for the viability of the construction industry is that skills and knowledge processed by experienced workers are not being passed onto younger generations because there is not enough new blood entering the industry. This challenge is compounded by the decline in training programs. Typically, training programs are funded by both owners and contractors through union and collective bargaining agreements. While open shop training programs exist, they tend to be rare.[31] Figure 3.3 shows that the percentage of private construction workers that are union members and the percentage of private construction workers that are covered by collective bargaining agreements have declined since the 1970s. With the decline of union membership and collective bargaining agreements, training programs and the number of apprentices also have declined.

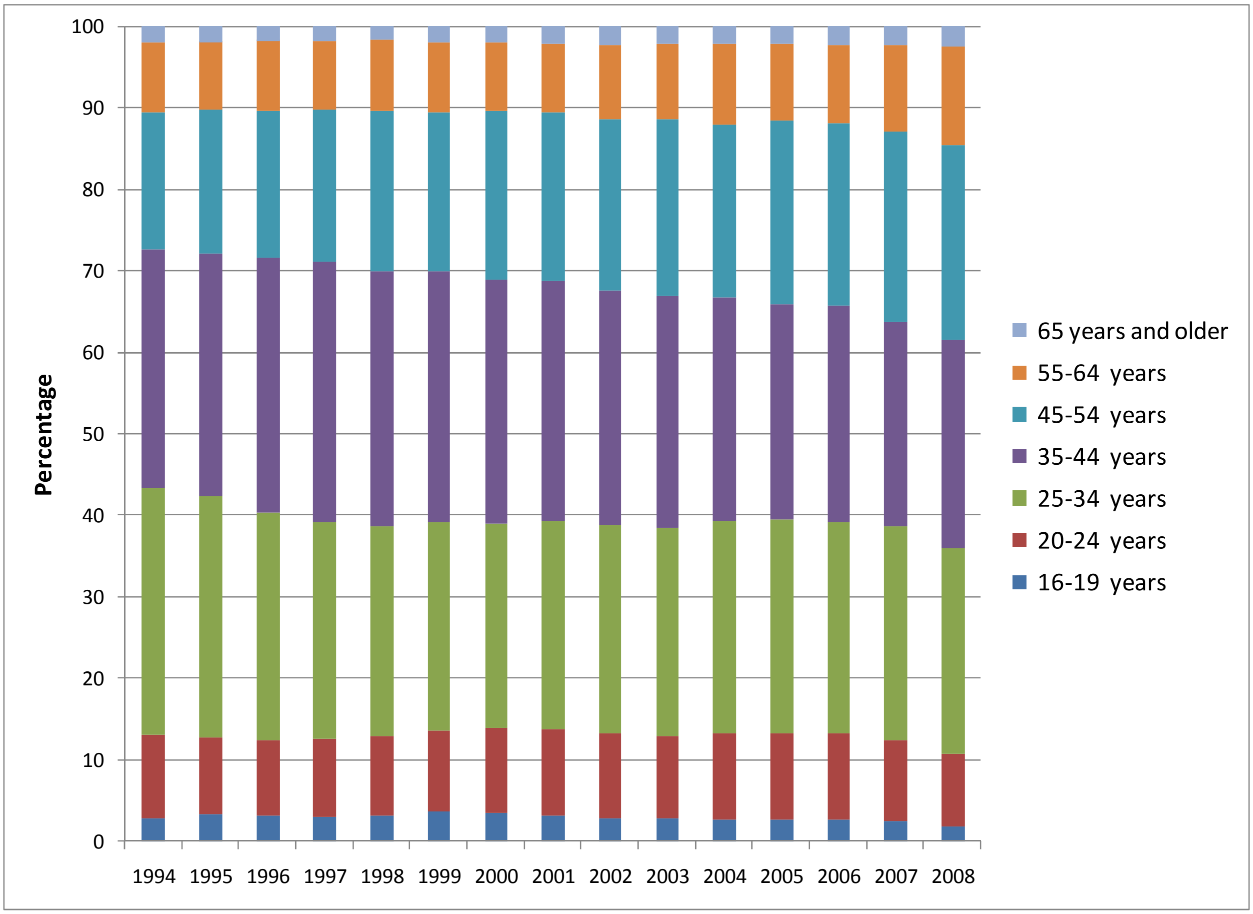
Figure 3.1 Annual Average Number of Employed Persons in the Construction Industry by Age Groups, 2000 through 2008[32]



[31] Construction Industry Institute, *Construction Industry Craft Training in the United States and Canada*. RS 231-1 (Austin, TX: Construction Industry Institute, 2007).

[32] Current Population Survey. Median age data were not collected prior to 2000.

Figure 3.2 Percentages of Employed Persons in the Construction Industry by Age Groups, 2008 through 2008[33]



Difficulty in staffing projects has resulted in increasing costs and schedule delays.[34] Skilled labor shortage might pose a greater challenge in years to come, as the Bureau of Labor Statistics has projected, prior to the current financial crisis, an annual 1 % increase of jobs in the construction sector by 2016, reaching a level of 8.5 million.[35] This increase in employment amounts to 10.2 % from 2006 to 2016. This projected growth in construction jobs is based on a projected output growth at a rate of 1.4 % per year to reach $1.9 trillion by 2016.[36]

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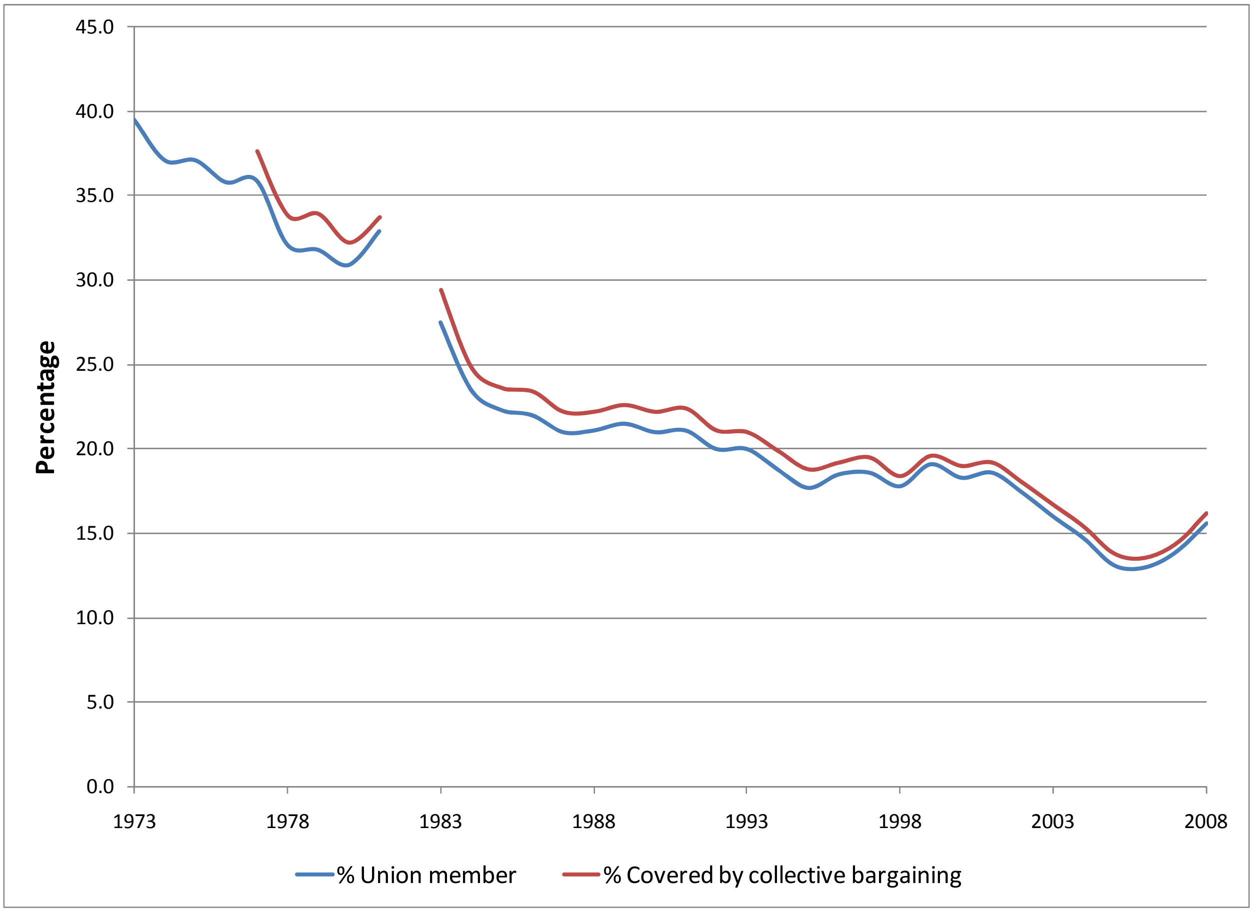
[33] Current population Survey.

[34] Construction Users Roundtable, *Confronting the Skilled Construction Workforce Shortage*. WP-401. (Cincinnati, OH: Construction Users Roundtable, June, 2004).

[35] Eric B. Figueroa and Rose A. Wood, “Industry Output and Employment Projections to 2016,” *Monthly Labor Review* November (2007): 53-85.

[36] *Ibid.*

Figure 3.3 Percentage of Private Construction Workers with Union Membership and Percentage of Private Construction Workers under Collective Bargaining Agreement, 1973 through 2008[37]



Employers have attempted to identify the root causes and to develop strategies to overcome these shortages. Construction Industry Institute (CII) and others have funded research on the problem and generated potential solutions.[38] For instance, using the CII model plant, actual data from companies that had implemented training programs, and estimations of benefits from experts, CII estimated the return for each dollar invested in training to be between $1.30 to $3.00.[39] These benefits are in the form of increased productivity and reductions in turnover, absenteeism, and

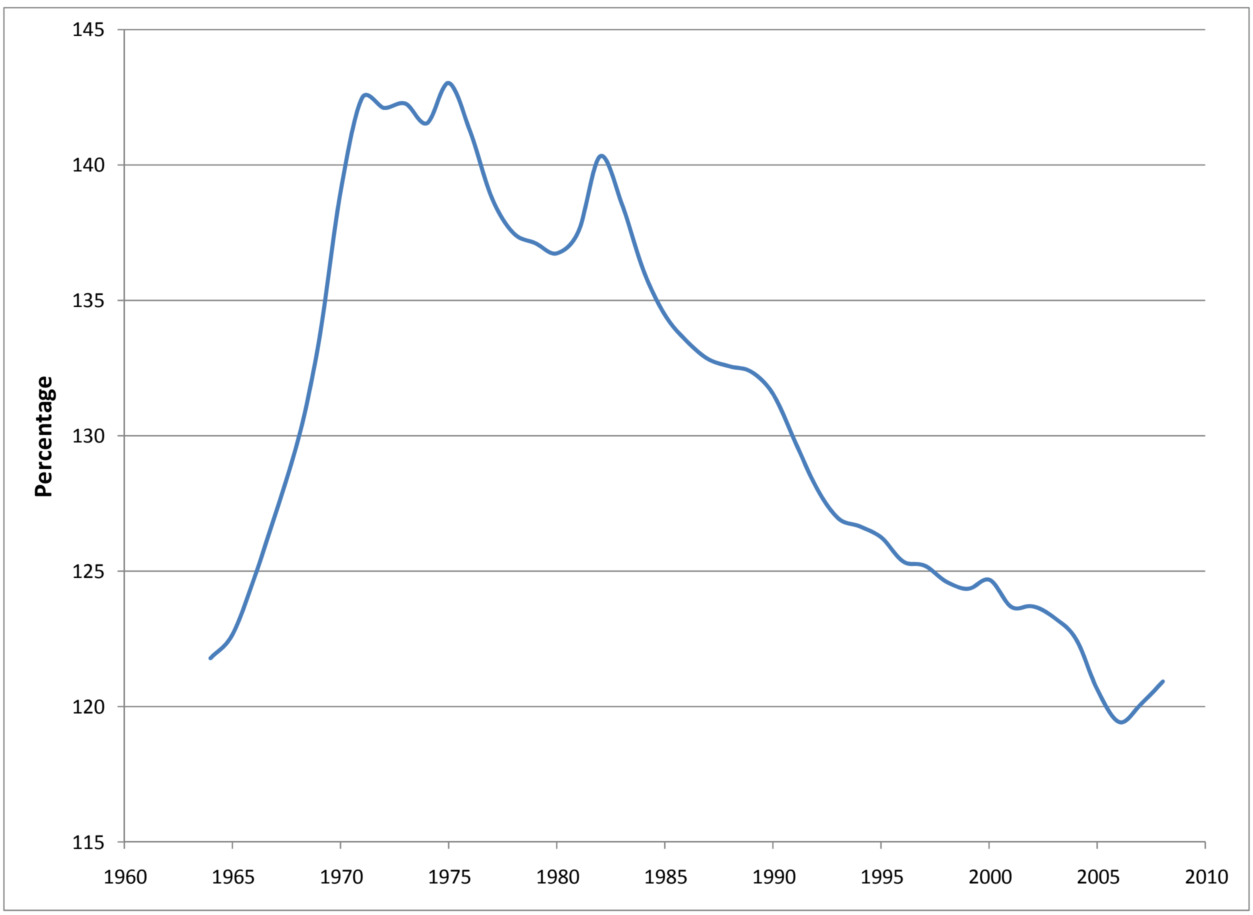
[37] Barry T. Hirsch and David A. Macpherson, "Union Membership and Coverage Database from the Current Population Survey: Note," *Industrial and Labor Relations Review,* 56(2003): 349-54.

[38] Construction Industry Institute, *The Shortage of Skilled Craft Workers in the U.S. Op. cit.*

[39] Construction Industry Institute, *Construction Industry Craft Training in the United States and Canada. Op. cit.*

rework.[40] Craft training benefits project financial performance by increasing the craft workers' average duration on a project and reducing turnover.[41] Craft training also benefits individual workers by increasing their skills and knowledge, income, and job satisfaction. It is also essential for providing the skilled labor the industry needs. Despite this research and efforts to stem the problem, the construction industry's skilled worker pool continues to shrink. The decreasing number of young people entering the work force and the failure to recruit from non-traditional labor pools exacerbate this trend. Over the past 30 years, real wages of construction workers have declined relative to those of other workers (Figure 3.4). Poor industry image, tough working conditions, the industry's perceived poor safety record, and limited career development opportunities also have contributed to the decline in the number of people willing to enter and remain in the industry.

Figure 3.4 Construction Industry Production Worker Average Weekly Hourly Wage as a Percentage of Total Private Sector Production Worker Average Hourly Wage[42]



[40] *Ibid.*

[41] *Ibid.*

[42] Source: Bureau of Labor Statistics.

3.2.2 Technology Utilization

Technology utilization impacts construction productivity in a number of ways. Historical changes in construction equipment have resulted in sustained improvements in task level labor productivity. Goodrum and Haas have shown, using commercially available cost estimation data, that these improvements stem from better control, amplification of human energy, increased functionality, better ergonomics, and better information processing and feedback.[43] Improved level of control refers to advances in machinery and hand tools with built-in capability to automatically adjust the level of power or other characteristics of the equipment. One example is a concrete vibrator that automatically adjusts the vibration frequency to match the concrete's slump. Better information processing and feedback refers to advances in heavy machinery that have the capability of performance monitoring and self-diagnosis systems. Overall, these technological advancements have enabled labor productivity to improve by 30 % to 45 %.[44] Goodrum *et al.* came to a similar conclusion regarding material characteristics that lead to reductions in unit weight and installation flexibility.[45] Reductions in unit weight enable ease of handling. Installation flexibility refers to the environmental conditions under which a material can be installed, such as temperature or moisture ranges. Comparing activities that experience such changes in materials with activities that did not, Goodrum *et al.* found labor productivity improved at least twice as much in activities with material improvements over the period of study (1977-2004).

Preliminary analyses of CII Benchmarking data covering information integration and automation technologies revealed significant task level productivity improvements.[46] Automation technologies focus on the degree to which individual work functions (e.g., supply management and project management) are automated. Integration technologies focus on the ability to exchange information between work functions and their associated databases (e.g., exchanges of information among supply management and project management functions). For the four trades examined—concrete, structural steel, electrical, and piping—labor productivity was about 30 % higher for projects with a high level of automation compared to projects with a low level of automation. The difference in labor productivity was about 45 % between projects with different levels of integration.

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[43] Paul M. Goodrum and Carl T. Haas, "Long-Term Impact of Equipment Technology on Labor Productivity in the U.S. Construction Industry at the Activity Level," *Journal of Construction Engineering and Management* January/February (2004): 124-133.

[44] Construction Industry Institute, *Leveraging Technology to Improve Construction Productivity*. RS 240-1 (Austin, TX: Construction Industry Institute, October, 2008).

[45] Goodrum, Paul M., M. Yasin, and Z. Dong. "The Relationship Between Changes in Material Technology and Construction Productivity." Mimeo. (Lexington, KY: University of Kentucky).

[46] Construction Industry Institute, *Leveraging Technology to Improve Construction Productivity*. *Op. cit.*

A field test was conducted to examine how materials tracking and locating technologies can contribute to productivity. The use of Radio-frequency identification (RFID) tags and a Global Positioning Satellite (GPS) system were coupled to track materials in lay down areas in two CII member projects.[47] Improved materials tracking was shown to increase productivity at the workface because material retrieval became efficient.

Previous paragraphs describe how technology can enhance productivity of individual tasks. Note that while technology can generally improve labor productivity, there is a cost associated with employing technology. Improvement in labor productivity is not an ultimate goal. For example, capital investment in technology can be increased to improve labor productivity, but this approach may not be the optimal solution when overall costs and benefits are considered.

Building Information Modeling is one technology that can enhance productivity of an entire project, from the planning phase to the decommissioning phase. Eastman *et al.* describe Building Information Modeling (BIM) as "a new approach to design, construction, and facility management in which a digital representation of the building process is used to facilitate the exchange and interoperability of information in digital format."[48] A previous NIST study on interoperability estimated the cost of inadequate interoperability in the U.S. capital facilities industry to be $15.6 billion per year,[49] and therefore enhanced interoperability has a great potential in efficiency gains. The National Research Council has identified the use of Building Information Modeling as a key activity that could lead to breakthrough improvements in construction productivity.[50]

Concerns over the perceived decline in construction productivity have stimulated interest in ways to use technology and management practices to address this challenge. Current industry efforts aimed at the seamless flow of information in an interoperable design and construction environment seek to promote labor productivity both by enabling the project team to respond quickly and effectively to new requirements, changes in scope, site conditions, and delivery delays and by promoting the use of value adding processes and technologies. The CII Strategic Plan,[51] the FIATECH Capital Projects Technology Roadmap,[52] CURT's efforts to address owner

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[47] *Ibid.*

[48] Chuck Eastman, Paul Teicholz, Rafael Sacks, and Kathleen Liston, *BIM Handbook: A Guide to Building Information Modeling for Owners, Managers, Designers, Engineers, and Contractors*, (Hoboken, New Jersey: John Wiley & Sons, Inc., 2008).

[49] National Institute of Standards and Technology, Cost Analysis of Inadequate Interoperability in the U.S. Capital Facilities Industry. NIST GCR-04-867. (Gathersburg, MD: National Institute of Standards and Technology, 2004).

[50] National Research Council, *Advancing the Competitiveness and Efficiency of the U.S. Construction Industry*, *Op. cit.*

[51] Construction Industry Institute. Strategic Plan (Austin, TX: Construction Industry Institute, 2005).

issues associated with productivity improvement and cost reduction, the American Institute of Steel Construction CIS/2 protocol, the Hydraulics Institute's initiative on electronic data exchange, and ASTM's E 57 Committee are several noteworthy examples.

3.2.3 Offsite Fabrication and Modularization

Prefabrication,[53] preassembly,[54] modularization,[55] and offsite fabrication[56] (PPMOF) offer potential benefits in the increasingly competitive global marketplace. Owners want better facilities faster, at the lowest possible cost, and with increased safety. Both owners and contractors view PPMOF as a means to meet challenges of demanding schedules, adverse site conditions, and limited availability of skilled labor. Offsite fabrication and modularization can enable speedier delivery because offsite manufacturing of building components and onsite field preparation can proceed in parallel.[57] Costs can be reduced because moving part of the onsite construction work to a controlled environment offsite can reduce the impact of adverse site condition on the project and can enhance safety and productivity.[58] Additionally, offsite fabrication and modularization is a way to mitigate skilled labor shortage. Modularization has been used in the industrial sector for decades. As recent developments in modular construction have made this concept more versatile and applicable to the commercial sector,[59] increasing demand for modularization may emerge.

However, CII research shows that effective use of these methods requires careful consideration of their implications for engineering, transportation, coordination, and project organization.[60] To

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[52] FIATECH. Capital Projects Technology Roadmapping Initiative (Austin, TX: FIATECH, October 2004).

[53] Prefabrication: a manufacturing process, generally taking place at a specialized facility, in which various materials are joined to form a component part of a final installation.

[54] Preassembly: a process by which various materials, prefabricated components, and/or equipment are joined together at a remote location for subsequent installation as a sub-unit; generally focused on a system.

[55] Module: a major section of a plant/building resulting from a series of remote assembly operations and may include portions of many systems; usually the largest transportable unit or component of a facility.

[56] Offsite fabrication: the practice of preassembly or fabrication of components both off the site and onsite at a location other than at the final installation location.

[57] Construction Users Roundtable, "Pre-Assembly Perks: Discover Why Modularization Works." *Op. cit.*

[58] Charles M. Eastman and Rafael Sacks, "Relative Productivity in the AEC Industries in the United States for On-site and Off-site Activities," *Journal of Construction Engineering and Management* 134, no. 7 (2008): 517-526.

[59] Construction Users Roundtable, "Pre-Assembly Perks: Discover Why Modularization Works." *Op. cit*.

[60] Construction Industry Institute, *Prefabrication, Preassembly, Modularization, and Offsite Fabrication in Industrial Construction: A Framework for Decision-Making*. RS 171-1 (Austin, TX: Construction Industry Institute, 2002).

successfully incorporate offsite fabrication and modularization in projects, careful upfront planning and early decision making are essential.[61] The use of PPMOF may also increase the level of details required in the design, it may increase the requirement for procurement logistics, and it may also limit the ability to inspect work in progress if the fabrication is done remotely.[62]

Recent advances in design and information technologies, combined with increasing emphasis within the industry to address cost, schedule, and labor issues, have proven the use of PPMOF to be more viable than ever. In a recent Construction Users Roundtable (CURT) publication, CII Director Wayne Crew noted that the use of PPMOF has increased in the last 10 years, especially with new technologies such as building information modeling and internet design capabilities.[63] Future workforce shortages will likely encourage the use of PPMOF. PPMOF benefits such as reduced construction time, decreased costs, and increased safety have all contributed to its popularity, and while many companies in the oil and gas industries have used it for decades, others are realizing its full set of benefits. Widespread use of PPMOF has also been identified by the National Research Council as a key activity that could lead to breakthrough improvements in construction productivity.[64]

3.2.4 Use of Industry Best Practices

Management practices affect productivity over the life cycle of a construction project in a number of ways, including planning, resource supply and control, and supply of information and feedback. Management practices that are inflexible or applied inappropriately can introduce inefficiencies that reduce productivity. A key opportunity for breakthrough improvement in productivity identified by the National Research Council is improved job-site efficiency through effective interfacing of people, processes, materials, equipment, and information.[65] To address issues associated with management of resources, organizations such as CII have developed a suite of best practices aimed at improving the project execution process.[66] These practices are directed at all phases of the project life cycle, from design, through procurement, fabrication,

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[61] Construction Users Roundtable, "Pre-Assembly Perks: Discover Why Modularization Works." *Op. cit*.

[62] Construction Industry Institute, *Prefabrication, Preassembly, Modularization, and Offsite Fabrication in Industrial Construction: A Framework for Decision-Making. Op. cit.*

[63] Construction Users Roundtable, "Pre-Assembly Perks: Discover Why Modularization Works." *Op. cit*.

[64] National Research Council, Advancing the Competitiveness and Efficiency of the U.S. Construction Industry. *Op. cit.*

[65] *Ibid.*

[66] For a list of CII knowledge areas, practices, and information resources, see: http://www.construction-institute.org/source/Orders/CII_Matrix.cfm?section=orders&OrdersSection=Matrix

construction, commissioning, and operations and maintenance.[67] One example of a best practice is to incorporate maintainability as a project goal in the design process to enhance reliability and reduce total life-cycle costs.[68] Other examples of best practices include front-end planning, alignment during front-end planning, partnering, team building, project delivery and contract strategy, constructability, project risk assessment, change management, zero accident techniques, and planning for startup.[69] In-depth analyses of the value of best practices on cost and schedule control, as well as field rework have been performed.[70] Increasing use of best practices is associated with improved cost, schedule, and safety performance, for both owners and contractors. For owners, the potential cost benefits are estimated to be $1.7 million to $3.4 million, depending on industry group and project size. For contractors, the potential cost benefits can be $7.2 million for the typical $88 million heavy industrial project. Owners benefit most from schedule reductions, which can be as much as 16 % or 27 weeks for large projects. Finally, in terms of CII's zero accident best practice, the difference between a 4th quartile (lowest practice use) project to a 1st quartile (highest use) project amounts to potential savings of more than $200 000 from lost workday cases avoided.[71] Note also that the use of BIM can facilitate effective planning and management, which are the foundation for efficient processes that contribute to overall project success.

3.3 Task Level Productivity Metrics

3.3.1 Task Level Productivity Measures

Tasks refer to specific construction activities such as concrete placement or structural steel erection. Task-level metrics are widely used within the construction industry. Most task-level metrics are single factor measures and focus on labor productivity. For example, R.S. Means has published task level metrics for many years. Typical task-level metrics published by R.S. Means estimate how much a given output is produced by a designated crew in a normal 8-hour day.[72]

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[67] Construction Industry Institute, *Design for Maintainability: Improving Project Return on Investment*. RS142-1 (Austin, TX: Construction Industry Institute, 1999).

[68] *Ibid.*

[69] Youngcheol Kang, William O'Brien, Jiukun Dai, Stephen P. Mulva, Stephen R. Thomas, and Pin-Chao Liao, *Measuring Interoperability and Best Practices Impacts on Capital Project Productivity.* NIST GCR 09-925 (Gaithersburg, MD: National Institute of Standards and Technology, 2009).

[70] Construction Industry Institute, *Benchmarking and Metrics Value of Best Practices Report*. BMM 2003-4 (Austin, TX: Construction Industry Institute, 2003).

[71] *Ibid.*

[72] R.S. Means. *Building Construction Cost Data: 2009.* 67th Edition. (Kingston, MA: R.S. Means, 2008).

In this case, the denominator is the number of hours associated with a designated "crew day." Thus, for a designated crew day, higher output is better. In this case higher output equates to higher task labor productivity. For some tasks, equipment may be involved, in such cases, R.S. Means provides estimates of output that is produced by a designated crew in an 8-hour day along with the equipment they use, and these measures can be considered multifactor.

The CII Benchmarking and Metrics Program uses a different metric to measure task labor productivity. CII fixes the output (e.g., cubic yards of concrete put in place) and measures the labor hours required to produce that output. In this case, the denominator is the fixed output and the numerator is the number of labor hours. Thus, for a given amount of output, lower labor hours is better. In this case, lower labor hours equates to higher task labor productivity.

Both the R.S. Means and the CII task labor productivity metrics include explicit measures of output and labor hours in the values reported. Such metrics are easy to understand and are widely used within the industry as a basic estimating tool. In addition to resorting to cost estimating guides, such as R.S. Means, some contractors collect output and labor hour information from their projects and these data become the basis for cost estimation for their future projects. To differentiate these metrics from alternative formulations, we use the term "raw metrics" to refer to these ratios of input and output. These metrics are raw in the sense that they include the units of measure and are based on unadjusted outputs and labor hours. For example, the relative prices for selected labor inputs and the given output may vary over time.

The CII Benchmarking and Metrics Program collects data on a project basis, where productivity is but one data element. The raw task level metrics produced by CII include not only the average productivity for that task—referred to as a baseline measure—but the full set of observed values. The observed raw task productivity values are then rank ordered into a distribution. Once this is done, the raw task productivity values can be assembled into quartiles. CII researchers can then examine the characteristics for a given task associated with projects in the best performing quartile and in the worst performing quartile.

A task productivity index is an alternative to the raw metrics discussed previously. An index is a dimensionless number, pegged to a reference data set, where the reference data set establishes the baseline value for one or more components of the index. An index can be a ratio of raw metrics. For example, the denominator could correspond to the baseline value for that task's labor productivity (e.g., labor hours per cubic yard of concrete) and the numerator could be the value for a specific project. In that case, the computed value of the index shows how that project's task productivity compares to the overall average of the reference data set. Alternatively, the numerator could correspond to an average value for a new data set of task productivity values collected at some future point in time. Thus, the index can be used to track how task productivity is changing over time.

An index can also incorporate additional information, such as the value of a deflator to help control for changes in relative prices over time. Because the index is a dimensionless number, users can focus on the changes in the index value rather than the functional form of the metric underlying the index. If for example, the index value was pegged at 100.0 at time zero and higher values are better, then a future value of 102.5 indicates improvement in the amount of 2.5 %.

3.3.2 Task Level Productivity Estimates

Goodrum and Haas examined productivity measures for 200 construction activities over a 22-year period. The data sources were cost estimating guides.[73] They found that average activity productivity has increased. Table 3.1 lists compounded annual rate of change in labor and multifactor productivity for activities by division from 1976 to 1998. This table is reproduced from Goodrum *et al.* (2002). Labor productivity and multifactor productivity increased for all divisions. One exception is that labor productivity for electrical work has stayed the same. Furthermore, studies by Goodrum and Haas show that activities that experienced a significant change in equipment technology (i.e., hand tools and machinery) generally also witnessed substantially greater long-term productivity improvements. Activities that experienced a significant change in material technology in terms of modularization, reduction in unit weight, or installation flexibility, also experienced greater productivity improvements. These results are summarized in Table 3.2. The partial factor productivity used by Goodrum and Haas was defined as units of physical output divided by the sum of labor costs and fixed capital costs. These authors also conducted other related studies and reached similar conclusions.[74]

[73] Paul M. Goodrum and Carl T. Haas, "Partial Factor Productivity and Equipment Technology Change at Activity Level in U.S. Construction Industry," *Journal of Construction Engineering and Management* 128 (2002): 463-472.

[74] Paul M. Goodrum, Carl T. Haas, and Robert W. Glover, "The Divergence in Aggregate and Activity Estimates of US Construction Productivity," *Construction Management and Economics* 20, no. 5 (2002): 415-423; Paul M. Goodrum and Carl T. Haas, "Long Term Impact of Equipment Technology on Labor Productivity in the U.S. Construction Industry at the Activity Level" *Op. cit.*; E. Allmon, C. T. Hass, J. D. Borcherding, and P. M. Goodrum, "U.S. Construction Labor Productivity Trends, 1970-1998," *Journal of Construction Engineering and Management* 126, no. 2 (2000): 97-104.

Table 3.1 Compounded Annual Rate of Change in Labor and Multifactor Productivity for Activities by Division from 1976 to 1998[75]

Construction Division	Change in labor productivity 1976-1998 (compound annual rates)	Change in multifactor productivity 1976-1998 (compound annual rates)
Sitework	+2.8 %	+2.4 %
Doors and Windows	+1.6 %	+1.8 %
Metals	+1.5 %	+1.0 %
Finishes	+1.2 %	+1.6 %
Masonry	+1.2 %	+0.8 %
Concrete	+1.1 %	+1.4 %
Mechanical	+1.0 %	+1.4 %
Wood and Plastic	+0.3 %	+0.4 %
Moisture and Thermal Protection	+0.2 %	+0.6 %
Electrical	+0.0 %	+0.8 %

Table 3.2 Changes in Equipment and Material Technology versus Changes in Labor Productivity[76]

Technology Characteristic	Change in Labor Productivity		
Equipment Technology Characteristic	**No Change in Equipment Technology Characteristic**	**Change in Equipment Technology Characteristic**	**Δ**
Energy	3.6 %	39.8 %	36.2 %
Control	14.9 %	16.6 %	31.7 %
Functional Range	13.5 %	51.8 %	38.3 %
Information Processing	21.0 %	56.4 %	35.4 %
Material Technology Characteristic	**No Change in Material Technology Characteristic**	**Change in Material Technology Characteristic**	**Δ**
Modularization	8.1 %	24.2 %	16.1 %
Reduction in Unit Weight	10.4 %	48.6 %	38.2 %
Installation Flexibility	8.7 %	23.1 %	14.4 %

[75] Table is reproduced from Paul M. Goodrum, Carl T. Haas, and Robert W. Glover, "The Divergence in Aggregate and Activity Estimates of US Construction Productivity" *Op. cit.*

[76] Table is reproduced from Construction Industry Institute, *Leveraging Technology to Improve Construction Productivity*. Research Summary 240-1. October 2008.

3.4 Project Level Productivity Metrics

3.4.1 Project Level productivity Measures

Projects are the collection of tasks required for the construction of a new facility (e.g., the construction of a new commercial office building) or renovation (i.e., additions, alterations, and major replacements) of an existing constructed facility. Since a project is a collection of tasks, project level metrics are more complicated. The inputs and outputs for a given task, say concrete placement, differ from those of another task, say structural steel erection. Thus, it is not possible to aggregate the individual raw task productivity metrics into a project productivity metric unless adjustments are made.

One way to make these adjustments is to use a reference data set to calculate baseline values for each task. Information is still needed, however, to calculate a meaningful project level productivity metric. For instance, information yielding the task weight (share that it represents to the overall project) is required, as is an understanding of the task flows. Because some tasks are completed in parallel, while other in series, the composition of the task flows affects overall project productivity. Therefore, each component of the project productivity metric contains: (1) the task weight; (2) the raw task productivity baseline value in the denominator; (3) the raw task productivity value for that project in the numerator; and (4) a measure of the task mix (in parallel versus in series task flows). The project productivity index value is a function of the individual components.

The project level productivity metric just described is useful in measuring how an individual project compares to the overall average in the reference data set. In addition, data from all projects can be compiled into a distribution. Further analyses can then be conducted to identify characteristics associated with the best performing or worst performing projects.

A project level productivity index can also be used to track changes in project productivity over time. In this case, the reference data set corresponds to time zero. For each index component, the values for the task weights and the task baseline values appearing in the denominator are equal to values computed in the reference data set. The numerator in each index component then becomes the average value of the corresponding task productivity in the future data set. As noted earlier, an index can also include a deflator to adjust for changes in relative prices over time.

An alternative project level productivity index can be produced as follows. We can create an index which is the quotient of two ratios, in each ratio the numerator is the value of construction put in place and the denominator is the number of field work hours. As noted earlier, a reference data set can be used to fix a baseline value for the ratio of value put in place to field work hours. The baseline value for the ratio is then used as the denominator in the index calculation. How an individual project compares to the baseline is determined by inserting its ratio of value put in place to field work hours in the numerator of the index. Alternatively, this project level productivity index can be used to track changes in productivity over time by following the process described in the previous paragraph.

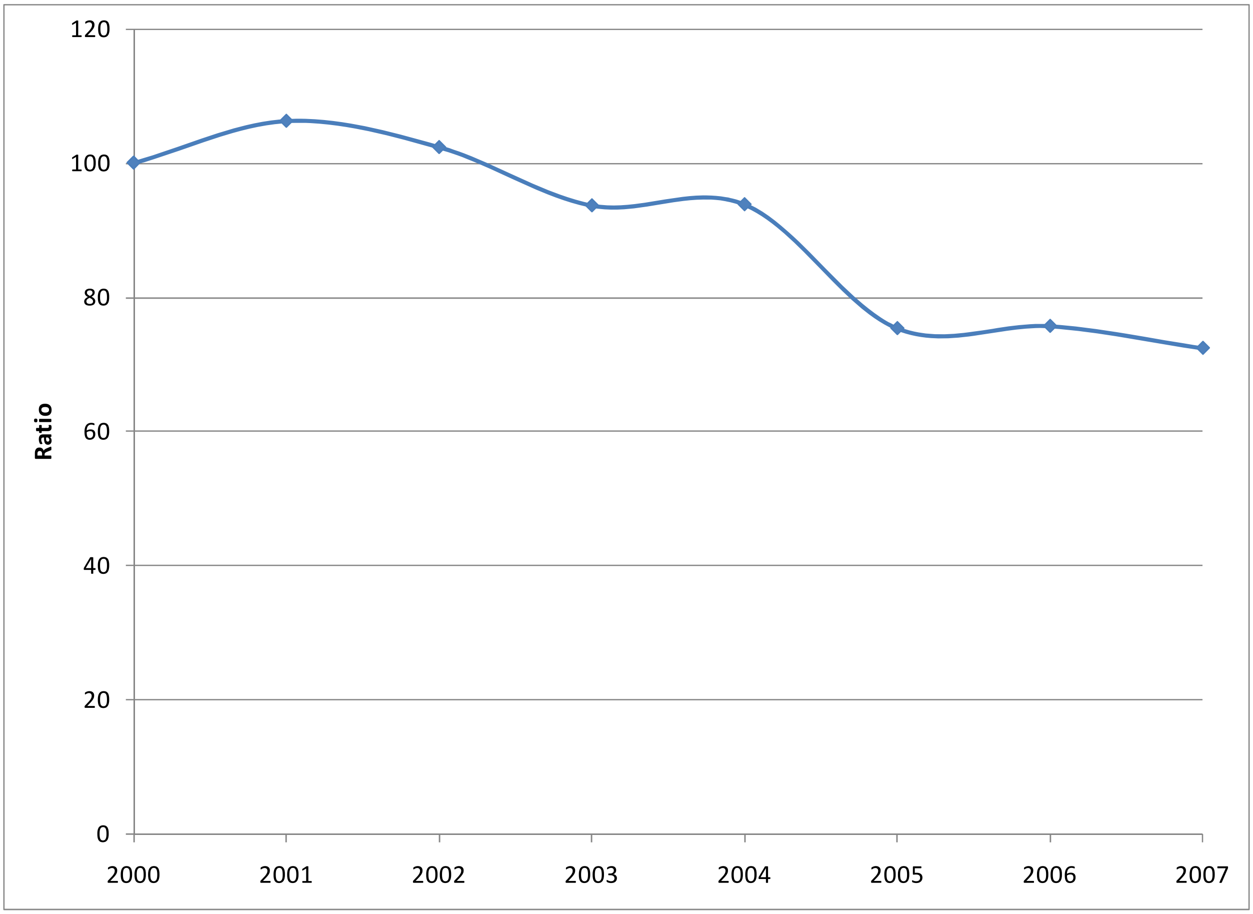
A related measure is cost per square footage data for a particular type of building. R.S. Means produces a square footage model that requires limited inputs, such as building type, exterior wall type, structural system, and square footage, and yields rough estimates for the overall cost of a project or its major components.

3.4.2 Project Level Productivity Estimates

Publicly available project-level productivity estimates tend to be rare. Construction firms collect data on project productivity for internal uses, such as cost estimation in bid preparation. As the information is pertinent to the competitiveness of the firms, it is not generally shared. The CII collects and compiles project-level data from its member organizations. The projects are predominantly industrial projects. The resultant dataset, Benchmarking and Metrics Productivity Database, is used to study project performance as influenced by factors such as technology and best practices. The CII studies are conducted such that information on individual projects remains confidential. Since the dataset contains projects of the member organizations, the dataset is considered to be representative of member organizations' projects, which tend to be more progressive in terms of project performance improvements, but not of the industry as a whole. Project level productivity measures can be calculated using this dataset. Figure 3.5 shows an index based on total installed cost per field work hour from 2000 through 2007.[77] The sample size varies from 16 in 2007 to 49 in 2004. The trend suggests a general decline over the seven-year span. However, it needs to be noted that changes in productivity may reflect changes in the composition of projects, in addition to changes in productivity. Each construction project is unique, and the mix of projects in each year is different. This is an intrinsic challenge in construction industry productivity analysis.

[77] Youngcheol Kang, William O'Brien, Jiukun Dai, Stephen P. Mulva, Stephen R. Thomas, and Pin-Chao Liao, *Measuring Interoperability and Best Practices Impacts on Capital Project Productivity*. *Op cit.*

Figure 3.5 Ratio of Total Installed Cost to Work Hour (Normalized to the Value of Year 2002[78]



[78] *Ibid.*

3.5 Industry Level Productivity Metrics

3.5.1 Industry Level Productivity Measures

At the industry level, productivity—the amount (or value) of output produced per unit of input—provides a measure of industrial efficiency. The Bureau of Labor Statistics (BLS) publishes two common measures of productivity: (single factor) labor productivity and multifactor productivity. Labor productivity is an output per hour measure. In the case of an industry producing multiple outputs, a Tornqvist index (weighted sum of the natural log of the ratio of output in different time periods) is used to chain multiple output indices together to form a single output measure (see Appendix A).

Increases in labor productivity may be due to increases in labor quality or labor efforts. However, it can also increase simply due to other factors such as technology or increased capital utilization, even when labor quality and worker efforts are held constant.

BLS measures multifactor productivity using output, labor, capital, and intermediate purchases input. A Tornqvist index is used to combine the inputs into a single measure of production. Multifactor productivity captures growth in output that is not explained by growth in these quantifiable inputs. In the growth accounting framework, multifactor productivity is calculated as a residual. Multifactor productivity growth can be attributed to factors such as management practices, best practices in the production process, etc. Because multifactor productivity is the part of output growth not explained by input growth, labor hours in multifactor productivity need to be quality adjusted. For instance, labor hours worked by workers with different skill levels need to be distinguished in multifactor productivity calculations. When an input quality increases, the input can be considered to have grown in quantity at the original quality level. In contrast, labor hours used in labor productivity calculations are simply the raw numbers of hours worked.

Multifactor productivity is often a preferred measure compared to labor productivity. This is because labor productivity measures are more prone to misinterpretation. Increases in labor productivity may reflect increases in the capital-labor ratio, rather than increases in labor quality and efforts. Additionally, a unit of production may achieve high levels of labor productivity, but the overall productivity may be compromised because the underlying capital-labor ratio may not be optimal. Similarly, low labor productivity might be efficient in the sense that low wages induce contractors to adopt more labor intensive practices and save on capital costs. Labor productivity measures are limited in the sense that they do not reveal a complete picture and are prone to misinterpretation. While labor productivity is often a less preferred measure of productivity compared to multifactor productivity, it is calculated with much more precision with fewer assumptions.[79] Obviously, the data requirement for labor productivity calculation is also significantly less compared to multifactor productivity calculation.

3.5.2 Industry Level Productivity Estimates

There are no official productivity measures published by the BLS for the construction industry due to lack of suitable data. Productivity estimates of the construction industry do, however, exist in the literature. These estimates are produced by scholars in governmental agencies and academia. One highly referenced work is the productivity comparison diagram plotted by Teicholz.[80] In this diagram, constant contract dollars of new construction work per field work hour is shown to have trended downward over the past 40 years at an average compound rate of -0.6 % per year. In contrast, labor productivity of all non-farm industries (which includes the construction industry) has trended upward at an average compound rate of 1.8 % per year. Teicholz believes the reasons for the declines in labor productivity are due to lack of R&D spending, fragmentation within the industry, and declining real wage rates. He also notes that despite the fact that there has been a significant adoption of new information technology by the construction industry over the past 35 years, these applications tend not to be integrated with other systems and therefore do not permit improved collaboration by the project team.

Industry-level productivity estimates made by other scholars tend to show a similar trend. Allen, for instance, shows that construction productivity declined between 1968 and 1978 and argues that the biggest factor in the decline was the shift in the mix of output from large-scale commercial and industrial projects to residential construction and its associated lesser skill requirements.[81] Stokes also argues that construction productivity declined between 1968 and 1978 and asserts that the major contributing factor to that decline was slower growth in capital per worker.[82] This belief that construction productivity is declining is shared by industry observers such as the Business Roundtable.[83]

Other scholars have analyzed productivity trends using more recent data. Harrison examined the period between 1961 through 2005 using data from the Bureau of Economic Analysis' National

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[79] Jerome A. Mark, "Problems Encountered in Measuring Single- and Multifactor Productivity," *Monthly Labor Review* (1986): 3-11.

[80] Paul Teicholz, "Discussion of 'U.S. Construction Labor Productivity Trends, 1970-1998,'" *Journal of Construction Engineering and Management* 127 (2001): 427-428.

[81] Steve G. Allen, "Why Construction Industry Productivity is Declining," *Review of Economics and Statistics* 67(1985): 661-669.

[82] H. Kemble Stokes, Jr, "An Examination of the Productivity Decline in the Construction Industry," *Review of Economics and Statistics* 63 (1981): 495-502.

[83] The Business Roundtable, *CICE—The Next Five Years and Beyond* (New York, NY: The Business Roundtable, 1988).

Economic Accounts and Industry Economic Accounts.[84] He found the productivity growth was -2.43 % for 1961-1981, 0.13 % for 1981-1989, -1.18 % for 1989-2000, and -0.53 % for 2000-2005. Multifactor productivity calculated by Jorgenson *et al.* for the construction industry was -1.08 % for the period of 1977-2000.[85] Faruqui *et al.* examined productivity growth for selected business sectors between 1987 and 2000.[86] During the 1987 to 1996 period, construction experienced a slight increase in productivity, whereas between 1996 and 2000, construction experienced a sharp decline in productivity. Even during the 1987 to 1996 growth period, construction productivity improvements significantly lagged productivity improvements in manufacturing, services, and primary industries (i.e., agriculture, fishing, mining, and forestry). The general pattern of productivity decline is also found in other studies that used national statistics.[87]

It should be noted that not everyone in the construction industry agrees that construction productivity is declining. For example, Young and Bernstein, in their McGraw-Hill SmartMarket Report, contend that the U.S. construction industry is making productivity improvements through innovation with new technologies, processes, and services.[88] Teicholz asserts, however, that a fragmented market with very small players makes application of these innovations less frequent than desired for a healthy increase in industry productivity. Another reason the Teicholz chart may show declining productivity is that it focuses on field work. For example, many of the improvements in construction productivity in the oil and gas industries over the past decade stem from the use of offsite fabrication facilities, where component production is well-controlled and highly-automated.[89] The debate about whether construction industry is declining, holding its own, or increasing cannot be easily resolved, because there are

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[84] Centre for the Study of Living Standards, *Can Measurement Error Explain the Weakness of Productivity in the Canadian Construction Industry?* Research Report no. 2007-01 (Ontario: Centre for the Study of Living Standards, 2007).

[85] Dale W. Jorgenson, Mun S. Ho, and Kevin J. Stiroh, *Productivity Volume 3: Information Technology and the American Growth Resurgence* (Cambridge, Massachusetts and London, England: MIT Press, 2005).

[86] Umar Faruqui, Wulong Gu, Mustapha Kaci, Mirielle Laroche, and Jean-Pierre Maynard, "Differences in Productivity Growth: Canadian-U.S. Business Sectors, 1987-2000," *Monthly Labor Review* 126 April (2003): 16-29.

[87] Martin Neil Baily and Robert J. Gordon, "The Productivity Slowdown, Measurement Issues, and the Explosion of Computer Power," *Brookings Papers on Economic Activity* 1988 No. 2 (1988): 347-420; Wulong Gu and Mun S. Ho, "A Comparison of Industrial Productivity Growth in Canada and the United States," American Economic Review 90 (2000): 172-175; William Gullickson and Michael J. Harper, "Possible Measurement Bias in Aggregate Productivity Growth," Monthly Labor Review February (1999): 47-67.

[88] Norbert W. Young Jr. and Harvey M. Bernstein, "Key Trends in the Construction Industry—2006." *SmartMarket Report* (New York, NY: McGraw Hill Construction, July 2006).

[89] Construction Users Roundtable, "Pre-Assembly Perks: Discover Why Modularization Works." *Op. cit.*

no accurate industry-level measures of productivity for either the construction industry as a whole or its components (i.e., commercial, industrial, infrastructure, and residential).

3.6 Reconciling Industry-Level Productivity Estimates with Task-Level Productivity Estimates

The disparity between the conclusions of industry-level studies and task-level studies has been recognized.[90] There are many explanations for the observed difference in productivity trends.

3.6.1 Quality of Industry-Level Productivity Estimates

The national statistics offices in the U.S. collect tremendous amounts of data. Many elements of data required for productivity measurement exist. However, there are challenges associated with different classification systems and incomplete coverage. These challenges arise primarily because the existing data collection approaches are not designed specifically for productivity measurement.

Productivity measurement requires highly accurate measures of output, inputs, and deflators. This requirement applies to both labor productivity and multifactor productivity measurements. The requirement is particularly challenging for multifactor productivity measurement because multifactor productivity by definition requires more data and because multifactor productivity is the residual, the portion of growth in output not explained by growth of inputs. Since the data requirement is more limited for labor productivity, this discussion will focus mainly on labor productivity measurement in demonstrating the fundamental challenges in implementation.

3.6.1.1 Appropriateness of Output Measure

The appropriateness of the output measure is a major challenge in productivity measurement. In addition, Lawson *et al.* have noted the low quality of output data in the construction industry.[91] The Economic Census is a major survey of industries. Because it is an establishment-based survey, it only surveys and reports data on establishments with payrolls, and a large number of workers in the construction industry are self-employed. Furthermore, because the Economic Census covers both general contractors and subcontractors, there is a significant amount of double counting. Double counting is a concern if the output measure is gross output, and it is not a concern if the output measure of interest is value added.

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[90] Paul M. Goodrum, Carl T. Haas, and Robert W. Glover, "The Divergence in Aggregate and Activity Estimates of US Construction Productivity" *Op. cit.*

[91] Ann M. Lawson, Brian C. Moyer, Sumiye Okubo, and Mark A. Planting, "Integrating Industry and National Economic Accounts, First Steps and Future Improvements," In *A New Architecture for the U.S. National Accounts*, ed. Dale W. Jorgenson, J. Steven Landefeld, and William D. Nordhaus. (Chicago and London: University of Chicago Press, 2006).

Another source of output data is Value of Construction Put in Place from the C30 reports produced by the Census Bureau. Value Put in Place is collected at the project level. Compared to manufacturing, for which data are collected at the establishment level, there are more data collecting units for the construction industry. This is one reason for less accurate data for the construction industry.[92] Another reason is the lack of annual data for benchmarking the value put in place data.[93] An additional complication associated with the use of value put in place as a data source for output measure is that the C30 reports document the total project costs, including architectural services, engineering services, construction services, and materials. These different types of costs are not distinguished in the reported summary statistics. Contract construction cost is reported separately from owner supplied materials and labor and architectural, engineering, and miscellaneous costs in the survey form. An output measure based on the contract construction cost or the total construction cost would be a gross output measure, with a boundary that approximates the construction industry.

3.6.1.2 Lack of Output Deflators

An important element in productivity measurement is the price deflators. Price deflators are needed to derive a quantity index of output. This is done by dividing the monetary value of construction in current dollars with an appropriate price deflator. Deflators are needed to strip away price changes due to inflation. In the case of construction, there is an additional challenge associated with the product not being uniform. Construction projects are heterogeneous even within a well-defined category, such as single family houses. Moreover, what is considered a typical new house in 1960 is very different from a typical new house in 2009. In addition to stripping away changes in prices due to inflation, there is also a need to define a uniform and time invariant "standard" house so that the output quantity index time series is meaningful. The nominal price of a new house in 2009 is higher than the price of a new house in 1960 for two reasons. The first reason is inflation. The second reason is that the house in 2009 is probably larger with more amenities. If the typical house in 1960 is chosen as the "standard house," the quantity index is defined in terms of units of this "standard house." The larger house with more amenities in 2009 is counted as more units of the "standard house," while taking into account price increase due to inflation.

The construction industry has been known to be deficient in the area of price deflators. Two notable price deflators with long time series are associated with the residential sector. The Census Bureau publishes price indices for new one-family houses sold and for new one-family houses under construction using a hedonic regression model. The series are monthly from 1963 and from 1964, respectively. Using a similar approach, the Bureau of Economic Analysis

[92] Eddy M. Rojas and Peerapong Aramvareekul, "Is Construction Labor Productivity Really Declining?" *Journal of Construction Engineering and Management* 129 (2003): 41-46.

[93] *Ibid.*

(BEA), in conjunction with the Census Bureau, has developed a price index for multifamily housing units.[94] This price index series extends back to 1978.

For many years, price deflators based on input data were used for nonresidential construction because appropriate deflators did not exist. While this practice of using input cost data still exists today, these input-based deflators are used to a lesser extent due to recent development of price deflators. Using a deflator based on inputs to deflate output biases multifactor productivity towards no change. In the growth accounting framework, multifactor productivity is the residual of output growth that is not explained by input growth. In other words, multifactor productivity is the ability to produce more output with the same inputs.[95] It is also the residual between output and input prices. It "represents the means by which a competitive position may be enhanced in the absence of input price reductions; the means by which the effects of input price increases may be mitigated; or the means by which payments to labor and to the owners of the capital may rise without increasing price."[96] If there is positive multifactor productivity growth, the prices of inputs should grow faster than the prices of outputs. In other words, when input cost data are used to deflate output, it is implicitly assumed that the relationship between inputs and outputs stays constant, which translates to constant productivity.[97] The use of input costs to deflate output has been cited as a reason for downward bias in productivity.[98] Note however, using a cost index to deflate output can affect labor productivity in different ways. That is, using a cost index to deflate output could bias output upward or downward.

Goodrum and Haas point out that a possible source of underestimation of output comes from decreases in real wage in construction, which is one component of value of construction put in place.[99] A properly constructed output price index takes into account decreases in real wage. To create an accurate output measure, a high quality price index is fundamental.

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[94] Frank de Leeuw, "A Price Index for New Multifamily Housing," *Survey of Current Business* Feb (1993) 73(2): 33-42.

[95] Jorgenson, Dale W., "Productivity and Economic Growth," in Fifty Years of Economic Measurement—the Jubilee of the Conference on Research in Income and Wealth, ed. Ernst R. Berndt and Jack E. Triplett (Chicago and London: University of Chicago Press, 1990).

[96] William Gullickson, "Measurement of Productivity Growth in U.S. Manufacturing," *Monthly Labor Review*. July (1995): 13-35.

[97] Paul Pieper, "The Measurement of Construction Prices: Retrospect and Prospect." In *Fifty Years of Economic Measurement: The Jubilee of the Conference on Research in Income and Wealth*, Volume 54, ed. Ernst R. Berndt and Jack E. Triplett (Chicago: University of Chicago Press, 1990).

[98] Edwin R. Dean, "The Accuracy of the BLS Productivity Measures," *Monthly Labor Review* February (1999): 24-34.

[99] Paul M. Goodrum and Carl T. Haas, "Closure to 'U.S. Construction Labor Productivity Trends, 1970-1998,'" *Journal of Construction Engineering and Management* 127 (2001): 427-429.

The BLS has recently developed producer price indices for the nonresidential sector of the construction industry. These new producer price indices cover four types of new building construction and four types of specialty trades. These newly available producer price indices have been incorporated by the BEA in its estimates of investments in private structures.[100] More details on the BLS producer price indices are discussed in Appendix A.

3.6.1.3 Quality of Input Measures

The main source of labor hours data is the Current Employment Statistics (CES). CES reports total number of employees, number of production workers, and average weekly hours of production workers by NAICS code. A challenge for the construction industry is that the CES is an establishment survey, and the self-employed and unpaid family workers are not within the scope of the survey. Based on Current Population Survey data, about 15 % to 19 % of total work hours and total workforce are attributable to the self-employed and unpaid family workers. At the Bureau of Labor Statistics, the CPS is used to supplement the CES, for data on proprietors and unpaid family workers. One limitation of using the CPS to obtain information on the self-employed is the sample size.[101] An implication is that the number of self-employed, the total number of workers, and the data work hours may not be accurate, particularly at the industry level or a sub-industry level. In CPS, the construction industry is not further categorized at a finer level. Coding of industries and reporting are more accurate in establishment level surveys compared to household surveys. For this reason, data from the CES are used as a primary source of data, and data from the CPS are used as a supplemental source of data in the BLS productivity programs.[102] For materials flows, which are needed for multifactor productivity measurement, it has been noted that although the input-output framework tracks materials flows, the data outside of manufacturing tends to be incomplete.

3.6.2 Changes in Output Mix

Rojas and Aramvareekul point out that productivity changes can simply be due to changes in output mix.[103] Residential and commercial building construction is labor intensive, compared to industrial and heavy construction, which tends to be capital intensive.[104] They contend labor

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[100] Paul R. Lally, "How BEA Accounts for Investment in Private Structures," *Survey on Current Business* February (2009): 9-15.

[101] Edwin R. Dean, "The Accuracy of the BLS Productivity Measures," *Op. cit.*

[102] Lucy P. Eldridge, Marilyn E. Manser, and Phyllis Flohr Otto, "Alternative Measures of Supervisory Employee Hours and Productivity Growth," *Monthly Labor Review* April (2004): 9-28.

[103] Eddy M. Rojas and Peerapong Aramvareekul, "Is Construction Labor Productivity Really Declining?" *Op. cit.*

[104] Based on 2002 Economic Census, capital labor ratio for construction of buildings was 0.06, and it was 0.15 for heavy and civil engineering construction.

productivity is lower for residential and commercial building construction than industrial and heavy construction. From 1964 through 2007, the output mix changed from 64 % residential and commercial and 36 % industrial and heavy construction to 76 % residential and commercial and 24 % industrial and heavy construction.[105] Figure 3.6 shows the general upward trend of residential and commercial construction as a fraction of total construction and the general downward trend of industrial and heavy construction as a percent of total construction. Following Rojas and Aramvareekul's argument, changing the output mix intrinsically translates into decline in measured "labor productivity."[106] This decline in labor productivity due to change in output mix is a result of shifting labor and capital usage, and it does not necessarily indicate lower labor quality or effort. Allen also argues that labor intensity associated with single-family house construction is higher and that the decline in construction productivity between 1968 and 1978 was partially due to the shift in output mix from large scale commercial, industrial, and institutional projects to single-family houses.[107] Figure 3.7 shows dollar amount of single-family house construction as a percent of residential, commercial, industrial, and institutional construction for the period of 1964 and 2002.[108] A relative increase in single-family house construction between 1968 and 1978 is evident. Between 1964 and 2002, we also observe a general upward trend. Estimates of industry-level labor productivity of the construction industry tend to show a declining trend. This decline could be partially explained by changes in the output mix.

Rojas and Aramvareekul also point out that the increase in labor productivity in manufacturing may be partially due to changes in output mix. If the changes in output mix are taken into account, the increase in labor productivity is smaller. This example illustrates the importance of accounting for all inputs in productivity measures. It also indicates the importance of focusing on homogenous products. When productivity is calculated for homogenous building or infrastructure types, the influence of changes in output mix is taken away.

[105] The raw data on which these values are based are originated from Census Bureau's Value of Construction Put in Place. The same dataset is used to generate Figure 3.6.

[106] Eddy M. Rojas and Peerapong Aramvareekul, "Is Construction Labor Productivity Really Declining?" *Op. cit.*

[107] Steve G. Allen, "Why Construction Industry Productivity is Declining," *Op. cit.*

[108] The data source is Census Bureau's Value of Construction Put in Place.

Figure 3.6 Changes in Construction Output Mix (1964-2007)

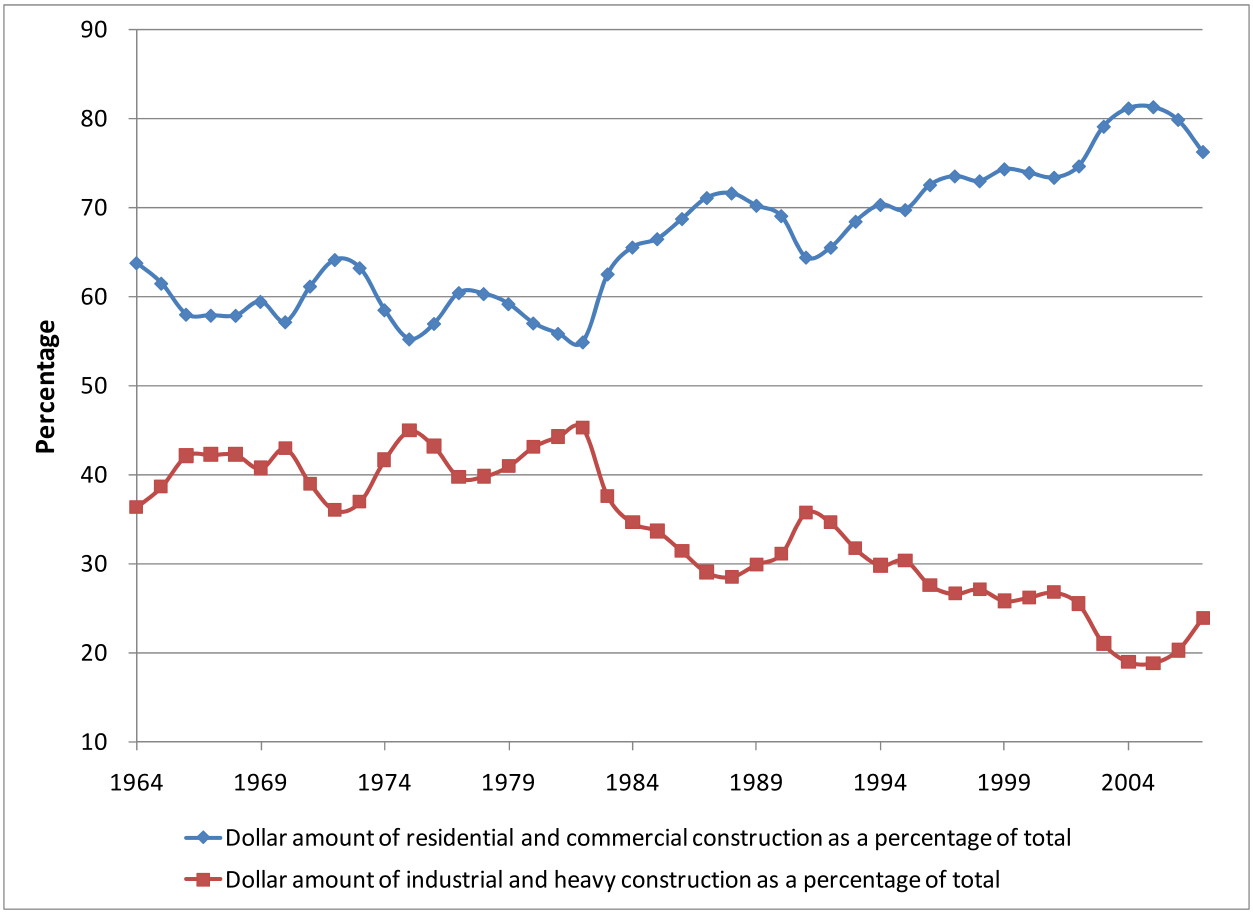
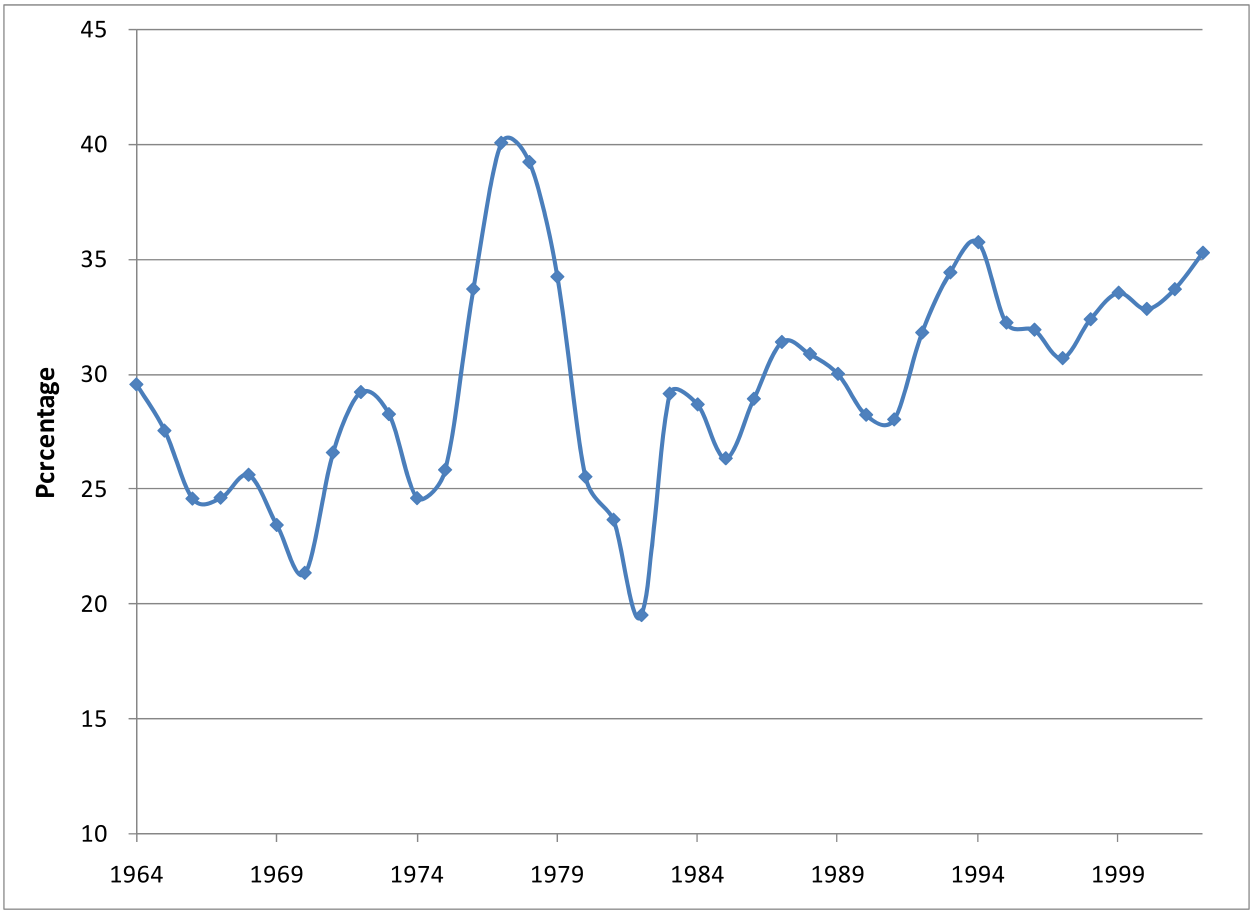


Figure 3.7 Dollar Amount Single-Family House Construction as a percentage of Residential, Commercial, Industrial, and Institutional Construction (1964-2002)



3.6.3 Task-Level Productivity Does Not Completely Reflect Industry-Level Productivity

Construction projects tend to be unique and are increasingly more complex. Task-level productivity does not capture project-level uniqueness and complexity. The trend of increasing project complexity could partly explain productivity decline at the industry level. High productivity at the task level also does not necessarily translate into high productivity at the project level. A project level success depends on managerial coordination and planning, which task-level productivity does not capture. For instance, idle time is not included in task-level productivity measurement, but it certainly can impede progress and productivity at the project level. Regulation is sometimes cited as one reason for low productivity in the construction industry. Regulation does not generally apply to task-level productivity, but it does affect project-level and therefore industry-level productivity.

3.6.4 Different Definitions of Productivity Measures and Different Definitions of the Construction Industry

When comparing productivity estimates, it is helpful to keep in mind the different definitions of productivity. In terms of labor productivity, two different output measures can be used. Labor productivity is often defined as output per hour. The output measure can be gross output or value added. The choice of the output measure is also related to the definition and scope of the construction industry. Industry practitioners tend to define labor productivity in concepts similar to the gross output based labor productivity.[109] In contrast, statistical offices, such as the BLS, tend to use value-added labor productivity measures. One difference between the labor productivity measures based on these two output measures can be seen by looking at prefabrication. Eastman and Sacks, for instance, have studied a number of similar on-site and off-site activities.[110] They have observed that off-site activities tend to have higher productivity than their on-site counterparts. These authors therefore argue that construction productivity is underestimated and that the production of prefabricated materials ought to be included in the construction productivity measurement. Eastman and Sacks' concept of construction labor productivity involves the gross output measure. Offsite activities, such as prefabrication, are productivity enhancing. If they are incorporated in a construction project, then labor productivity based on gross output is expected to improve. On the other hand, labor productivity based on value added is not expected to change with the use of prefabrication.[111] This difference in the definitions of output and the implied scope of the construction industry can lead to different estimates and may be one reason for the divergent perceptions of industry productivity trends.

The most commonly calculated labor productivity measure is defined to be value added per hour. This definition, for instance, is used by the BLS. In task-level productivity studies, the definitions usually vary. For instance, Goodrum *et al.* defined task-level labor productivity in terms of physical units of output per hour.[112] This measure was shown to have increased during 1976-1988. Differences in estimates may be partly due to different definitions.

The rate of change in multifactor productivity in the growth accounting framework is defined to be the rate of change in output minus the weighted rates of change in capital, labor, and

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[109] Centre for the Study of Living Standards, *Can Measurement Error Explain the Weakness of Productivity in the Canadian Construction Industry? Op. cit.*

[110] Charles M. Eastman and Rafael Sacks, "Relative Productivity in the AEC Industries in the United States for On-site and Off-site Activities" *Op. cit.*

[111] Centre for the Study of Living Standards. *Can Measurement Error Explain the Weakness of Productivity in the Canadian Construction Industry? Op. cit.*

[112] Paul M. Goodrum, Carl T. Haas, and Robert W. Glover, "The Divergence in Aggregate and Activity Estimates of US Construction Productivity" *Op. cit.*

intermediate inputs. The weights are cost shares of the corresponding inputs. The multifactor productivity measure defined in Goodrum *et al.* for task-level productivity analysis is also different from the definition conventionally used at the industry level. It is defined as units of physical output divided by the deflated sum of labor cost and equipment cost. For multifactor productivity analysis, the productivity literature recommends the use of gross output (as opposed to value added) as the output measure along with symmetrical treatment of labor, capital, and intermediate inputs.[113] While gross output measures are used in both formulations, task-level productivity defined by Goodrum *et al.* does not incorporate intermediate inputs. The presumed increase in prefabrication of materials could explain some of the increase in multifactor productivity and labor productivity defined in Goodrum *et al.*, which are not reflected in productivity measures at the industry level.[114]

3.7 Conclusions and Observations

Task-level productivity estimates tend to show improvement in construction productivity over time, while industry-level productivity estimates tend to suggest otherwise. Some industry practitioners believe the construction industry has witnessed enhancements in productivity, while others believe productivity has been lagging. This divergence in estimates and in perceptions highlights the challenges associated with productivity measurement of the construction industry. If we set aside the issue of data not collected for the purpose of productivity measurement, we find that there is an intrinsic difficulty in construction productivity measurement. Much of this difficulty lies in the heterogeneous nature of the industry. Construction building or infrastructure types are heterogeneous. Within each building or infrastructure type, there is also heterogeneity as each project is unique. Building processes are heterogeneous, as demonstrated by the diversity of contract work on which the North American Industry Classification System (NAICS) is based. Finally, there is heterogeneity in the composition of construction firms, with large operations taking advantage of economies of scale and scope and making more profits than small companies. The heterogeneity that exists in these multiple dimensions means that productivity may be improving or deteriorating for a particular segment of the industry, at a particular level of analysis. Changes in productivity at an aggregated level may simply be caused by changes in the composition of projects or firms involved, rather than reflecting productivity change per se. The next chapter will discuss possible approaches of disaggregating the industry to create productivity measures that are more meaningful.

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[113] Frank M. Gollop, "Accounting for Intermediate Input: The Link Between Sectoral and Aggregate Measures of Productivity Growth," in Measurement and Interpretation of Productivity, National Research Council (Washington, D.C.: National Academy of Sciences, 1979); Dale W. Jorgenson, Mun S. Ho, and Kevin J. Stiroh, Productivity Volume 3: Information Technology and the American Growth Resurgence (Cambridge, Massachusetts and London, England: The MIT Press, 2005).

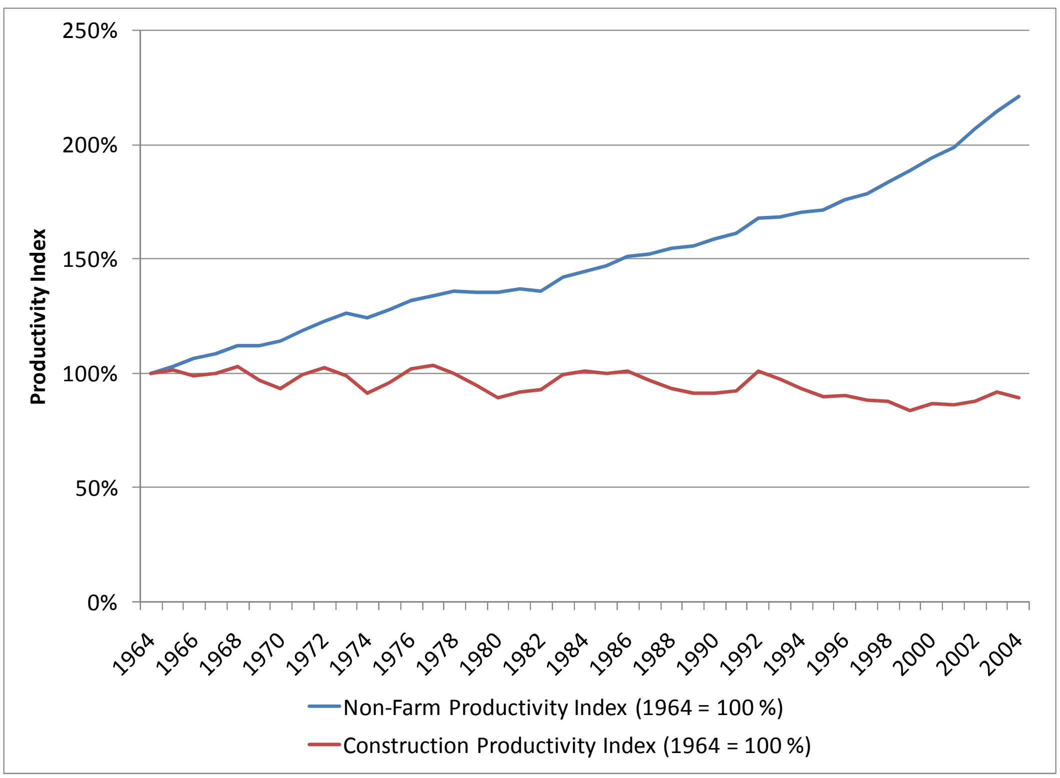
[114] *Ibid.*

4 Challenges and Opportunities in Construction Productivity Measurement Using National Statistics

4.1 Discussion of the Teicholz Diagram

One highly referenced work in construction productivity is the productivity comparison diagram plotted by Teicholz.[115] This following discussion focuses on the productivity calculations by Teicholz and highlights the data challenges associated with construction productivity measurement. In Teicholz's diagram, constant contract dollars of new construction work per field work hour is shown to have trended downward over the past 40 years at an average compound rate of -0.6 % per year. In contrast, labor productivity of all non-farm industries, which includes the construction industry, has trended upward at an average compound rate of 1.8 % per year.

Figure 4.1 Construction Labor Productivity and Non-Farm Business Labor Productivity Comparison[116]



[115] Paul Teicholz, "Labor Productivity Declines in the Construction Industry: Causes and Remedies," *AECbytes Viewpoint.* Issue 4, April 14, 2004.

[116] *Ibid*.

In the Teicholz calculations, the output measure for the construction industry, constant contract dollars of new construction work, is from the C30 Value of Construction Put in Place reports produced by the Census Bureau. Value Put in Place, as defined by the C30 survey, includes architectural design, engineering costs, construction management (since 1997), force-account construction, and secondary construction, in addition to total construction cost as defined by the Economic Census.[117] The Census reports that about two thirds of Value Put in Place corresponds to the work performed by the construction industry as defined by the Economic Census.[118] Defined as such, the output measure contains contributions of industries outside of the construction industry.

C30 reports published contract amounts in constant dollars, and these published figures were the output measure in the Teicholz calculations. The Census Bureau used an array of price and cost indices for the deflation. Possibly because of the lack of appropriate deflators, C30 reports currently only publish contract amounts in current dollars.

Labor hours data that Teicholz used are field work hours, and they came from the Bureau of Labor Statistics. The BLS collects and reports labor hours data under the Current Employment Statistics Survey. Field work hours are work hours of the so-called production workers. Executive and managerial personnel, professional and technical employees, and workers with routine office jobs are considered non-production workers and therefore are excluded. In the BLS productivity program, hours of both production workers and non-production workers are combined to form total hours, which are used in labor productivity calculations.[119] The CES is an establishment survey that covers establishments with payrolls. The self-employed are not under the sampling universe of the CES. About 15 % to 19 % of workers in the construction industry are self-employed or unpaid family workers, and therefore non-negligible.[120] The labor hours data used in Teicholz productivity calculations come from the CES and do not include hours worked by the self employed. Excluding the self employed in the labor hours biases productivity measure upward.

In addition, the Census notes that there is “a significant amount of construction work done in the underground economy.”[121] The existence of an underground economy might be more likely to

[117] United States Census Bureau. Construction Statistics Data Users’ Conference. October 28, 1997. Washington, DC. Document issued March, 1999.

[118] *Ibid.*

[119] Appendix A discusses the estimation of non-production worker hours, as they are not collected under the Current Employment Statistics.

[120] Current Population Survey.

[121] *Ibid.*

affect the labor input than the output measure when the output measure is based on projects. The labor input is underestimated if the labor in the underground economy is ignored.

Finally, changes in labor productivity may be a result of changes in the mix of outputs. Residential and commercial building construction is labor intensive, compared to industrial and heavy construction, which tends to be capital intensive. Rojas and Aramvareekul argue that Labor productivity is lower for residential and commercial building construction than industrial and heavy construction.[122] From 1964 through 2007, the output mix changed from 64 % residential and commercial and 36 % industrial and heavy construction to 76 % residential and commercial and 24 % industrial and heavy construction.[123] Increasing residential and commercial construction in the overall output mix could translate into decline in "labor productivity." The decline in construction labor productivity illustrated in the Teicholz diagram might be partly explained by change in output mix. This illustration indicates the importance of focusing on homogenous products in productivity measurement. A productivity measure at the industry level alone is not sufficiently informative.

4.2 Data Issues Associated with the Teicholz Diagram

The C30 survey form specifically asks for contract construction cost, owner supplied materials and labor, and total construction cost, which is the sum of the former two. Architectural, engineering, and miscellaneous costs is asked of the survey respondent separately, as well as estimated amount of all other capital expenditures. These separate cost estimate data are not reported in the published C30 reports. Therefore, data on contract construction cost and total construction cost are not readily available. The contract construction cost and the total construction cost both contain labor costs and material costs. Value of Construction Put in Place includes architectural design, engineering costs, construction management, force-account construction, secondary construction, and total construction cost. In contrast, an output measure based on the contract construction cost or the total construction cost would be a gross output measure, with a boundary that approximates the construction industry. An additional investigation is needed to examine how labor hours data from the Current Employment Statistics treat owner supplied labor to determine whether contract construction cost or the total construction cost is a better output measure.

One source of data challenge for productivity analysis in the construction industry is the lack of appropriate price deflators. The output data from the C30 reports used to be deflated using an array of price and cost indices, and the more recent data are no longer deflated and are reported only in current dollars. The Bureau of Economic Analysis (BEA), on the other hand, deflates output from the construction industry for GDP estimation. For the residential sector, price

[122] Eddy M. Rojas and Peerapong Aramvareekul, "Is Construction Labor Productivity Really Declining?" *Op. cit.*

[123] Data source is Census Bureau's Value of Construction Put in Place.

deflators based on hedonic regressions are used and are considered reliable. For the nonresidential sector, the newly developed Producer Price Indices (PPI) by the Bureau of Labor Statistics are used. Two limitations are that these PPIs have only been available recently, and they have been developed for only four types of building construction projects. For the historical data, indices based on input costs are used for deflation. For the more recent data, this practice still continues as the price deflators do not exist for all construction types.

The main source of data on labor hours is the CES, which does not cover the self-employed. The Current Population Survey is one data source where the self-employed are covered. The Current Population Survey is a household survey and covers the self-employed. Additionally, the CPS collects data on hours worked and weeks worked. Therefore, hours of the self-employed can be obtained from the CPS. CPS hours data are hours at work, while the CES hours data are hours paid. Ratios of hours at work to hours paid may be available from the National Compensation Survey to convert hours paid to hours worked. Additionally, the CPS data are reported for all workers in the construction industry, while the CES hours data are reported only for production workers. Official productivity measures published by the BLS are constructed using hours worked for both production and nonproduction workers. Therefore, the same definition needs to be used to calculate a labor productivity measure for the construction industry that is consistent with official labor productivity measures of other segments of the economy.

4.3 Approaches for Measuring Construction Productivity

Literature review reveals that there is no consensus on the trend of construction productivity. This document aims to examine what data are available in national statistics that would allow us to create meaningful productivity measures for the construction industry. This effort focuses on labor productivity, rather than multifactor productivity, because the data requirements for labor productivity measurement are more limited and therefore more feasible.

The construction industry is highly heterogeneous. As a result, a single industry-level productivity measure alone is not sufficiently informative. Changes in the industry-level productivity may be due to changes in the composition of projects and therefore may not reveal true productivity changes. There are two possible types of approaches in classifying the industry into a finer level. The first approach is to focus on products. That is, productivity measures can be developed for different building types or infrastructure types. For each building or infrastructure type, productivity measures can be created, and these productivity measures can serve as benchmarks for practitioners who engage in such projects. The second approach is focused on production units, akin to how the NAICS codes are structured. The Economic Classification Policy Committee decided that “as a matter of principle, an industry classification system should be based on producing units rather than products or services."[124] In 2002, the NAICS codes for the construction industry were structured such that there are three broad categories: (1) construction of buildings, (2) heavy and civil engineering construction, and (3) specialty trade contractors. This basic structure of categorization was the foundation for SIC codes of the construction industry that were in use until supplanted by the NAICS codes in 1997. Since much data from national statistics are based on the NAICS codes, creating productivity measures that follow NAICS structure is a natural possibility. Five possible specific approaches are described below.

4.3.1 Focus on Building Types, Gross Output

Output:

Focusing on building types, say an office building, an output measure could be square footage of a project. Square footage values are collected in the C30 survey, which is part of the Census Bureau's Value Put in Place Program. The sampling frame of the C30 survey for private nonresidential and for state and local government construction is based on F.W. Dodge reports,[125] which is a compilation of construction projects, and the Dodge reports also contains the square footage values of projects. Dodge reports go back to 1967. Using square footage as an output measure avoids the problem of lack of good output deflators, and a long time-series is also available.

Labor Input:

Data for labor input can come from the Economic Census. The Economic Census is an establishment survey and it covers all large establishments and a sample of small establishments. These establishments include general contractors and specialty trade contractors. The Economic Census reports "number of construction workers."[126] The Economic Census also asks establishments regarding percentages of their work, based on sales, shipments, receipts, or revenue, in various building and infrastructure types. Starting with general contractors, we can first focus on establishments that specialize in office building construction. Obtaining the number of construction workers that work in office building construction is straight forward for establishments that specialize in office building construction. For establishments that work in

[124] Yuskavage, Robert E. 2007. "Converting Historical Industry Time Series Data from SIC to NAICS" Paper prepared for the Federal Committee on Statistical Methodology 2007 Research Conference, November 5-7, Arlington, VA.

[125] United States Census Bureau. Construction Statistics Data Users' Conference. October 28, 1997. Washington, DC. Document issued March, 1999. *Op. cit.*

[126] Number of construction workers is available from the Economic Census for 2007 and 1992. For 1997, annual payroll costs for construction workers are reported instead of number of construction workers. For 2002, both number of construction workers and number of leased construction workers are reported.

office building construction but do not specialize, extrapolation is needed. For example, we can draw values of number of construction workers per dollar revenue from the distribution based on establishments that specialize. Using data on percentage revenue on office building construction and total revenue, we can obtain an estimate for number of construction workers. The same procedure can be applied to specialty trade contractors to obtain number of construction workers in office building construction.

The number of construction workers can then be combined with average weekly hours of production workers from the Current Employment Statistics Survey to yield an estimate of annual hours, which is the labor input that can be used in labor productivity calculation. The Current Employment Statistics Survey is an establishment survey, and it contains monthly data for detailed classification, largely based on NAICS. In the case of office building construction, average weekly hours of production workers in commercial building construction can be used, and data for this variable is available monthly starting from January 1990.

Challenges:

In terms of the output measures, square footage and the value of construction put in place are both gross output measures. A labor productivity measure can be constructed using gross output measures, but we need to keep in mind that only part of the output is contributed by the construction industry. An additional caveat is that while square footage is a sensible proxy for gross output and using it as an output measure avoids the problem of deflators, it does not control for quality and complexity changes over time.

There is no data on the self-employed (proprietorships and partnerships) in terms of number of construction workers or hours devoted to different building types. The Economic Census is an establishment survey that covers only establishments with payrolls. The Economic Census does report monetary amount of subcontract work, but this value includes both labor and materials. In addition, the subcontract work reported by a general contractor may be performed by a specialty trade contractor who is also included in the Economic Census. It is not possible to estimate the amount of work performed by the self-employed in particular types of building construction work.

The Current Population Survey is one data source where the self-employed are covered. From the Current Population Survey, about 15 % to 19 % of workers in construction are self-employed or unpaid family workers. The self-employed therefore represent a non-negligible portion of the construction work force. While the Current Population Survey is a household survey and covers the self-employed, the construction industry is not further categorized at a finer level. Under the CPS occupation classification, there are 31 occupation types of construction trades. Some of the construction occupations may fall under categories such as installation, maintenance, and repair workers or management occupations. Using data from the CPS, the BLS compiles construction occupations with the most substantial percentage of self-employed workers. Additionally, the

CPS collects data on hours worked and weeks worked. Therefore, information on the occupations of the self-employed workers is available. What is missing is the project types the self-employed engage in.

Another data source on the self-employed is the Nonemployer Statistics, annually published by the Census Bureau, as previously discussed. But this data source also does not allow us to link the self-employed to different project types. An additional issue is the lack of labor data from the underground economy.

Under this approach, although square footage data is available monthly and average weekly hours are also available monthly, number of construction workers working in the office building construction is available only every five years. The C30 survey contains project cost information; however, the labor and materials costs are not distinguished from each other. Labor input cannot be extrapolated using C30 results. Another data source on establishments is the County Business Patterns, which is an annual data on number of employees, payroll, and number of establishments by NAICS codes. It also reports number of establishments by employment-size class for NAICS categories. However, this data source also does not contain information pertinent for productivity measurement with a focus on project types. As a result, productivity estimates can only be made every five years.

4.3.2 Focus on Building Types, Value Added

Output:

The previous approach suffers from the lack of labor data for the self-employed and the underground economy. An alternative approach is to confine the scope and focus on the output of establishments with payrolls and the labor input of establishments with payrolls. Economic Census surveys ask individual establishments about labor costs, materials costs, the amount of business done, and percentage dollar value of work done by different building types. "Value added for the construction industry is defined as the dollar value of business done less costs for construction work subcontracted to others and payments for materials, components, supplies, and fuels."[127] Therefore information needed to calculate value added at the individual establishment level is available. Since the individual components of value added are collected at the establishment level only (rather than at the establishment level by building types), value added of new construction by building types needs to be extrapolated.

To estimate value added by building types, we can first obtain value added from establishments that specialize in, say, office building construction. We can then construct a distribution based on value added as a fraction of total revenue. Then for establishments that engage in office building construction but do not specialize, we can draw values from the distribution. This a sensible

[127] Economic Census 2002.

approach to the extent that value added as a fraction of revenue is similar for the same building type. The Economic Census forms ask respondents to report percent of construction work by building type and by types of construction (new construction; additions, alterations, or reconstruction; and maintenance). Using the percent of construction work and the randomly drawn fraction of value added divided by total revenue, we can derive value added by building type for each establishment. If there are not enough establishments that specialize in certain building or infrastructure types, then it may be sensible to combine several building or infrastructure types together.

Labor Input:

Labor input data is the same as in the first approach (4.3.2).

Challenges:

To use the value added approach, two deflators are needed. The so-called double deflation method involves first deflating gross output by an appropriate price deflator and second deflating intermediate inputs by an appropriate deflator. Subtracting the deflated intermediate inputs from the deflated gross output yields a deflated value added measure.

Currently, the Producer Price Index (PPI) published by the Bureau of Labor Statistics for the new office building construction is available monthly only from June 2006. PPI for new industrial building construction has been available monthly since June 2007. PPI for new warehouse building construction is available monthly from December of 2004. Finally, PPI for new school building construction is available from December 2005. The short data series of PPIs presents a limitation.

In terms of deflators for intermediate inputs, the BLS constructs producer price indices for material and supply inputs to the construction industries. There is an index for the overall inputs to construction industries, and under which there are indices for new construction and maintenance and repair construction. The breakout of new construction is: single-unit residential, multi-unit residential, nonresidential buildings, highway and street construction, and other heavy construction. The breakout for maintenance and repair is: residential and non-residential. Each of the indices is based on a list of NAICS industries that supply materials to the sector in question and their relative weights. The lists of NAICS industries and the relative weights come from the BEA’s input-output tables. Since the input-output tables are based on NAICS codes, data to reconstruct deflators for intermediate inputs to specific project or building types, such as office building construction, are not readily available. A compromise might be simply to use the index for non-residential building construction as a proxy for office building construction. Another limitation is the infrequent data collection of the Economic Census.

4.3.3 Focus on Infrastructure Type, Value Added

Output:

This approach is similar in nature to the previous approach. Instead of focusing on a particular building type, we focus on an infrastructure type. Under the category "Heavy and Civil Engineering Construction," we could focus on "highway and street construction," which includes both general contractors and specialty trade contractors who work in this area. The output measure is value added by establishments that specialize in this area plus imputed value added by establishments that work in this area but do not specialize.

Labor Input:

From the Economic Census we can obtain number of construction workers. From Current Employment Statistics Survey, available monthly from January 1990, we can obtain number of production workers for "highway, street, and bridge construction," as well as total number of employees and average weekly hours of production workers in "highway, street, and bridge construction." From the Current Employment Statistics survey under SIC, we can obtain monthly data for the period of January 1988 through March 2003, although the category is "highway and street construction."

Challenges:

Because the output measure is value added by establishments with payrolls, this approach avoids the problem of lack of labor data associated with self-employment. Producer Price Index is available for material and supply inputs to "highway and street construction" from the Bureau of Labor Statistics monthly from June 1986. Whether a producer price index is available for the output needs to be investigated.

Another challenge is that labor data from the Current Employment Statistics Survey are available for the combined highway, street, and bridge construction for the new series, while labor data is available for only highway and street construction in the old series. Assumptions are needed to use data from these different sources together.

4.3.4 Focus on Specialty Trades

Output:

Since much of existing data are classified under the NAICS system, it is natural to follow the NAICS system when creating productivity measures. PPIs have been developed for four specialty trades by the BLS: concrete contractors (nonresidential building), roofing contractors (nonresidential building), electrical contractors (nonresidential building), and plumbing/HVAC contractors (nonresidential building). These four types of specialty trades are also covered under the Economic Census. Gross output obtained from the Economic Census can be deflated using the corresponding PPIs.

Labor Input:

The Economic Census contains information on the number of construction workers and the number of total employees. Current Employment Statistics Survey contains average weekly hours, number of all employees, and number of production workers for "poured concrete structure contractors," "steel and precast concrete contractors," "roofing contractors," "electrical contractors," and "plumbing and HVAC contractors."

Challenges:

These PPIs for the specialty trades have become available monthly since December 2007. As a result, there is not a long enough time series to construct a productivity trend using these data. Specialty trades may subcontract work to other contractors, and some of which may be self-employed. This issue can be mitigated, as previously discussed, by focusing on value added by the establishments with payrolls and labor input by these establishments with payrolls. To obtain deflated value added, deflators of intermediate inputs are not currently available and therefore would also need to be constructed.

4.3.5 Focus on Residential Building Construction

Output:

Focusing on establishments with payrolls avoids the lack of data associated with the self-employed. Value added output measure can be derived using data from the Economic Census. The PPIs for "new one-family houses under construction" and "new one-family house sold" are available monthly for 1964 through 2007 and 1963 through 2007, respectively. These PPIs are published by the Census Bureau. The BEA and the Census also produce a PPI for multifamily housing. This latter PPI was introduced in 1991. The data series starts from 1958 in the BEA's National Income and Product Accounts (NIPA) tables. The PPIs for the residential sector are derived using the hedonic regression approach and are considered high quality. In terms of deflators for intermediate inputs, deflators for material and supply inputs for single-unit residential construction and multi-unit residential construction from the BLS can be used.

Labor Input:

Number of all employees, number of production workers, and average weekly hours of production workers are available from the Current Employment Statistics Survey for construction of residential buildings and new single-family general contractors. These data are available monthly from January 1990, except the number of all employees for construction of residential buildings is available monthly from January 1985. Number of all employees is available for new multifamily general contractors from January 1990. Starting in January 2001, the number of all employees is collected for residential specialty trade contractors, residential building foundation and exterior contractors, residential building equipment contractors, residential building finishing contractors, and other residential trade contractors.

Challenges:

Using data from Economic Census, we can produce a productivity trend using data from 1987, 1992, 1997, 2002, and 2007.

5 Summary and Recommendations for Future Research

5.1 Summary

Although the construction industry is a major component of the U.S. economy, it has experienced a "perceived" prolonged period of decline in productivity. Due to the critical lack of measurement methods, however, the magnitude of the productivity problem in the construction industry is largely unknown. The measurement problem is exacerbated by the fact that the construction industry is composed of four sectors that differ significantly in the outputs produced, firm size, and use of technology. The four sectors, which taken together define the construction industry, are residential, commercial/institutional, industrial, and infrastructure.

This report describes efforts underway that focus on the measurement of construction productivity at three levels—task, project, and industry—and how such measurements can be developed. This report analyzes the measurement challenges associated with the development of meaningful measures of construction productivity at the task, project, and industry levels and establishes a framework for addressing those challenges. Specifically, this report identifies the metrics, tools, and data needed to move forward in collaboration with key construction industry stakeholders. Once produced, these metrics,tools, and data will help construction industry stakeholders make more cost-effective investments in productivity enhancing technologies and improved life-cycle construction processes; they will also provide stakeholders with new measurement and evaluation capabilities. Finally, this report lays the foundation for future research and for establishing key industry collaborations that will enable more meaningful measures of construction productivity to be produced at the task, project, and industry levels.

5.2 Recommendations for Future Research

The background work for this report uncovered additional areas of research that might be of value to private-sector organizations and government agencies concerned with the measurement and analysis of construction productivity. These areas of research are concerned with: (1) the development of a standard practice for measuring task-level and project-level productivity; (2) the establishment of a database of project-level productivity measures for selected types of capital facilities; (3) factors affecting the use of prefabrication, preassembly, modularization, and off-site fabrication techniques and processes; and (4) industry-level productivity metrics.

5.2.1 Standard Practice for Measuring Task-Level and Project-Level Productivity

Standards are an efficient way of translating research results into practice. Improved metrics, if embodied in a voluntary industry consensus standard, will increase the rate of investment in productivity enhancing technologies, including information, communication, and automation and integration technologies, conveying benefits on individuals, businesses, and government in the form of lower costs of building services and products. Future research aimed at developing, in collaboration with ASTM International, a standard practice for measuring task-level and project-level productivity will fill that need. Ideally, the standard practice will incorporate metrics that enable leading-indicators of performance to be calculated and used to identify areas for improvement during the construction phase. The Building Economics Subcommittee, ASTM E06.81, is the ideal venue for producing this standard practice. Furthermore, the 45 members of the ASTM E06.81 Subcommittee on Building Economics and over 600 ASTM E06 Committee members on Building Performance and Constructions provide an excellent user base as well as industry marketing spokespersons for such a standard practice. Over the longer term, the metrics defined in the standard practice can be embodied in supporting software products that will help implement the standard by various stakeholder groups.

5.2.2 Database of Project-Level Productivity Measures for Capital Facilities

Although there are a number of sources for task-level productivity data, no such sources exist for project-level productivity measures. A recent study, sponsored by NIST and conducted by the Construction Industry Institute (CII), discussed two promising approaches for reporting project-level productivity metrics.[128] Additional research on these two approaches in conjunction with CII's Benchmarking and Metrics Program and other key construction industry stakeholders, could result in a database of project-level productivity measures for selected types of capital facilities (e.g., industrial facilities, commercial and institutional buildings, and infrastructure projects). Such a database would offer a means for disseminating information on project-level productivity. The database would consist of both raw metrics (e.g., direct measures of inputs and outputs) and index-based metrics (e.g., a reference value of 100 pegged to some reference point in time). An advantage of index-based metrics is that they enable project-level productivity to be tracked over time and to spot trends. Ideally, the database would incorporate the capability to analyze how the use of industry best practices and automation and integration technologies affect project-level productivity.

5.2.3 Prefabrication, Preassembly, Modularization, and Off-Site Fabrication

Prefabrication, preassembly, modularization, and off-site fabrication (PPMOF) involve the fabrication or assembly of systems and components at off-site locations and manufacturing plants. Once completed, the systems or components are shipped to a construction job site for installation at the appropriate time. Both owners and contractors view PPMOF as a means to meet challenges of demanding schedules, adverse site conditions, and limited availability of skilled labor. PPMOF offers the promise—if used appropriately—of lower project costs, shorter schedules, improved quality, and more efficient use of labor and materials. However, various obstacles stand in the way of the widespread use of PPMOF, including building codes that hinder innovation as well as conventional design and construction practices. In addition to the obstacles referenced above, CII research shows that using PPMOF techniques and practices requires

[128] Youngcheol Kang, William O'Brien, Jiukun Dai, Stephen P. Mulva, Stephen R. Thomas, and Pin-Chao Liao, *Measuring Interoperability and Best Practices Impacts on Capital Project Productivity*. *Op. cit.*

careful consideration of their implications for engineering, transportation, coordination, and project organization.[129] Additional research is needed to better understand why the successful use of PPMOF techniques and practices in the industrial sector has not been duplicated in the commercial/institutional and infrastructure sectors. Ideally, this research would be conducted as part of a broad-based initiative to understand the pros and cons of PPMOF techniques and practices from a market-based perspective.

5.2.4 Industry-Level Productivity Metrics

Statistical agencies, such as the Census Bureau, the Bureau of Labor Statistics (BLS), and the Bureau of Economic Analysis (BEA), fulfill many needs of the nation through collection and compilation of high-quality data. For instance, an accurate account of the size of the GDP and sizes of contributions by various industry sectors are fundamental for a basic understanding of the nation's economy. Data on housing starts serve as an important indicator that captures the cyclic nature of the economy. To understand how industries make decisions on labor and capital utilizations, data on labor and capital investments are indispensible. To achieve goals like these, the national statistics offices have collected much of the data that are relevant to productivity measurement of the construction industry.

One key element in productivity measurement is output deflators. BLS has recently produced several producer price indices in the nonresidential sector, and this effort has enhanced the estimates of investments in BEA's National Income and Product Account tables. BEA and BLS may collaborate further to develop other nonresidential building construction indices, such as price indices for highways, hospitals, retail, communication, power, and lodging structures.[130] Efforts such as this improve the quality of existing statistics and have spillover benefits for productivity measurement.

There are currently no official productivity statistics on the construction industry due to the lack of adequate data. One challenge that stands out is the mismatch of classification systems between different data sources. One potential remedy may be to classify micro-level data in two or more classification systems designed for different purposes. For instance, the updated classification system of Value of Construction Put in Place is based on end use. For productivity measurement of the construction industry, a classification system based on building type is preferable. Information on both the building type and the end use is available, and therefore it is possible to classify the same data under two systems for different uses. The use of microdata for reclassification can be applied to datasets that have undergone classification changes as well. For instance, the Economic Census and the Current Employment Statistics both transitioned

[129] Construction Industry Institute, *Prefabrication, Preassembly, Modularization, and Offsite Fabrication in Industrial Construction: A Framework for Decision-Making. Op. cit.*

[130] Paul Lally, "How BEA Accounts for Investment in Private Structures." *Op. cit.*

from SIC to NAICS, and as a result, there is a major break in the time series. Reconstructing historic SIC-based data by reclassifying establishments surveyed is one approach.

Another remedy for reconciling the different classification systems under which output and labor input data are organized may be to ask additional questions on existing surveys. The Value of Construction Put in Place survey, for instance, is reported monthly. The main variable is construction costs, which includes costs of both materials and labor. The current Value of Construction Put in Place does not request owners to report material cost and labor cost separately. If information on labor costs and/or hours can also be collected in the same survey, then productivity measures can be developed for different project types and possibly for different geographic regions. Alternatively, the Current Employment Statistics Survey could ask respondents the types of projects they are currently working on. If monthly surveys such as the Value of Construction Put in Place or the Current Employment Statistics Survey can be slightly amended, a rich data set for productivity measurement could be within reach and can enable calculations of labor productivity by project types. Such a productivity measure could be used as a benchmark for owners and contractors engaged in specific project types. Another challenge is the under coverage of the self-employed in establishment-based surveys. A solution may be to develop a supplementary survey that aims to fill this gap.

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Appendix A Metrics of Productivity

Methodologies described in this section are largely based on the approach use by BLS in its productivity programs. BLS has been recognized as a world leader in productivity measurement, and its approach, based on work by Jorgenson and others, has been incorporated in the Organization of Economic Cooperation and Development (OECD) manual titled "Measuring Productivity," which sets the international standard.[131]

A.1 Industry-Level Productivity Measures

A.1.1 Labor Productivity

Labor productivity is an output per hour measure. It is defined as $\frac{Q_t}{Q_0} \div \frac{L_t}{L_0}$, in the BLS formulation, where $\frac{Q_t}{Q_0}$ is the index of output in the current year (*t*) and $\frac{L_t}{L_0}$ is the index of labor input in the current year. Output Q_t can be a physical quantity measure or a deflated value of production, where output expressed in a monetary unit is divided by a price index, such as BLS producer price indices. Deflating value of production using appropriate producer price indices takes away changes in the value of output due to price changes. L_t is labor hors in year *t*. The construction industry produces different products—such as different building types and infrastructure types. To aggregate the different types of outputs, the output index can be calculated using a Tornqvist formula,[132] in which quantities of different products are weighted using the value shares of the products:

$$\frac{Q_t}{Q_{t-1}} = exp\left[\sum_{i=1}^{n} w_{i,t}\left(ln\frac{q_{i,t}}{q_{i,t-1}}\right)\right]$$

where:

$\frac{Q_t}{Q_{t-1}}$ =the ratio of output in the current year (*t*) to previous year (*t-1*)

n =number of products,

$ln\frac{q_{i,t}}{q_{i,t-1}}$ =the natural logarithm of the ratio of the quantity *q* of product *i* in current *t* year to the quantity in the previous year, and

$w_{i,t}$ =the average value share weight for product *i*

The average value share weight for product *j* is:

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[131] OECD (Organization for Economic Co-operation and Development), *Measuring Productivity—Measurements of Aggregate and Industry-Level Productivity Growth* (Paris: OECD, 2001).

[132] Bureau of Labor Statistics, *Handbook of Methods* (Washington D.C.: Bureau of Labor Statistics, 1997).

$$w_{j,t} = \frac{S_{j,t} + S_{j,t-1}}{2}$$

Where: $S_{j,t} = p_{j,t} \times q_{j,t} \div \left(\sum_{i=1}^{n} p_{i,t} \times q_{i,t}\right)$

And $p_{i,t}$ =price of product *i* at time *t*

The Tornqvist formula yields the ratio of output in year *t* to output in year (*t-1*). The series of ratios can be chained to form the index of output used in the productivity formula. That is,

$$\frac{Q_t}{Q_0} = \frac{Q_t}{Q_{t-1}} \times \frac{Q_{t-1}}{Q_{t-2}} \times \dots \times \frac{Q_2}{Q_1} \times \frac{Q_1}{Q_0}$$

$q_{i,t}$ is generally calculated by dividing the value of output by the corresponding price index (BLS's producer price index). This approach is conceptually equivalent to indices based on physical quantities of output.

$\frac{L_t}{L_0}$ is calculated by dividing total labor hours in year *t* with total labor hours in the base year. BLS does not distinguish between different types of labor hours in the output per hour measures.[133]

Changes in labor productivity reflect changes in output that cannot be attributed to changes in the hours of labor in production.[134] Labor productivity reflects influences such as changes in capital input per labor unit, changes in technology, rates of capacity utilization, level of output, managerial skill, and effort and quality of labor. Changes in labor productivity cannot be solely attributed to changes in labor effort or quality.

A.1.2 Multifactor Productivity

Multifactor productivity (or total factor productivity) is the ability to produce more output with the same inputs.[135] It represents a shift in production function. Changes in multifactor productivity reflect changes in output that cannot be attributed to changes in capital inputs, labor inputs, and intermediate inputs. Changes in multifactor productivity reflect technological change, changes in capacity utilization, economies of scale, changes in managerial skills, changes in the organization of production, changes in the resource allocation, and measurement

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[133] *Ibid.*

[134] Bureau of Labor Statistics, *Multifactor Productivity Trends, 2007* (Washington DC: Bureau of Labor Statistics, 2009).

[135] Dale W. Jorgenson, Mun S. Ho, and Kevin J. Stiroh, *Productivity Volume 3: Information Technology and the American Growth Resurgence*. *Op. cit.*

error.[136] Productivity represents the residual between output and inputs, and it also represents the residual between output prices and input prices.[137] It is the ability to mitigate input price increases without increasing the price of output. Or it is the ability to gain a competitive edge without input price reductions.[138]

In the growth accounting framework, multifactor productivity growth is the growth in output minus weighted growth rates in capital, labor, and intermediate inputs. It is the residual, which is not accounted for by growth in labor and capital. The weights are the average value shares of the respective inputs in the value of the output between the two periods of consideration. In the equation form, the multifactor productivity growth is:

$$\frac{\dot{A}}{A} = \frac{\dot{Q}}{Q} - S_k * \frac{\dot{K}}{K} - S_l * \frac{\dot{L}}{L} - S_x * \frac{\dot{X}}{X}$$

where A is multifactor productivity, Q is output, K is capital, L is labor, X is intermediate input, S_k, S_l, and S_x are cost shares of capital, labor, and intermediate input, respectively, assuming competitive factor markets and constant returns to scale. That is,

$$S_i = \frac{p_i * i_i}{\sum(p_i * i_i)}$$

where p_i is the price of input i, and i is the quantity of input i.

A specific functional form of the production function must be chosen for implementation. The translog function is used because the assumptions associated with it are the least restrictive.[139] The Tornqvist index, which is consistent with the translog function, is used for aggregation. By being consistent, it is meant that "changes in output consistent with the very general translog production function are exactly measured by changes in Tornqvist indices."[140] The

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[136] National Research Council, *Measurement and Interpretation of Productivity* (National Academy of Sciences, Washington D.C.: National Academy of Science, 1979); Bureau of Labor Statistics, *Handbook of Methods* (Washington D.C.: Bureau of Labor Statistics, 1997); Jorgenson, Dale W., Mun S. Ho, and Kevin J. Stiroh, *Productivity Volume 3: Information Technology and the American Growth Resurgence* (Cambridge, MA and London, England: The MIT Press, 2005).

[137] William Gullickson, "Measurement of Productivity Growth in U.S. Manufacturing." *Op. cit.*

[138] *Ibid.*

[139] Bureau of Labor Statistics, *Labor Composition and U.S. Productivity Growth, 1948-90* (Washington D.C.: Bureau of Labor Statistics, 1993).

[140] *Ibid.*

instantaneous growth rates are replaced by annual growth rates. For instance, $\frac{\dot{L}}{L}$ is replaced by $\Delta \ln L = \ln L_t - ln\, L_{t-1}$.[141]

The Tornqvist index of multifactor productivity growth is:

$$\Delta \ln A = \Delta\, lnQ - \frac{1}{2} * \left(S_k(t) + S_k(t-1)\right) * \Delta \ln K - \frac{1}{2} * \left(S_l(t) + S_l(t-1)\right) * \Delta \ln L - \frac{1}{2} * \left(S_x(t) + S_x(t-1)\right) * \Delta \ln X$$

Note that the output measure should not include any commodity taxes, because the producers do not receive these taxes.[142] Intermediate input costs, on the other hand, should include commodity taxes because these taxes are paid by the producers.

For the multifactor productivity measures developed by the BLS, KLEMS inputs are used—capital, labor, energy, materials, and purchased business services. The construction of the productivity statistic using more input types is analogous to the case presented above.

A.1.3 Value-Added Function, Choice of Output Measure, and the Role of Intermediate Inputs

Note in the multifactor productivity formula, all outputs—capital, labor, and intermediate inputs—are treated symmetrically. When all outputs are treated symmetrically, substitution between any inputs is allowed. In contrast, when a value-added sub-function is assumed, intermediate inputs cannot be substituted with capital or labor inputs.[143] With the assumption of a value-added sub-function, the production function is written as:

$$Q = f(V(K, L, t), X)$$

This formulation assumes that the value added function is separable from intermediate inputs and that intermediate inputs do not influence the relative use of labor and capital. For instance, when the price of intermediate inputs decrease, a construction project may increase the use of intermediate inputs and reduce labor input. The assumption of a value-added function does not allow for such shifts in resource allocation. Additionally, this assumption implies that

[141] *Ibid.*

[142] W. Erwin Diewert, "Which (Old) Ideas on Productivity Measurement Are Ready to Use?" in *New Developments in Productivity Analysis*, ed. Charles Hulten, Edwin Dean, and Michael J. Harper. Conference on Research in Income and Wealth. (Chicago: University of Chicago Press, 2001).

[143] National Research Council, *Measurement and Interpretation of Productivity*. *Op. cit.*

productivity growth can only be accomplished through the value-added function. That is, intermediate inputs cannot be the medium or source of productivity growth.[144]

Jorgenson *et al.* have developed an econometric method to test the existence of a value-added function.[145] They rejected the existence of a value-added function for construction industry, which was among the 40 of the 45 industries that were rejected for this assumption in their analysis. They observed that intermediate inputs constitute a large proportion of gross output for about 70 percent of the industries studied, suggesting for the use of gross output concept rather than value-added concept for productivity studies at the industry level.[146]

Intermediate inputs are often substitutable with capital or labor in reality. For instance, at a construction site, putting together a door may involve cutting a door to fit certain dimensions, sanding the door, painting the door, and finally installing the door. In this process, all the activities are done by direct labor of the construction crew. The construction supervisor could also decide to purchase a pre-fabricated door. In this case, only the installation of the door involves direct labor, and the rest is accomplished through the purchase of an intermediate input.

Traditionally, construction is defined to include only activities at the work site. Labor productivity of construction associates value-added with labor input. Off-site prefabrication is considered manufacturing in Census classification. Comparable on-site and off-site activities, such as precast concrete, cast-in-place reinforced concrete, sheetrock installation, and elevators and escalators, were studied by Eastman and Sacks, and it was observed that onsite activities are less productive than the counterpart off-site activities.[147] The authors therefore argue that construction productivity is underestimated and that the production of prefabricated materials ought to be included in the construction productivity measurement. The observation by Eastman and Sacks and the theoretical and empirical work of Jorgenson *et al.* highlight the importance of treating intermediate inputs symmetrically in the productivity measurement. Including intermediate input in productivity measurement in this way recognizes the interdependence between sectors and makes it possible to evaluate the impact of contributions by other sectors, such as off-site prefabrication, on productivity growth.

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[144] Frank M. Gollop, "Accounting for Intermediate Input: The Link Between Sectoral and Aggregate Measures of Productivity Growth." *Op. cit.*

[145] Jorgenson, Dale W., Mun S. Ho, and Kevin J. Stiroh, *Productivity Volume 3: Information Technology and the American Growth Resurgence. Op. cit.*

[146] *Ibid.*

[147] Charles M. Eastman and Rafael Sacks, "Relative Productivity in the AEC Industries in the United States for On-site and Off-site Activities," Journal of Construction Engineering and Management 134, no. 7 (2008): 517-526.

A.1.4 Output Measures

A.1.4.1 Gross Output versus Value Added

For multifactor productivity calculation, as discussed earlier, it is preferable to treat intermediate inputs symmetrically with capital and labor inputs. The proper measure of output is therefore gross output, rather than value added, where value added is defined to be gross output minus intermediate inputs.

Some researchers use value-added as the output measure, and incorporate only capital and labor inputs in their multifactor productivity measurement. This is the approach BLS uses for multifactor productivity for the two major sectors, namely, private business and private nonfarm business sectors. Value-added and gross output may be close in value at this level of aggregation.[148] But for disaggregated industries, gross output is preferred. And although it is more appropriate to use gross output, rather than value-added as the output measure, it might be preferable to use value-added as the output measure, for international productivity comparisons, as value-added data tend to be more available.[149]

Which output measure is the preferred output measure in the labor productivity calculation is not clear, however, and there has been little coverage of this issue in the literature.[150]

One data source for gross output is the C30 Value of Construction Put in Place, which includes architectural and engineering design, construction management, force-account construction, and secondary construction, in addition to construction services performed by the construction industry. Value of construction Put in Place is collected from the owners at the project level. Therefore, construction by the self-employed, homeowner construction, and construction done as a secondary source of revenue by nonconstruction establishments are covered.[151] In contrast, these types of construction are not covered by an establishment-level survey such as the Economic Census. Contract construction cost is reported separately from owner supplied materials and labor and architectural, engineering, and miscellaneous costs in the survey form. Therefore, it is possible to obtain separate data on total construction cost. An output measure based on the contract construction cost or the total construction cost would be a gross output measure, with a boundary that approximates the construction industry. The classification of the

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[148] Edwin R. Dean, Michael J. Harper, and Mark S. Sherwood, "Productivity Measurement with Changing-Weight Indices of Outputs and Inputs" In *Industry Productivity: International Comparison and Measurement Issues*, (Paris: OECD, 1996).

[149] *Ibid.*

[150] *Ibid.*

[151] Bureau of Economic Analysis, Concepts and Methods of the U.S. Input-Output Accounts (Washington D.C.: Bureau of Economic Analysis, 2009).

Value of Construction Put in Place data is based on end usage, and the pre-1993 classification system was based on building and infrastructure types. Data classified under these two systems are generally not comparable, particularly at a disaggregated level. Value of Construction Put in Place data are collected monthly and are not deflated.

The only data source that allows the calculation of a value added output measure is the Economic Census. The Economic Census collects data on value of business done, costs for construction work subcontracted to others, and payments for materials, components, supplies, and fuels, which are components needed for calculating value added. One limitation of the Economic Census is that only establishments with payrolls are covered. The Economic Census is collected every five years with SIC/NAICS classification.

A.1.4.2 Price Deflators

An important element in productivity measurement is the price deflators. Price deflators are needed to derive a quantity index of output. This is done by dividing current dollars with an appropriate price deflator. Deflators are needed to strip away price changes due to inflation. Construction industry has been known to be deficient in this area, although many advances have been made in recent years.

Two notable price deflators with long time series are associated with the residential sector. The Census Bureau publishes price indices for new one-family houses sold and for new one-family houses under construction using the hedonic regression model. The series are monthly from 1963 and from 1964, respectively. Using a similar approach, the Bureau of Economic Analysis, in conjunction with the Census Bureau, has developed a price index for multifamily housing units.[152] This price index series extends back to 1978.

The hedonic approach is a multiple regression approach, where the price is regressed on a number of characteristics that determine the price. The regression coefficients tell us how much each of the characteristics contribute to the price. If we choose a "typical" house in 1970 as the "standard house," we can figure out what the price of this house, if constructed new, would be in a later year. This is done by substituting the characteristics of the "standard house" in the regression model of, say 2009, to get the price of the house in 2009. Using this approach, we can get a price series through time for the same "standard house." If we then divide the monetary value of construction with the corresponding price, we can get a quantity index series through time. This quantity index series is in terms of the number of "standard houses" in each year. In this way, we keep the "product" quality constant. This quantity index can be an output measure in productivity studies. A bigger house in 2009 would cost more to construct than the standard house in 1970, for two reasons. One reason is that there is inflation. The other reason is that the house is bigger. The price series obtained from the above approach addresses both of these

[152] Frank de Leeuw, “A Price Index for New Multifamily Housing.” *Op. cit.*

issues. Inflation is accounted for because the regression model from year 2009 was used to "predict" the price of the "standard house." Houses in 2009 are bigger, and since we are artificially keeping the "product" constant, we are giving more credit to the output of 2009. That is, the actual number of houses constructed in 2009 is inflated to reflect the fact that the unit is the smaller "standard house."

In the previous section, two output data sources were discussed. The C30 Value of Construction Put in Place data are classified by project types or end usage while the Economic Census data are classified by SIC/NAICS. Two agencies currently create price deflators relevant to the construction industry. The BEA uses the C30 Value of Construction Put in Place data from the Census Bureau for its fixed investment and fixed assets data. In addition to construction spending defined by the Census Value of Construction Put in Place, BEA includes mining exploration, shafts, and wells, brokers' commissions on the sale of new and used structures, mobile structures, manufactured homes, and net purchases of used structures. The BEA reports quantity and price indices for categories of structures based on end usage, which correspond to C30 classification. Although the added categories are not of relevance in terms of construction output, the BEA's price deflators could potentially be used in conjunction with C30 Value of Construction Put in Place data to yield a constant-dollar output time series.

The other agency that produces price deflators is the BLS. BLS has recently developed producer price indices for the construction industry that are based on prototypes of buildings. The appropriate price deflators contain the contractor's profit, materials costs, and labor costs. Producer price indices are produced for the following new building construction categories: (1) New industrial building construction (NAICS 236211), (2) New warehouse building construction, (3) New school building construction (NAICS 236222), and (4) New office building construction (NAICS 236223). Producer price indices are also produced for four types of special trades in the nonresidential setting: (1) Concrete contractors (NAICS 23811X), (2) Roofing contractors (NAICS 23816X), (3) Electrical contractors (NAICS 23821X), and (4) Plumbing/HVAC contractors (NAICS 23822X).

The PPIs are available for new industrial building construction starting from June 2007. The PPIs for new warehouse building construction are available from December 2004. For new school building construction, the PPIs are available from December 2005. And for new office building construction, June 2006 was the first time the PPIs are available. All of the newly available PPIs for nonresidential structures have been incorporated in BEA's estimates of investments in private structures.[153] For nonresidential structure types for which PPIs are not available, the BEA combines an input cost index with an output cost index to capture some of the productivity and quality changes in the industry and the costs for a particular building type.[154]

[153] Paul R. Lally, "How BEA Accounts for Investment in Private Structures." *Op. cit.*

[154] *Ibid.*

Using hospitals as an example, the BEA uses Census Bureau's single-family houses under construction index along with the Turner Construction Company building cost index. BEA and BLS may collaborate further to develop other nonresidential building construction indices, such as price indices for highways, hospitals, retail, communication, power, and lodging structures.[155] For the four special trades groups, the PPIs are available starting from December of 2007.

These PPIs correspond to NAICS categories, which is the basis of the Economic Census. However, the Economic Census is conducted every five years, and the PPIs have been available only since 2004. Coupling the output data from the Economic Census and the BLS PPIs would require longer time series than what is currently available.

A.1.5 Labor Input

A.1.5.1 Hours (Production Workers)

The BLS Current Employment Statistics (CES) program is used as the primary source of industry employment and hours data. The data are collected monthly and the employment levels are benchmarked yearly using data from State unemployment insurance programs, which covers about 98 % of all nonfarm employees.[156] The classification of industries in this survey is the NAICS system since 2003, and the historic data were classified by the SIC system. The CES reports the number of all employees, the number of production workers, the number of women workers, the average weekly hours of production workers, the average weekly earnings of production workers, and the average weekly hours of overtime of production workers. In the case of the construction industry, the production workers include "workers, up through the level of working supervisors, who are engaged directly in a construction project, either at the site or in shops or yards, at jobs ordinarily performed by members of construction trades."[157] For non-production workers, which are executive and managerial personnel, professional and technical employees, and workers in routine office jobs, only employment data is available from this survey. Note that the numbers of jobs are counted, not persons in the CES program. The hours are hours paid, not hours at work. Work hours of non-production workers are not collected, and therefore would need to be estimated.

A.1.5.2 Conversion from Hours Paid to Hours Worked

One disadvantage of the CES data set is that hours paid, instead of hours worked are reported. Hours paid include vacation, paid sick leave, and holidays, in addition to hours worked. Hours at work includes paid time for traveling between jobs sites, coffee breaks, and machine

[155] *Ibid.*

[156] Bureau of Labor Statistics, *Handbook of Methods. Op. cit.*

[157] *Ibid.*

downtime.[158] While some of the hours at work do not increase productivity, others do. One such example is activities that motivate workers and reduce shirking. Paid leave is best considered a benefit.[159] BLS has been collecting annual establishment level data on actual hours worked for production and nonsupervisory workers (Hours-at-Work Survey) since 1981. Data from the Hours at Work Survey are used to derive ratios of hours at work to hours paid. This is done for 1-digit Standard Industrial Classification (SIC) industry groups on an annual basis. These ratios are then used to convert hours paid data from the establishment survey. Hours-at-Work Survey by itself, however, is not detailed enough to be used in industry-level productivity measurement. The BLS terminated the Hours at Work Survey in 2000, and replaced the HWS with National Compensation Survey. The Employment Cost Index (ECI) from the National Compensation Survey is used to convert hours paid to hours worked. The Hours at Work Survey had a few limitations. Eventually, because of stringent data reporting requirements, the response rate decreased to the point where not enough data were usable. The ECI was designed to capture the hourly cost of wages and benefits, including paid leave. Ratios of hours at work to hours paid can also be constructed using the ECI data. These ratios are calculated using the ECI data since 2001. For the years before 2001, the ratios are based on Hours at Work Survey. The HWS survey included production and nonsupervisory workers in nonagricultural establishments. The National Compensation Survey, on the other hand, covers all workers. Another advantage of the National Compensation Survey is that it contains a bigger sample. The sample size is 37000 occupations within 8500 private establishments whereas the HWS sampled fewer than 6000 establishments. The response rate associated with the NCS is also higher than that of the HWS.

A.1.5.3 Hours (Nonproduction Workers)

The BLS Current Employment Statistics (CES) Survey reports the number of all employees, the number of production workers, the number of women workers, the average weekly hours of production workers, the average weekly earnings of production workers, and the average weekly hours of overtime of production workers. What the CES survey does not collect is the average weekly hours of supervisory and professional workers. For the non-production workers, only employment data are available from this survey.

The Current Population Survey (CPS) collects data on hours worked. And it is used by the BLS in its productivity program to derive annual ratios of supervisory (or nonproduction) worker average weekly hours to nonsupervisory (or production) worker average weekly hours, and subsequently nonproduction worker hours. The CPS asks respondents for their occupation and

[158] Bureau of Labor Statistics, *Handbook of Methods. Op. cit.*

[159] Lucy P. Eldridge, Marilyn E. Manser, and Phyllis Flohr Otto, "Alternative Measures of Supervisory Employee Hours and Productivity Growth." *Op. cit.*

employment status. The information on occupation and employment status is used to sort the data into supervisory (nonproduction) and nonsupervisory (production) categories.[160]

Ratios of supervisory (nonproduction) worker average weekly hours to nonsupervisory (production) worker average weekly hours are calculated. These ratios are multiplied by nonsupervisory (production) worker average weekly hours from the CES. Note the hours data from the CES are for hours paid (rather than hours worked), and therefore some discrepancy is introduced. The ratios between hours worked and hours paid are available at major sector level (from the National Compensation Survey), but not available at detailed industry level. The resultant number, supervisory (nonproduction) worker average weekly hours, is then multiplied by the number of supervisory workers to yield total supervisory worker weekly hours. Total supervisory worker hours are obtained by multiplying total supervisory worker weekly hours by 52. Total supervisory worker hours are then combined with total nonsupervisory worker hours from CES and total self-employed hours and unpaid family worker hours to yield total hours for an industry.

A.1.5.4 Self-Employment

The Current Population Survey (CPS) is used to supplement the CES, for data on proprietors and unpaid family workers. Self-employed individuals are not included in the CES. This is particularly a concern for the construction industry where a large proportion of the workers are self-employed. Starting in 1994, the CPS collects monthly data on employment and hours for primary job and all other jobs separately.[161] In contrast, prior to 1994, CPS reports hours worked for all jobs a person holds, but only the primary job is recorded.

The CPS is based on Census Bureau's Industry Classification System (ICS). The CPS currently uses 2002 Census occupational classification and the 2007 Census industry classification. These are derived from the 2000 Standard Occupational Classification (SOC) and the 2007 North American Industry Classification System (NAICS). Crosswalks are available on BLS's website to link census classification systems with SOC and NAICS. One limitation of using the Current Population Survey to obtain information on the self employed is the sample size. Coding of industries and reporting are more accurate in establishment level surveys compared to household surveys. For this reason, data from the Current Employment Statistics program should be used

[160] Bureau of Labor Statistics, *Construction of Average Weekly Hours for Supervisory and Nonproduction Wage and Salary Workers in Detailed Industries*, Technical Note. (Washington D.C.: Bureau of Labor Statistics, 2005).

[161] Bureau of Labor Statistics, *Construction of Employment and Hours for Self-employed and Other Nonfarm Workers and for all Farm Workers, Using Current Population Survey Data for Primary and Secondary Jobs*, Technical Note. (Washington D.C.: Bureau of Labor Statistics, 2006).

as a primary source of data, and data from the Current Population Survey should be used as a supplemental source of data.[162]

In a BLS study, self-employed were excluded from the analysis of productivity. The reason was that proprietors' incomes include both returns from labor and capital.[163] It is difficult to separate the income into these two components. The more recent BLS approach[164] is similar to the Jorgenson *et al.* approach.[165] First, it is assumed that the self-employed and unpaid family workers are paid the same hourly wages as employees with similar characteristics in the same sector. It is also assumed that the noncorporate rate of return is the same as after-tax rates of return for corporate businesses. These two rates are then adjusted proportionately such that the reported proprietor's income matches with the sum of labor income and noncorporate income.

A.1.5.5 Labor Costs

In labor productivity calculations, labor input is simply expressed in hours. For multifactor productivity calculations, various inputs are combined using corresponding costs as weights. Since the price of labor includes both wage and benefits, from the producer's point of view, both wage and benefits should be included in labor costs. BLS includes in the labor compensation wages, salaries, supplemental payments, including employer's contribution to social security, unemployment insurance taxes, and payments for health insurance and pension plans.[166] Supplemental payments also include paid leave, such as vacation and holiday leave. The labor compensation data come from the National Income and Product Account (NIPA) developed by the BEA and is based on establishment-level data. Labor compensation for proprietors and unpaid family workers needs to be estimated. Real compensation per hour are calculated using Consumer Price Index.[167] Labor costs also include a portion of noncorporate income.[168]

A.1.5.6 Labor Quality

Levels of labor quality are not distinguished in labor productivity calculations. However, accounting for labor quality is important in multifactor productivity. Jorgenson presented

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[162] Lucy P. Eldridge, Marilyn E. Manser, and Phyllis Flohr Otto, "Alternative Measures of Supervisory Employee Hours and Productivity Growth," *Op. cit.*

[163] Bureau of Labor Statistics, *Labor Composition and U.S. Productivity Growth, 1948-90, Op. cit.*

[164] Bureau of Labor Statistics, Technical Information About the BLS Multifactor Productivity. *Op. cit.*

[165] Dale W. Jorgenson, *Productivity, Volume 1: Postwar U.S. Economic Growth* (Cambridge, MA and London: MIT Press, 1995).

[166] Bureau of Labor Statistics, *Handbook of Methods*, *Op. cit.*

[167] *Ibid.*

[168] *Ibid.*

evidence suggesting that the assumption that labor and capital inputs are homogenous is not valid.[169] For instance, for the period between 1947 and 1985, more than a third of labor input growth is from the growth of labor quality. It is important to take into account varying levels of labor quality. Jorgenson *et al.*, for instance, categorizes labor into two gender, eight age, five education, two employment status (employed and self-employed), and ten occupation categories.[170] In their approach, labor input growth is a function of growth in labor hours, as well as growth in labor quality. For each industry, a price matrix is established using labor categorizations. Characteristics of labor input include gender (2 groups), age (8 groups), employment class (2 groups), occupation (10 groups), education (5 groups), and industry (51 groups). This matrix contains 81 600 cells, which is the product of the numbers of groups for each labor input characteristic. Each cell of this price matrix would be populated with the corresponding labor compensation of the particular labor category. Similarly, a quantity matrix is established with each cell of the matrix being populated with hours worked by labor in a particular category. With these two matrices, labor input can be obtained by summing labor inputs of various categories with the corresponding weights, where the weights are the average value shares of the two periods in consideration.

BLS cross classifies the hours of workers by different schooling levels, gender, and age for its multifactor productivity measures, only at the major sector level. In contrast, for multifactor productivity measures at a less aggregated level, such as the manufacturing industries, labor input is simply a sum of all hours. For a few detailed industries, the number of employees is used as the labor input measure.[171] Similarly, labor productivity is an output per hour measure and is calculated assuming all hours are homogenous.

BLS labor classification used to include experience. The recent removal of experience from labor classification is consistent with Jorgenson *et al.*[172], who assume that experience is implicitly included through data on education and age.[173] The hours at work by the different types of workers are weighted and aggregated using an annually chained (Tornqvist) index. An earlier approach BLS used regarding labor costs was to estimate earnings using data from

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[169] Dale W. Jorgenson, "Productivity and Economic Growth," in *Fifty Years of Economic Measurement—the Jubilee of the Conference on Research in Income and Wealth*. *Op. cit.*

[170] Dale W. Jorgenson, F. M. Gollop, and B. M. Fraumeni, *Productivity and U.S. Economic Growth*. *Op. cit.*

[171] Edwin R. Dean, Michael J. Harper, and Mark S. Sherwood, "Productivity Measurement with Changing-Weight Indices of Outputs and Inputs," *Op. cit.*

[172] Dale W. Jorgenson, Mun S. Ho, and Kevin J. Stiroh, *Productivity Volume 3: Information Technology and the American Growth Resurgence*. *Op. cit.*

[173] Bureau of Labor Statistics, "Changes in the Composition of Labor for BLS Multifactor Productivity Measures, 2007." Technical Report. (Washington D.C.: Bureau of Labor Statistics, 2009).

education, estimated experience, and other characteristics. The recent approach is to simplify the procedure by using actual earnings.

An alternative approach utilized the Longitudinal Employer-Household Dynamics database to estimate human capital.[174] Dale Jorgenson commented that this methodology is "taking productivity analysis to the next level."

A.1.6 Capital Input

This section is based largely on Harper.[175] Capital could include anything that is costly to obtain at the present, but it earns return in the future.[176] Capital therefore could include equipment, structures, land, inventories, financial assets, human capital, and intangibles such as software development, advertising costs, or organizational efforts.[177] In productivity studies, only equipment, structures, land, and inventories are accounted for as capital inputs. Although data on financial assets exist, they are not included in capital input calculations because it is difficult to link decisions about financial assets with production decisions.[178] While intangible assets play direct roles in production, they are excluded because it is hard to quantify their service flows.[179]

Property income of capital is defined as nominal revenues minus expenses for variable inputs. It represents the return of the capital to the investor who made the capital investment. It also represents the nominal cost paid by the production manager to the investor for the use of the capital. Property income of capital is readily available in firm's accounting records.[180]

To construct capital input, the first step is to use the perpetual inventory method to convert investment data into capital stocks. Capital stocks then are combined with property income data

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[174] LEHD, "A Layman's Guide to the LEHD Human Capital Measures" Longitudinal Employer-Household Dynamics Informational Document No. ID-2003-04. 2003; John M. Abdowd, Paul A. Lengermann, and Kevin L. McKinney. "The Measurement of Human Capital in the U.S. Economy," Longitudinal Employer Household Dynamics. Technical Paper No. TP-2002-09. 2002

[175] Michael J. Harper, "Estimating Capital Inputs for Productivity Measurement: An Overview of U.S. Concepts and Methods," *International Statistical Review* 67(1999):327-337. 1999.

[176] *Ibid.*

[177] *Ibid.*

[178] *Ibid.*

[179] *Ibid.*

[180] *Ibid.*

to derive rental prices. These rental prices are then used as weights to aggregate capital services from different assets into a capital input index.[181]

The BEA uses BLS producer price indices as a basis to deflate nominal investments to yield real investments. The price indices used incorporate quality change such that investments of higher quality are treated as being higher in quantity, while the quality is kept constant. BLS then uses an age/efficiency function to weight real investments by age/efficiency, and weighted real investments are aggregated by asset types. The productive capital stock $K_{i,t}$ at time t for the i^{th} type of capital asset is a sum of past investments, $I(i, t-\tau)$, of asset type i and age τ, weighted by the age/efficiency function, S_τ:

$$K_{i,t} = \sum_{\tau=0}^{\infty} S_\tau \, I(i, t-\tau)$$

The age/efficiency function, S_τ, used in BLS productivity program is of the following functional form:

$$S_\tau = \frac{L-\tau}{L-B\tau}$$

Where L is service life of the asset, τ is the age of the asset, and B is a parameter. B is assumed to be 0.5 for equipment and 0.75 for structures. The age/efficiency profile is based on empirical evidence when it is available. However, such information tends to be limited. Note that the vintage aggregation is based on efficiency of the asset rather than its value.

Property income,Ψ_t, is the total rent from different assets at time t. That is,

$$\Psi_t = \sum_i c_{i,t} K_{i,t}$$

where $K_{i,t}$ is the productive stock of the i^{th} asset and $c_{i,t}$ is the rental price. The rental price can be written as the following equation if the price of the asset is assumed to be the discounted sum of all future rents.

$$c_{i,t} = p_{i,t}\, r_t + p_{i,t}\delta_{i,t} - (p_{i,t} - p_{i,t-1})$$

where $\delta_{i,t}$ is the rate of depreciation, r_t is the discount rate, and $p_{i,t}$ is the price. The rate of depreciation is derived from the age/price profile that corresponds to the age/efficiency profile used to aggregate assets of different vintages earlier. With data on property income, productive capital stock, the rate of depreciation, the two equations above are used to estimate the rate of return, r_t and thus $c_{i,t}$, the rental price. The rental price is implicit and needs to be estimated

[181] Dale W. Jorgenson, Mun S. Ho, and Kevin J. Stiroh, Productivity Volume 3: Information Technology and the American Growth Resurgence, *Op. cit.*

because companies often own the capital they use and there is no actual transactions that take place.

Property taxes for specific asset types are then added to the rental price, and a multiplier is created to take into account corporate income tax, depreciation deductions, and credits. This procedure takes into account the different effective tax rates on different types of assets. For instance, the effective cost for equipment use is lower than that of structures due to investment tax credit for equipment and possible depreciation deductions for equipment over very short periods of time.

Productive stocks of different asset types are then aggregated for each industry, using the rental price shares as weights. These aggregated productive stocks then constitute capital input for the industry. For the productivity measurement at the major sector level, such as the private business sector, then the industry-level capital inputs are aggregated using relative capital income as weights.

Similar to labor, capital quality is accounted for in capital input calculation in the framework of Jorgenson *et al.*[182] Capital is broken down by class of asset and legal form of organization. Capital stock at any time point is the sum of weighted past investments. The weights represent relative efficiencies of capital due to age differences. The cross-classification, however, was not done by industry.

BLS classifies capital assets into 42 types for equipment, 21 types for nonresidential structures, 9 types for residential structures, 3 types for inventories (by stages of processing), and land.[183] Notably, information processing equipment and software is included under the equipment category.

A.1.7 Intermediate Inputs

Intermediate inputs include energy, materials, and purchased business services inputs. These data are available from BEA's input output tables. The role of intermediate inputs becomes more important when the focus is on a more disaggregated industry level.[184] Intermediate inputs are constructed only for manufacturing industries in the BLS productivity program as manufacturing as a whole and 18 3-digit NAICS manufacturing industries are the only industries for which KLEMS productivity measures are published.[185] Data for energy input come from price and quantity of fuels used for heat or power. For the productivity calculation of

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[182] Dale W. Jorgenson, F. M. Gollop, and B. M. Fraumeni, *Productivity and U.S. Economic Growth, Op. cit.*

[183] Bureau of Labor Statistics, Technical Information About the BLS Multifactor Productivity, *Op. cit.*

[184] *Ibid.*

[185] *Ibid.*

manufacturing industries, materials are non-energy inputs but include fuel-type materials that are used as raw materials in manufacturing. Purchased business services are purchased services from service industries by manufacturing industries. Costs associated with intermediate input purchases should include commodity taxes because they are paid by the producer.[186]

The present input-output framework is designed to track material flows. Data is limited regarding contracted labor services and leased capital equipments.[187] As regards to materials flows, data tend to be incomplete outside of the manufacturing industries.[188]

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[186] W. Erwin Diewert, "Which (Old) Ideas on Productivity Measurement Are Ready to Use?" in *New Developments in Productivity Analysis. Op. cit.*

[187] *Ibid.*

[188] *Ibid.*

A.2 Aggregation Methods

When choosing an aggregation method, it is best to choose one that uses weights that change over time. When fixed weights are used, the quality of estimates that are closer to the base year is generally high, whereas estimates that are further from the base year are likely to be error prone.[189] For instance, when the price of capital increases, the quantity of capital decreases relative to labor. The value share of capital may increase, decrease, or stay constant, but the fixed-weight approach dictates the value share to be constant.[190] Fisher Ideal[191] and the Tornqvist indices are aggregated using weights that can change over time. Diewert shows that "certain index number formulas, which he coined "superlative," such as the Tornqvist and the Fisher Ideal, are consistent with flexible production functions."[192] "Aggregation methods that use fixed weights are consistent with a more restrictive production function." Diewert shows that "chained time series of superlative index numbers are approximately consistent."[193] On theoretical grounds, Fisher Ideal and Tornqvist indices are both good choices. There is also little difference between these indices in practical applications.[194] As Dumagan shows, the Tornqvist index and the Fisher ideal index numerically approximate each other.[195] As the Tornqvist index requires less data to calculate, it may be may be more practical to use.[196] Although more researchers prefer the Tornqvist index, there is no strong reason to prefer the Tornqvist index or the Fisher ideal index.[197] BLS uses the Tornqvist index in labor productivity calculations, while the BEA uses the Fisher ideal index for chain-type indices.

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[189] William Gullickson, "Measurement of Productivity Growth in U.S. Manufacturing," *Op. cit.*

[190] Edwin R. Dean, Michael J. Harper, and Mark S. Sherwood, "Productivity Measurement with Changing-Weight Indices of Outputs and Inputs" In *Industry Productivity: International Comparison and Measurement Issues*, OECD (Paris: OECD, 1996).

[191] For more information on Fisher Ideal Indices, please see R.D. Rossiter, "Fisher Ideal Indices in the National Income and Product Accounts," *Journal of Economic Education* Fall (2000): 363-373.

[192] W. Erwin Diewert, "Exact and Superlative Index Numbers," *Journal of Econometrics* vol 4, no. 4 (1976): 115-45.

[193] W. Erwin Diewert, "Superlative Index Numbers and Consistency in Aggregation," *Econometrica* July (1978): 883-900.

[194] William Gullickson, "Measurement of Productivity Growth in U.S. Manufacturing," *Op. cit.*

[195] Jesus C. Dumagan, "Comparing the superlative Tornqvist and Fisher ideal indices," *Economic Letters* 76(2002): 251-258.

[196] *Ibid.*

[197] Edwin R. Dean, Michael J. Harper, and Mark S. Sherwood, "Productivity Measurement with Changing-Weight Indices of Outputs and Inputs," *Op. cit.*

The Tornqvist index can be used to aggregate different types of outputs. It is also the approach used to individually aggregate different types of labor inputs, capital inputs, or intermediate inputs. When different types of labor are aggregated, the weights used in the Tornqvist index formula are relative shares of labor compensation. For aggregation of different capital assets, relative shares of capital income the assets generate are used as weights. Again when finally calculating the productivity, all inputs are aggregated using the Tornqvist index, with weights being each input's share of total costs. Generally it is desirable to use the most disaggregated data and then aggregate different components to a more aggregate level.

A.3 Overview of BLS Productivity Program

BLS does not publish labor productivity or multifactor productivity measures for the construction industry. BLS produces labor productivity for business, private nonfarm business, manufacturing (total, durable, and nondurable sectors), and nonfinancial corporations. Labor productivity is available also for over 400 selected industries in manufacturing, mining, utilities, wholesale and retail trade, and services.

BLS has two multifactor productivity programs—the Major Sector Multifactor Productivity program and the Industry Multifactor Productivity program. In the Major Sector Multifactor Productivity program, the BLS publishes multifactor productivity the private business sector, the private nonfarm business sector, the aggregate manufacturing sector, and 18 3-digit NAICS manufacturing industries and the utility and gas industry. The productivity measures for the private business sector and the private nonfarm business sector are based on value added output, and labor and capital inputs. For the aggregate manufacturing sector and the 18 3-digit NAICS manufacturing industries, gross output, KLEMS inputs (capital, labor, energy, materials, and purchased business services) are used.

In its Industry Multifactor Productivity program, the BLS publishes multifactor productivity for 86 4-digit NAICS manufacturing industries, air transportation, and railroad transportation. For these industries, inputs include employee hours, capital services, and intermediate purchases.

The BLS also produces multifactor productivity for manufacturing industries of U.S., France, and Germany for comparison of productivity trends. These measures are based on value-added and labor and capital inputs.

A.4 Classification Issues

There are two types of classification issues. One issue concerns the different classification systems used in different datasets. For instance, the Economic Census and the Current Employment Statistics are both establishment-based surveys, and they are organized using SIC and NAICS systems. Census Bureau's Value of Construction Put in Place survey uses projects as units of data collection. To create labor productivity measures using output data from the

Value of Construction Put in Place is difficult because labor hours data are collected using NAICS/SIC, but not organized by project types.

The other classification issue concerns the change of classification systems within a dataset. The most prominent example of this issue is the change of industry classification system from SIC (Standard Industrial Classification) system to NAICS (North American Industry Classification System) in 1997. Under the SIC system, establishments were mainly classified by product or activity types, but in some instances, end use, raw materials, or market structure was as the basis for classification. The classification system of SIC was not consistent. NAICS was devised to incorporate new industries that were not covered under SIC and also to provide a consistent framework for classification. With the rapid changes in the composition of the economy, a new classification was needed to accommodate the new and evolving economy. The NAICS system classifies industries by their production processes, as opposed to final products.

Some of the categories of construction under the two classification systems appear to be similar. One such example is SIC 152 General Building Contractors-Residential and NAICS 2361 Residential Building Construction. However, these two categories are not completely comparable due to rule changes, such as the treatment of auxiliary units.[198] Efforts have been made to concord or bridge the two classification systems and reclassify older data using the new classification system.

For instance, the microdata of the Current Employment Statistics survey from March 2001 were coded in both SIC and NAICS.[199] For the data from March 2001, 97.2 % of the employment of the construction industry under NAICS can be classified under the construction industry in the SIC system. A small percent (0.3 %) of the employment of the construction industry falls under mining in the SIC system.[200] Some of the employment (1.3 % and 1.2 %, respectively) fall under Finance, insurance, and real estate, and services in the SIC system. These ratios were used to reconstruct historic data.

In the case of the Economic Census, establishments surveyed in 1997 were coded both with SIC and NAICS, and bridge tables were developed based on the 1997 data. The bridge tables list the NAICS codes and the corresponding SIC codes. Since the matches are not always exact, the tables also list the proportions of total SIC sales, receipts, or value of shipment under particular SIC codes that are under specific NAICS codes. Using these proportions to "translate" NAICS codes into SIC codes, or vice versa, could cause problems.

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[198] Teresa L. Morisi, "Recent Changes in the National Current Employment Statistics Survey," *Monthly Labor Review* June (2003): 3-13.

[199] *Ibid.*

[200] *Ibid.*

For cases where the SIC code does not translate into a NAICS code, one approach is to directly look at micro-level data. If an establishment is surveyed in 1997, then its 5-digit identification number and its SIC and NAICS assignments can be used to assign NAICS codes to the older data associated with this particular establishment. This is possible because establishments surveyed in 1997 were assigned both a SIC code and a NAICS code.

If establishments cannot be classified with a NAICS code using the above approaches, then they could be assigned NAICS codes by following the procedure outlined below using data from the 1997 Economic Census. Information on the characteristics, such as shipments per worker or hourly wages (in the case of the manufacturing industry), can be used to derive probabilities of specific NAICS code assignment. A NAICS code can then be drawn from the distribution.[201] Another example is Klimek and Merrell,[202] who used 1997 Economic Census data on retail and wholesale industries and established proportions of establishments originally assigned a SIC code that are assigned to a NAICS code. Using these proportions, the authors constructed a distribution from which NAICS codes are randomly drawn and assigned to individual establishments. The newly NAICS coded data were then used to produce aggregate data. This latter approach was shown to be reasonable as two thirds of the establishments that required random assignment were cases where over 90 % of the establishments in 1997 were coded into a single NAICS industry. The authors also suggested that multiple random assignments can be done and used to generate standard errors. Another possibility is to use a firm's NAICS code to assign to its associated establishments.

[201] Kimberly N. Bayard and Shawn D. Klimek, "Creating a Historical Bridge for Manufacturing Between the Standard Industrial Classification System and the North American Industry Classification System," Proceedings of the American Statistical Association, Business and Economic Statistics Section [CD-ROM] (2004), pp. 478-84.

[202] Shawn D. Klimek and David R. Merrell, "On Reclassifying Industries from the Standard Industrial Classification System to the North American Industry Classification System," presented at the Second International Conference on Establishment Surveys, Buffalo, New York, 2000.

Appendix B Productivity and Competitiveness: An Annotated Bibliography

This annotated bibliography summarizes key documents in productivity measurement with an emphasis on the construction industry. Challenges in construction productivity measurement have been recognized for many decades. While some aspects of construction productivity measurement have received attention, and notable improvements have been made, many fundamental challenges exist. This annotated bibliography provides a focused view of the state of knowledge and, for researchers and practitioners, an updated and centralized source of documents in this area.

This annotated bibliography contains three sections. Section B.1 focuses on documents with a specific focus on the productivity, its measurement, and other related issues in the construction industry. Some of the measurement issues are deflators, quality adjustments of output, the definition of what constitutes the construction industry, and the underground economy. Most studies on construction productivity focus either on task-level productivity or industry-level productivity. Metrics used include labor productivity, multifactor productivity, and direct work rate. There are, however, different definitions for each of these metrics in the literature. Some of the causes for differences of changes in construction productivity are economies of scale, labor quality, capital-labor ratio, changes in output mix, and institutional issues (prevailing wage laws, unions, and collective bargaining). This section also includes studies from other countries, such as the United Kingdom and Canada.

Section B.2 is titled "construction data." It includes a document from the Construction Statistics Data Users' Conference in 1997, published by the Census Bureau. This document discusses governmental statistics on construction and on how the data are collected and reported.

Section B.3 contains studies that are on the general topic of productivity methods and measurement. It includes many documents published by the Bureau of Labor Statistics. It also includes documents from the OECD and academic sources. Methods and challenges on measurement of output, deflators, capital, labor, and data quality are presented.

B.1 Construction Productivity and Related Issues

Allen, Steve G. "Unionized Construction Workers are More Productive." ***Quarterly Journal of Economics*** **99, no. 2 (1984): 251-274.**

This is an empirical paper that shows that unionized workers are more productive, controlling for capital-labor ratio, capital recentness, measurable labor quality, scale of production, industry, region, and interstate price differences. Productivity is defined as value added per worker. The factors that contribute to higher productivity levels among unionized workers may include better training, reduced use of unskilled labor, lower foreman to journeyman ratios, reduced recruiting and screening costs, and greater managerial ability.

Allen, Steve G. “Why Construction Industry Productivity is Declining.” *Review of Economics and Statistics* 67, no. 4 (1985): 661-669.

This paper studies the sources of construction productivity change. Value added per employee deflated by the Dodge cost index was regressed on capital per employee, labor hours per establishment (economy of scale), labor quality, union, region variables, and building types. Data used was at the state level for 1972 and 1977. The coefficients from the regression model were then combined with data from these two years to yield percent productivity change due to the various factors. The total predicted productivity change from the regression was -8.8 %. The shift of output mix from commercial, industrial, and institutional projects to residential projects resulted in a reduction in skilled labor, and this was the most important factor that contributed to the decline in productivity.

Alternative deflators were also devised. For instance, a deflator for nonresidential building construction was calculated using the difference between the rate of change of value put in place and the rate of change of square footage put in place. Adjusting for bias in the deflators accounts for -10.5 percentage points in reported productivity, which was -21.4 %. The predicted change from the regression, together with the adjustment of the deflators, therefore can explain 92 % of the productivity change.

Allen, Steven G. “Why Construction Industry Productivity is Declining: Reply.” *Review of Economics and Statistics* 71, no. 3 (1989): 547-549.

Allen responds to Pieper’s (1989) comments. The capital-labor ratio was shown to be decreasing in the original paper, but Pieper showed that it was increasing. The sources of data and the assumptions contribute to this discrepancy. Allen made several adjustments and reported that 56.5 % of the observed decline in productivity can be explained, instead of 92 % as in the original paper.

Allmon, E., C. T. Hass, J. D. Borcherding, and P. M. Goodrum. “U.S. Construction Labor Productivity Trends, 1970-1998.” *Journal of Construction Engineering and Management* 126, no. 2 (2000): 97-104.

This study focuses on task-level productivity. Unit labor costs in constant dollars and daily output factors were obtained from Means cost manuals, for tasks such as hand trenching, welded steel pipe installation, ceiling tile installation, and compaction with a sheepsfoot roller, over three decades. The tasks were chosen such that tasks that are impacted by varying degrees of technology improvement are included in the study. The daily output increased for most of the tasks, and the unit labor costs decreased in real terms for all tasks. The two main reasons for the increase in productivity are low wages and technology improvement. Time use data from 72 projects in Austin, Texas over 25 years were also studied. It was found that direct work rate is positively correlated with construction productivity.

Azari-Rad, Hamid, Peter Philips, and Mark J. Prus, eds. *The Economics of Prevailing Wage Laws.* Hampshire, England: Ashgate Publishing Limited, 2005.

This book is a collection of chapters that examine the prevailing wage laws and how they affect various aspects of the American construction industry. The book presents a history of prevailing wage laws and an overview of the construction industry. The underlying vision of the prevailing wage laws is a society where labor is highly skilled, highly paid, and the industries are capital intensive and utilize advanced technologies. The main thesis of the book is that prevailing wage laws solve a free-rider problem and they allow long-term costs to be paid, such as costs on training, safety, insurance, and pensions, despite the short-term nature of projects. These arguments are supported by empirical evidence based on heterogeneity in prevailing wage laws across states and time. The discussion on productivity is limited.

Baily, Martin Neil and Robert J. Gordon. "The Productivity Slowdown, Measurement Issues, and the Explosion of Computer Power." *Brookings Papers on Economic Activit,* no. 2 (1988): 347-431.

This paper examines the source of U.S. productivity slowdown after 1973. There is a section that is devoted to construction productivity. The average annual growth rate in terms of GDP per hour in construction was estimated to be between -1.67 % to -1.99 % in the period of 1973-1987. Trends of output and inputs are examined, and the paper documents the "implausibility" of the data. This paper indicates data problems and the need for better data collection, particularly on output. Included at the end of the paper is a discussion by William Nordhaus and David Romer.

Bosch, Gerhard and Peter Philips, eds. *Building Chaos—An International Comparison of Deregulation in the Construction Industry.* London: Routledge, 2003.

This book contains case studies of 9 countries—the Netherlands, Germany, Denmark, Canada (Province of Quebec), Australia, Spain, the United States, the United Kingdom, and Republic of Korea, in descending order of the level of regulation of their construction labor markets. The construction industry is intrinsically volatile. Because construction projects are neither storable nor transportable, the industry is particularly vulnerable to economic downturns. It was shown that construction industries in these countries follow two paths of development. On one path of development, long term costs are paid for. These long term costs include training of workers, health insurance, retirement, compensation for instability of the industry, and development and use of advanced technologies. This model of development is capital intensive, human capital intensive, and "technically dynamic." Productivity tends to be high in construction industries that are on the technically dynamic path. The other model of development is characterized by a free-rider problem. The long term costs are not paid for because there is no legal requirement or because there are no arrangements made between contractors and organized labor. Labor quality tends to be low and not well equipped, and labor intensity tends to be high.

In the case of the United States, in some regions organized unions and organized employer associations engage in collective bargaining and develop agreements for apprenticeship programs, health insurance, and retirement. In other regions, no such agreements exist.

Canadian Construction Innovation Council. ***Measuring the Performance of the Canadian Construction Industry: Metrics*****. Ontario: Canadian Construction Innovation Council, 2006.**

This is an initial document of the Canadian Construction Innovation Council's effort to assess the performance of the Canadian construction industry. This document includes a literature review of benchmarking efforts and a preliminary set of metrics.

Canadian Construction Innovation Council. ***Measuring the Performance of the Canadian Construction Industry: Pilot Project Final Report.*** **Ontario, 2007.**

This report is the follow-up report of the Metrics report dated 2006 (see above). This document reports the findings of the pilot study where metrics of performance were applied to 37 projects, including buildings and water and wastewater piping systems. It was pointed out that only using productivity measurements may not capture a complete picture of the performance. In addition, the industry prefers descriptive measures. The metrics system used is based on benchmarking programs of the Construction Industry Institute in the U.S. and the Movement for Innovation (M4I) in the United Kingdom. Project and organizational performance metrics are the focus, and aggregation from the project or organizational level to industry level is feasible. A project timeline with 6 phases is defined, along with metrics in costs, time, quality, safety, scope, innovation, and sustainability. The results are presented using radar charts, box-and-whisker plots, and cumulative distribution curves.

Centre for the Study of Living Standards. ***Productivity Trends in the Construction Sector in Canada: A Case of Lagging Technical Progress.*** **CSLS Research Report, no. 2001-3. Ontario, 2001.**

This report documents the trends in productivity growth in Canada and uses regression models to explain output per hour in the total construction and residential construction sectors. The independent variables include capital intensity, educational attainment, capital utilization, and the unemployment rate. None of these variables can explain the productivity decline in the sector. Comparing the late 1970s with the late 1990s, capital-labor ratio and educational attainment have increased. While increases in both of these factors are expected to increase output per hour, the observed output per hour declined. After examination of other variables, the report concludes that measurement error and lack of technical progress are the main factors for the observed productivity decline. The section on taxation examines how taxation policy affects companies' decisions to make investments in equipment and workforce. Allocation of these resources could potentially have a great impact on productivity growth.

Crawford, Paul and Bernard Vogl. "Measuring Productivity in the Construction Industry." ***Building Research and Information*** **34, no. 3 (2006): 208-219.**

This paper provides an overview of methods of productivity measurement and presents data on construction productivity in the UK. It points out that labor productivity in the UK is relatively low compared to the rest of Europe, and it is likely a result of low capital intensity adopted in the UK. This observation is consistent with Bosch and Philips (2003), in which construction industries of nine countries are ranked by levels of regulation and two paths of development are identified. The construction industry of the UK is characterized by low levels of regulation, low labor wages, labor intensive production processes, and limited use of technology. Crawford and Vogl point out that high levels of labor productivity can be achieved at the expense of overall productivity due to suboptimal capital-labor allocations. Therefore, measures of labor productivity do not tell the whole story. There is a need to improve existing data and creating new data for productivity measurement. The paper also points out the need to have measures for the quality of inputs.

Eastman, Charles M. and Rafael Sacks. "Relative Productivity in the AEC Industries in the United States for On-site and Off-site Activities." ***Journal of Construction Engineering and Management*** **134, no. 7 (2008): 517-526.**

This paper examines on-site and off-site sectors of the construction industry. The authors found that productivity is higher for off-site sectors compared to on-site sectors. Furthermore, off-site sector productivity growth is also higher. Some of the off-site sectors are classified as manufacturing under Census. When construction industry productivity measurement does not properly account for the role of intermediate inputs, such as pre-fabricated construction products, productivity estimates could be biased downward. The empirical evidence presented in this paper highlights the importance of treating intermediate inputs properly in the growth accounting framework. More specifically, the evidence is consistent with the productivity measurement approach where output measure is gross output and all inputs, including intermediate inputs, are treated symmetrically.

Goodrum, Paul and Carl T. Haas. "Partial Factor Productivity and Equipment Technology Change at Activity Level in U.S. Construction Industry." ***Journal of Construction Engineering and Management*** **128, no. 6 (2002): 463-472.**

This paper examines task-level productivity for 200 activities between 1976 and 1998. More specifically, this paper looks at whether equipment technology enhances labor productivity. The data sources were cost estimating guides, including Means, Richardson, and Dodge. Partial factor productivity is defined to be units of physical output divided by the sum of labor costs and fixed capital costs. The authors concluded that activities that experienced a significant change in equipment technology also experienced a greater improvement in partial factor productivity.

Most of the activities examined experienced improvement in partial factor productivity during the study period.

Goodrum, Paul M., Carl T. Haas, and Robert W. Glover. "The Divergence in Aggregate and Activity Estimates of US Construction Productivity." ***Construction Management and Economics*** **20, no. 5 (2002): 415-423.**

This paper compares productivity estimates at the industry level and at the task level. While industry-level productivity estimates tend to show declining trends, task-level activity productivity estimates tend to suggest productivity increases. This paper discusses productivity output measures, particularly the construction of output deflators. It lists the types of indices used to deflate different types of construction outputs. For task-level productivity, the measure of labor productivity is defined to be units of physical output divided by work hours, and the measure of multifactor productivity is defined to be units of physical output divided by the sum of deflated labor cost and equipment cost. The data used for task-level productivity calculations are from estimating manuals. Labor productivity and multifactor productivity at the task level were shown to be increasing from 1976 to 1998.

Goodrum, Paul M. and Carl T. Haas. "Long Term Impact of Equipment Technology on Labor Productivity in the U.S. Construction Industry at the Activity Level." ***Journal of Construction Engineering and Management*** **130, no. 1 (2004):124-133.**

Using cost estimating guides, the authors identified 200 construction activities during 1976 and 1998. Five technology factors were identified: amplification of human energy, level of control, functional range, ergonomics, and information processing. 43 types of hand tools and 31 types of machinery associated with the 200 activities were studied and a technology index was developed. The technology index captures changes in the equipment in terms of technology factors. The technology index was constructed for each activity. Using this approach, the authors found that 107 of the 200 activities increased labor productivity, while 30 activities showed a decline and 63 activities showed no change in labor productivity. Equipment technological advances can therefore explain some of the labor productivity increase during the 22-year period.

Centre for the Study of Living Standards. ***Can Measurement Error Explain the Weakness of Productivity in the Canadian Construction Industry?*** **By Peter Harrison. Centre for the Study of Living Standards Research Report, no. 2007-01. Ontario, 2007.**

This report presents productivity trends, reviews productivity literature, presents views of industry practitioners, describes methodology used by Statistics Canada, and discusses possible sources of mismeasurement. This report is an accessible, thorough, and comprehensive resource for construction productivity, with a focus on Canada. Statistics Canada's productivity measurement methodology is described, with an emphasis on the construction of price deflators. This document also contains discussions on prefabrication and demonstrates that incorporating more productive prefabrication results in higher productivity if the output measure is gross output. If the output measure is value added, then more productive prefabrication does not result in higher construction productivity. The document also indicates lack of empirical evidence regarding the increasingly important role of prefabrication perceived by industry practitioners.

Haas, Carl T., James T. O'Connor, Richard L. Tucker, Jason A. Eickmann, and Walter R. Fagerlund. ***Prefabrication and Preassembly Trends and Effects on the Construction Workforce.*** **Center for Construction Industry Studies Report No. 14. Austin, Texas, 2000.**

Prefabrication and preassembly use in the U.S. is studied in this report using a survey instrument. The survey respondents were 29 managers. The survey results indicate increased usage of prefabrication and preassembly, from 14 % in 1984 to 27 % in 1999, as a fraction of overall project work. The main reasons for using prefabrication and preassembly were schedule, workforce issues, and economic factors. The areas where prefabrication and preassembly are most often used are piping, mechanical, equipment, and structural assembly. In addition to the survey design and the results, this report also includes historic accounts and a literature review.

Hendrickson, Chris. "Discussion of 'Is Construction Labor Productivity Really Declining?' by Eddy M. Rojas and Peerapong Aramvareekul" ***Journal of Construction Engineering and Management*** **131, no. 2 (2005): 269-270.**

Hendrickson discusses the paper by Rojas and Peerapong (2003), who argue that the data quality is so low that it is not possible to conclude whether construction productivity is declining or increasing. Hendrickson uses Census of Construction Industries data from 1982 through 1997 and calculated a productivity measure defined as construction contribution to GDP divided by hours. Construction contribution to the GDP was deflated using the GDP price deflator index. This productivity measure increased from 1982 to 1987 and stayed constant through 1997. It is noted that real wage has declined during this period. The author also notes the lack of difference in trends for input costs, output prices, and general price indices. If there is productivity decline, then we would expect output prices to be increasing at a higher rate than input costs and general price inflation.

This discussion is followed by a closure by Rojas. He argues that the conclusion of moderate improvement in productivity reached by Hendrickson was based on the assumption that the output measure is reliable, but he argues that the output measure is not reliable. Both Hendrickson and Rojas agree there is a need for meaningful measures of productivity.

National Bureau of Standards. ***Productivity Measurement for the Construction Industry.*** **NBS Technical Note no. 1172. Washington, D.C., 1983.**

This report describes the measurement of single and total factor productivity. It summarizes the approaches and indicates how they apply to the construction industry. This document concludes with a discussion on data availability and challenges. The lack of appropriate price and cost indices to convert output values into quantity indices is one obstacle. Another challenge is establishing a quantity index for capital input. It also points out that the definitions of some four-digit construction industries have been changed between Economic Censuses. It would not be possible to construct five-year TFP growth estimates based on Census data for these industries. This report contains an appendix with an annotated bibliography on productivity measurement methods, productivity in the construction industry, and productivity measurement case studies.

National Research Council. *Advancing the Competitiveness and Efficiency of the U.S. Construction Industry*. Washington D.C.: National Academies Press, 2009.

In 2008, the National Institute of Standards and Technology requested the National Research Council to appoint an ad hoc committee of experts to provide advice for advancing the competitiveness and productivity of the construction industry. Over 50 industry experts were gathered at a two-day workshop in November of 2008 to brainstorm and identify activities that could lead to breakthrough improvements in construction productivity. The committee incorporated its expert opinions and the discussions from the workshop and produced this report. Five opportunities for breakthrough improvements were identified. They are: (1) Widespread deployment and use of interoperable technology applications, also called Building Information Modeling (BIM); (2) Improved job-site efficiency through more effective inferfacing of people, processes, materials, equipment, and information; (3) Greater use of prefabrication, preassembly, modularization, and off-site fabrication techniques and processes; (4) Innovative, widespread use of demonstration installations; and (5) Effective performance measurement to drive efficiency and support innovation. The report also provides three recommendations: (1) greater collaboration among construction industry stakeholders to implement interoperable technology applications, job-site efficiencies, off-site fabrication processes, demonstration installations, and effective performance measures; (2) the development of a technology readiness index to evaluate and mitigate risks of new technologies; and (3) collaborative efforts among governmental agencies to develop industry-level productivity measures.

O'Grady, John, and Prism Economic Analysis. *Estimates of Revenue Losses to Government as a result of Underground Practices in Ontario's Construction Industry*. Document prepared for the Ontario Construction Secretariat. Ontario, 2001.

This document provides an update to the 1998 report titled "The Underground Economy in Ontario's Construction Industry." Estimates in the 1998 report were amended using new input/output data, and new estimates are developed for the 1998-2000 period. The rate of self employment and share of cash in total transactions are two indicators of underground activity. These two indicators have moderately increased. The share of underground income in total construction income has declined from 22 % to 19 %, as a result of changes in composition of the construction activities, increased enforcement, and increase in the share of housing starts by large developers. However, the amount of the underground income has increased, and the underground economy in construction remains a serious problem.

O'Grady, John, Greg Lampert, and Bill Empey. ***The Underground Economy in Ontario's Construction Industry: Estimates of Its Size and the Revenue Losses to Government and the WISB*****. Document prepared for the Ontario Construction Secretariat. Ontario, 1998.**

This document presents estimates of the size of the underground economy in the construction industry in Ontario, in addition to estimates of the fiscal impact for the governments and the Ontario Workplace Safety and Insurance Board. It is estimated that between 1995 and 1997, the underground employment in the construction industry in Ontario was about 25 % to 35 % of total employment. For residential construction, the estimates are between 35 % and 48 %. For nonresidential construction, it is between 11 % and 17 %. Annual total fiscal cost to the governments is between 1.1 and 1.7 billion dollars. Factors contributing to the growth of the construction underground economy include the introduction of the GST (Goods and Services Tax) in 1991, increase in unemployment due to economic conditions, and increased competition in obtaining contracts.

Oppedahl, David B. "Understanding the (Relative) Fall and Rise of Construction Wages." ***Chicago Fed Letter*** **July, no. 155 (2000).**

Construction wages relative to all private production worker wages peaked in the 1970s and has generally declined, with a slight increase from 1996 to 2000. The decline is a result of a number of factors. Increases in the wage premium associated with higher levels of education reduce the relative wage in construction because construction workers tend to have lower educational attainment. Another factor is immigration of low-skilled workers. Technology improvement is also cited as a reason for deskilling. As advanced technologies become available, the author argues that the skills required by the labor are lessened. An example given in the article is on prefabrication. However, it should be pointed out that when more advanced technologies (such as Building Information Modeling) are used in construction, perhaps more (and different) skills are needed, which may increase labor wages. Other reasons for wage declines include the existence of an informal economy, increased safety, decline in union representation and bargaining power, and wage laws that allow hiring of less skilled workers.

Park, Hee-Sung, Stephen R. Thomas, and Richard L. Tucker. "Benchmarking of Construction Productivity." ***Journal of Construction Engineering and Management*** **131, no. 7 (2005): 772-778.**

This paper describes the Construction Industry Institute's (CII) effort on construction productivity benchmarking. The Construction Productivity Metrics System (CPMS) was developed through a consensus of industry experts. CPMS is a framework for data collection and productivity analysis. With a focus on heavy industrial projects, seven activity areas were identified: concrete, structural steel, electrical, piping, instrumentation, equipment, and insulation. Specific tasks to be included in productivity measurement are identified, and units of measurement are specified. This framework was applied to a sample of 16 industrial projects, and the results indicate this approach can yield meaningful productivity measures.

Pieper, Paul. "Why Construction Industry Productivity is Declining: Comment." ***Review of Economics and Statistics*** **71, no. 3 (1989): 543-546.**

In Allen (1985), construction productivity decline was explained largely by shifts from high to low productivity sectors, declines in average establishment size, labor quality, capital-labor ratio and percentage union members. Pieper challenges Allen's conclusion. Pieper argues that the capital-labor ratio has increased, rather than decreased, as claimed by Allen (1985). Pieper agrees with Allen that there is a shift in the sector output, but he believes the effect on productivity is overestimated by Allen. He believes the problem lies in Allen's use of a cost index to deflate value added. Allen claimed that the BEA deflator was largely based on cost indices. Pieper points out that only about one quarter of construction expenditures are deflated using cost indices. The majority of total construction expenditures are deflated using the Census Single Family Homes and the Federal Highway Administration indices, which are price indices.

Pieper, Paul. "The Measurement of Construction Prices: Retrospect and Prospect." In ***Fifty Years of Economic Measurement: The Jubilee of the Conference on Research in Income and Wealth,*** **Volume 54. Edited by Ernst R. Berndt and Jack E. Triplett. Chicago: University of Chicago Press, 1990.**

This chapter discusses thoroughly the history of the development of construction price indices during the previous 40 years. This work has been highly cited in construction productivity measurement literature. Pieper argues that when the cost index is used to deflate output, productivity is assumed to be constant, and it is considered the least desirable type of price index. The cost index, however, has been commonly used to deflate output due to lack of appropriate output price deflators. Pieper also criticizes Dacy's (1964, 1965) method of deflation by pointing out that an embedded assumption is that factors of production are not substitutable. He discusses alternative price indices, including bid prices, hedonic price indices, estimation indices, and cost indices. This chapter is followed by comments by Robert Parker from the BEA. Parker summarizes Pieper's chapter and points out that the construction industry appears to lack a lobbying group that advocates the Congress to appropriate resources for improved construction statistics. Parker also describes BEA's efforts in this area.

Rojas, Eddy M. and Peerapong Aramvareekul. "Is Construction Labor Productivity Really Declining?" ***Journal of Construction Engineering and Management*** **129, no. 1 (2003): 41-46.**

This paper discusses factors that affect the quality of labor productivity measures at the industry level. It argues that the uncertainty in the data prevents researchers to reach a conclusion as to whether the construction labor productivity is indeed declining during 1979 to 1998. Value Put in Place is collected at the project level. Compared to manufacturing, for which data is collected at the establishment level, there are more data collecting units for the construction industry. This is one reason for less accurate data for the construction industry. Another reason is the lack of annual data for benchmarking the value put in place data. Problems with lack of price indices for nonresidential construction are also discussed. There is also a disconnect between Construction Put in Place and Census of Construction Industries. For instance, architectural and engineering work, force-account construction, and secondary construction are included in the Construction Put in Place, but not the Census of Construction Industries. This paper also discusses the impact of changes in output mix on labor productivity and suggests that labor productivity should be calculated for different sectors within the construction industry.

Schriver, William R. and Roger L. Bowlby. "Changes in Productivity and Composition of Output in Building Construction, 1972-1982." ***Review of Economics and Statistics*** **67, no. 2 (1985): 318-322.**

Cost of building per square foot in 1972 dollars was regressed on characteristics of buildings, such as number of stories, location, end-use, and framing type. The data used was from Dodge contract construction, which is based on ex ante cost estimates. The deflators used were the Census Bureau price index for a new one-family house, Turner Construction Company cost index, and American Appraisal Company cost indices. A shift to more office buildings and less residential construction was observed. Cost increase per square foot of output is interpreted as a decline in total factor productivity. This study concludes that there is a significant decline in total factor productivity in construction from 1980 through 1982, after composition of output is accounted for. There is no decline in productivity from 1972 through 1979.

Stokes, H. Kemble, Jr. An Examination of the Productivity Decline in the Construction Industry. ***Review of Economics and Statistics 63*** **no. 4 (1981): 495-502.**

Labor productivity in the construction industry rose at an annual rate of 2.4 % between 1950 and 1968, and it declined at an annual rate of 2.8 % between 1968 and 1978. Labor productivity is measured using real value added as the output measure. The decline in productivity appears to be robust, regardless of which labor input measure is used (employees, hours paid, or hours worked). This paper examines possible causes of the decline. Only 25 % of the decline could be explained by the factors examined, which include measurement of output, shifts in the output mix, changes in capital-labor ratio, demographic changes of the labor force, economies of scale, regional shifts, and shifts in work practices. BLS has conducted studies on construction labor productivity defined as gross output per employee hour. Labor productivity defined as such increased during the 1970s. This observation is consistent with the increased use of prefabricated materials during the same period. It is also consistent with the decline of value added and an increase in manufactured construction supplies during the same period.

Teicholz, Paul, Paul M. Goodrum and Carl T. Haas. "U.S. Construction Labor Productivity Trends, 1970-1998." Journal of Construction Engineering and Management 127, no. 5 (2001): 427-429.

Teicholz discusses the paper titled "U.S. Construction Labor Productivity Trends" by Allmon, Haas, Borcherding, and Goodrum (2000). Allmon *et al*. (2000) report that decreasing real labor costs and more productive equipment are major factors which made labor costs lower for accomplishing tasks in the 1990s compared to the 1970s. Task-level productivity has increased because the same tasks cost less in terms of labor. Teicholz presents labor productivity trends from 1964 to 1999, for the construction industry and all non-farm industries. Labor productivity is calculated by dividing deflated value of construction put in place with field labor hours. Labor productivity trends downward for the construction industry while it trends upward for all non-farm industries. This graph of labor productivity trends is frequently cited in reports on construction productivity.

Goodrum and Haas respond to the discussion by Teicholz. They provide a concise and informative review of the problem of productivity measurement in construction. They point out the problem with output deflators, which is embedded in the deflated value of construction put in place data. Output deflators are often based on input cost indices, and as a result, tend to overestimate inflation and underestimate output and productivity. The Census Single-Family House Under Construction Index was constructed using a hedonic approach. The authors argue that this index, while preferred, may not capture changes in quality of output. As a result, output could be biased downward. This index is used for over half of the value of construction put in place. Another possible source of underestimation of output comes from decreases in real wage in construction, which is one component of value of construction put in place. Teicholz, Goodrum, and Haas agree there is a significant need for further studies to resolve the productivity puzzle in construction industry.

B.2 Construction Data

Census Bureau. Construction Statistics Data Users' Conference. October 28, 1997. Washington, D.C. Document issued March, 1999.

This report summarizes the discussions and presentations at the Construction Statistics Data Users' Conference. The programs that survey and compile construction statistics are described. These programs include the Building Permits Program, Survey of Construction, Value Put in Place Program (VIP), Manufactured (Mobile) Home Program, and Economic Census: Construction Sector. The Building Permits Program, the Survey of Construction, and the Manufactured (Mobile) Home Program all focus on the residential sector. The Survey of Construction is used to develop price indices using hedonic regression models. The nonresidential sector is covered by the Value Put in Place Program and the Economic Census. The Value Put in Place Program is based on construction projects. The Economic Census is an establishment survey. The report points out that the VIP data are not comparable to the Economic Census data. The VIP construction costs include architectural and engineering design, construction management, force-account construction, and secondary construction, in addition to construction performed by the construction industry, as defined by the Economic Census. It also points out that the Economic Census does not survey establishments with no payrolls. Sole proprietorships and partnerships are therefore not included. Also not included in the Economic Census is construction work performed in the underground economy.

Census Bureau. Statistical Abstracts of the United States

The Census Bureau compiles Statistical Abstracts of the United States using data from a variety of governmental agencies and private sources. Examples of construction related data include number of establishments, number of paid employees, and annual payroll from County Business Patterns, characteristics of commercial buildings from U.S. Energy Information Administration, producer price indices of construction materials from Bureau of Labor Statistics, and Value of Construction Put in Place from the Census Bureau.

R.S. Means Building Construction Cost Data

The R.S. Means Building Construction Cost Data provide, for individual construction tasks, estimates of daily output, crew requirement, labor hours, material cost, labor cost, equipment cost, and overhead and profits. It is a reference guide for budgeting and estimating. The data are based on surveys of contractors and suppliers. This book is published yearly. The latest version is the 67th edition (2009).

B.3 Productivity Data and Measurement

Bureau of Labor Statistics. *Trends in Multifactor Productivity, 1948-81*. Bureau of Labor Statistics Bulletin no. 2178. Washington, D.C., 1983.

This is the first publication on multifactor productivity measurement in BLS. This document describes the methodology and data sources used in BLS's multifactor productivity measurement program, and presents results. It describes the incorporation of recommendations from the Rees Report regarding aggregation methods (the adoption of Tornqvist index) and construction of capital inputs in the BLS productivity program. This document provides a brief and accessible derivation of the multifactor productivity growth equation starting from a production function. It also compares BLS estimates with productivity measures made by Denison, Jorgenson, and Kendrick.

Bureau of Labor Statistics. "Chapter 10. Productivity Measures: Business Sectors and Major Subsectors." In *BLS Handbook of Methods*. Washington, D.C., 1997.

This chapter describes the construction of labor productivity and multifactor productivity indices by the BLS. This chapter, like other chapters in the BLS Handbook of Methods, is succinct and informative. The labor productivity is an output per hour measure. Labor quality is not taken into consideration in this construct. Multifactor productivity is constructed in two ways. First, it is constructed using labor and capital inputs for major sectors. It is also constructed using capital, labor, energy, materials, and purchased business services inputs (KLEMS inputs) for more detailed manufacturing industries. For multifactor productivity, labor is categorized into 1008 types by education, experience, and gender. Note, however, that BLS recently dropped the experience categorization. It discusses the data sources and procedures used. Inputs are aggregated using a Tornqvist chain index. Properties of this index are nicely described. This document points out that the output data for the construction industry are not satisfactory, and the productivity measures for this industry need to be used with caution. An annotated bibliography is also included.

Bureau of Labor Statistics. "Chapter 11. Industry Productivity Measures." In *BLS Handbook of Methods*. Washington, D.C., 1997.

This chapter describes labor productivity and multifactor productivity measures. It begins with a history of BLS's involvement in productivity measurement. It then describes the methodology the BLS uses to calculate the productivity measures, the sources of data, and the assumptions associated with the calculations. Specific details are included for industries for which BLS calculates productivity. This document also discusses the use and limitation of these measures. A list of technical references with brief annotation is included.

Bureau of Labor Statistics. *Labor Composition and U.S. Productivity Growth, 1948-90.* Bureau of Labor Statistics Bulletin no. 2426. Washington, D.C., 1993.

This document is a study that examines labor productivity, taking into account the heterogeneity of labor. Labor is categorized into groups by educational attainment, work experience, and gender. Labor productivity growth is decomposed into two components—changes in labor hours and changes in labor composition. The estimation of earnings is done in two steps. First, experience is econometrically estimated using historic data on actual work experience. Then the estimated experience is used, along with education data, to estimate labor earnings. The hourly earnings for each type of workers were estimated using econometric models instead of using averages from the survey. One reason why this approach was used was that precision is increased due to small sample sizes of some of the worker types. An appendix describes how the productivity growth equation is derived starting from a production function and the assumptions used in the process. Note that BLS recently dropped experience from its labor classification and it uses actual wages rather than estimated wages.

Bureau of Labor Statistics. *Productivity: A Selected Annotated Bibliography, 1983-87.* Bureau of Labor Statistics Bulletin no. 2360. Washington, D.C., 1990.

This annotated bibliography contains over 1000 publications published between 1983-87 on the concepts, methods, measurement, sources of productivity change, the relation between productivity to economic variables such as wages, prices, and employment, and economic growth. An author index and a subject index are included. This bibliography is the 7th in the series. Previous BLS bibliographies include Bulletin 1226 (1958), Bulletin 1514 (1966), Bulletin 1776 (1971), Bulletin 1933 (1977), Bulletin 2051 (1980), and Bulletin 2212 (1984).

Bureau of Labor Statistics. ***Construction of Average Weekly Hours for Supervisory and Nonproduction Wage and Salary Workers in Detailed Industries.*** **Technical Note. Washington D.C., 2005.**

This document describes the construction of annual ratios of supervisory worker average weekly hours to nonsupervisory worker average weekly hours using occupation data from the Current Population Survey. It also discusses the issues with classification systems associated with CES and CPS.

Bureau of Labor Statistics. ***Construction of Employment and Hours for Self-employed and other Nonfarm workers and for all Farm workers, using Current Population Survey data for primary and secondary jobs.*** **Washington, D.C., 2006.**

This document describes the calculation of number of employed and hours worked for self-employed using the Current Population Survey. Prior to 1994, CPS collected hours worked at all jobs, but only collected industry and occupation information on the primary job. Beginning in 1994, CPS collected hours worked and industry and occupation data on all primary and secondary jobs. This document describes methodologies for estimating hours worked by the self-employed and unpaid family workers using historic and more recent CPS data.

Bureau of Labor Statistics. ***Technical Information About the BLS Multifactor Productivity Measures*****. Washington, D.C., 2007.**

This document describes the BLS multifactor productivity program, including data sources and calculation procedures. It also discusses using a simplified methodology and preliminary data to generate estimates of productivity. The list of references is annotated and is very extensive.

Dean, Edwin R. Michael J. Harper, and Mark S. Sherwood. "Productivity Measurement with Changing-Weight Indices of Outputs and Inputs." In ***Industry Productivity: International Comparison and Measurement Issues.*** **Paris: OECD, 1996.**

This paper details the history of BLS's productivity program and its improvements over time. Changing-weight indices are more preferable than fixed-weight indices, and the properties of Tornqvist index are discussed. The paper discusses value-added being a more appropriate output measure than gross output in multifactor productivity measurement. However, it might be better to use value-added output measures for international productivity comparisons, since value-added output measures tend to be more readily available in the international arena.

Dean, Edwin R. and Michael J. Harper. "The BLS Productivity Measurement Program." In ***New Developments in Productivity Analysis.*** **Edited by Charles R. Hulten, Edwin R. Dean, and Michael J. Harper. Chicago: University of Chicago Press, 2001.**

This document is a historic account of BLS's productivity program, including its expansion and improvements due to changes in data availability, developments in the literature, and needs of

data users.   It provides an accessible summary of the literature on labor inputs and capital inputs and how they are operationalized in the BLS program. Topics of discussion include production theory, aggregation methods, labor composition, hours at work, the perpetual inventory method, capital deterioration and depreciation, and choices of output measures. In addition to providing links to the economic literature and data sources, the document points out best practices, limitations, and potential improvements.

Diewert, W. Erwin. "Which (Old) Ideas on Productivity Measurement Are Ready to Use?" In *New Developments in Productivity Analysis.* Edited by Charles R. Hulten, Edwin R. Dean, and Michael J. Harper. Chicago: University of Chicago Press, 2001.

This paper describes areas of improvement for productivity measurement. This paragraph summarizes some of the comments. The input-output framework tracks materials flows, but there is limited information on contracted labor services or rented capital equipment. Even for material flows, the data outside of manufacturing tend to be incomplete. The current System of National Accounts does not collect enough information on the self-employed. How the operating surplus of the self-employed is allocated between labor and capital incomes needs to be imputed. This problem could be more significant as the self-employed population grows. Issues associated with capital inputs include the limited data on efficiency declines of assets and service life of assets. Currently the opportunity cost associated with capital purchases is not included in the user cost. Another issue is the interest rate that should be used. There are also comments on a unified national statistical system in which surveys and resultant data are designed and organized in a coordinated way.

Gullickson, William. "Measurement of Productivity Growth in U.S. Manufacturing." *Monthly Labor Review* July (1995): 13-37.

This paper focuses on the multifactor productivity of the manufacturing industry and describes basic principles in productivity measurement. First, inputs should be as comprehensive as possible. Second, double-counting should be avoided in input and output measures. The third principle is on aggregation. Changing weights, rather than fixed-weights, are preferred in aggregation. It contains a discussion on value-added output concepts and gross output concepts, indicating a distinct drawback associated with the value-added approach, particularly for disaggregated industry analysis. This paper also contains an informative discussion on productivity and prices. Productivity is a residual between output and inputs. It is also a residual between output and input prices. For instance, productivity is the means by which output price can stay constant while input prices increase.

Harper, Michael. "Estimating Capital Inputs for Productivity Measurement: An Overview of U.S. Concepts and Methods." *International Statistical Review* 67, no. 3 (1999): 327-337.

This paper describes the concepts and methods of capital input calculation adopted by BLS. It is very readable and informative. It begins with a conceptual framework, in which there are two agents: investors and production managers. The rental price of a capital stock is later tied back to these two decision-makers. This paper lays out the construction of capital input measures in a step-by-step fashion. It includes a discussion on what constitutes capital and why some types of capital are not included in productivity measurement. It discusses the perpetual inventory method for vintage aggregation, the assumption associated with the age/efficiency profile, procedures used to determine the rental prices of the assets, taking account of tax treatment of different assets, and finally, aggregation methods.

Jorgenson, Dale W., Frank M. Gollop, and Barbara M. Fraumeni. *Productivity and U.S. Economic Growth.* Cambridge, Massachusetts: Harvard University Press, 1987.

This book is a study of U.S. productivity from 1948 to 1979. The growth accounting framework has been adopted by the BLS in its productivity programs and has become the international standard (Jorgenson *et al*. 2005). The authors describe in detail their methodology in deriving the components in the productivity growth equation—output, labor, capital, and intermediate inputs. All the inputs were treated symmetrically. That is, labor, capital, and intermediate inputs can all contribute to growth in output, in contrast to a more restricted approach where a value-added function is assumed with an implication that intermediate inputs are not involved in productivity growth. All the inputs are also treated as being heterogeneous in their quality in this framework. Therefore, growth in an input can be due to both growths in the quantity and the quality of this input. Sectoral productivity is calculated and then aggregated to the economy level. Sources of growth were identified. Assumptions, such as Hicks neutrality and the existence of a value-added function, were tested empirically.

Jorgenson, Dale W., Mun S. Ho, and Kevin J. Stiroh. *Productivity Volume 3: Information Technology and the American Growth Resurgence.* Cambridge, Massachusetts and London, England: MIT Press, 2005.

This book presents the Jorgenson's productivity framework, incorporating information technology as an intermediate input. Intermediate inputs are a significant input in more than 70 % of the industries studied. Explicitly accounting for them by using gross output as the output measure is the proper approach. This work also demonstrates that it is fruitful to separate heterogeneous components of inputs. For instance, IT-related capital was separated from other types of capital, and sources of growth can be properly allocated. Similarly, labor was separated into college educated and non-college educated types. More detailed categorization of inputs enables explanation of industry productivity trends.

Lally, Paul R. "How BEA Accounts for Investment in Private Structures." *Survey on Current Business* February (2009): 9-15.

This paper describes the use of recently available BLS PPIs in BEA's estimates on private nonresidential structure investments. These include PPIs for office buildings, warehouses, industrial buildings, and schools. For building types for which PPIs are not currently available, alternative deflation methods are discussed. This paper also mentions the possibility of developing PPIs for highways, hospitals, retail, communication, power, and lodging structures.

Lawson, Ann M. Brian C. Moyer, Sumiye Okubo, and Mark A. Planting. "Integrating Industry and National Economic Accounts, First Steps and Future Improvements." In *A New Architecture for the U.S. National Accounts*. Edited by Dale W. Jorgenson, J. Steven Landefeld, and William D. Nordhaus. Chicago and London: University of Chicago Press, 2006.

This chapter discusses quality of value-added estimates in the I-O accounts and in the GDP-by-industry accounts. Value-added estimates from both the I-O accounts and the GDP-by-industry accounts for the construction industry were pointed out to be poor in quality. The poor data quality is due to incomplete coverage in the Economic Census and the large number of low-quality enterprise-establishment adjustments.

Mark, Jerome A. "Problems Encountered in Measuring Single- and Multifactor Productivity." *Monthly Labor Review* (1986): 3-11.

This paper contains data sources and methods BLS uses for productivity calculation. It also discusses lack of good price deflators, particularly for the construction industry, among other challenges. Construction industry output for nonresidential structures is deflated using cost indices. This results in a productivity index that is biased towards no change. It was pointed out that the lack of appropriate price deflators is the determinant for whether a productivity measure can be derived in many cases. This paper recognizes that productivity measurement is not an easy task. BLS has made many improvements in its productivity program throughout the years, and more improvements will need to be made in the future. While labor productivity is often a less preferred measure of productivity compared to multifactor productivity, it is calculated with much more precision and with fewer assumptions.

National Research Council. *Measurement and Interpretation of Productivity*. Washington D.C.: National Academy of Sciences, 1979.

This document is also known as the Rees report, produced by the Panel to Review Productivity Statistics set up by the National Academy of Sciences. This book consists of two parts—a report that gives an overview of the productivity measurement issues and recommendations, and a collection of papers on productivity measurement. Much of BLS's improvements on its productivity program can be traced to recommendations in this document.

Notably, a paper by Gollop shows that the assumption of the existence of a value-added sub-function in the production function is too restrictive. This assumption implies that the marginal rates of substitution between the arguments of the value-added sub-function—capital, labor, and time—are independent of intermediate inputs. It also implies that the intermediate inputs are not involved in technological change and that technological change can only occur through capital and labor. This work shows the importance of explicitly treating capital, labor, and intermediate inputs symmetrically in productivity measurement.

OECD (Organization for Economic Co-operation and Development). ***Measuring Productivity—Measurement of Aggregate and Industry-Level Productivity Growth*****. Paris: OECD, 2001.**

"The OECD Productivity Manual is the first comprehensive guide to the various productivity measures aimed at statisticians, researchers and analysts involved in constructing industry-level productivity indicators." This users' guide focuses on productivity growth, rather than productivity levels, at the industry level, using non-parametric methods. A variety of productivity measurements are described. How to choose among the different options depends on the purpose and data availability. This manual is very accessible and practical. It points out desirable qualities associated with different approaches, but it also indicates practical challenges. It focuses on the index number approach in a production theoretic framework, but a section of the manual is devoted to the growth accounting approach. The growth accounting approach integrates the theory of the firm, index number theory and national accounts. The growth accounting technique looks at the rates of changes in output and the rates of changes in inputs. The multifactor productivity growth is determined as the "unexplained" residual.

This manual points out that availability of data poses a significant challenge in the construction of productivity measures. Examples include price indices for output measures by industry, hours worked by industry (in particular, statistics for self-employed individuals, and cross-classification by productivity related characteristics), service life of assets, age-efficiency and age-price profiles of assets, and updated input-output tables integrated with national accounts.

OECD. Measuring Capital—Measurement of Capital Stocks, Consumption of Fixed Capital and Capital Services. Paris: OECD, 2001.

This OECD manual describes concepts related to capital measurement and provides guidelines for estimation of capital stocks, consumption of fixed capital, and capital services. In addition to established methods, it discusses alternative methods, what is commonly implemented in practice, alternative data sources, and some unresolved issues. It is a very detailed reference on measuring capital.

Schreyer, Paul, and Dirk Pilat. ***Measuring Productivity.*** **Economic Studies no. 33, OECD, Second Quarter. Paris: OECD, 2001.**

This document provides an overview of the growth accounting approach of productivity measurement, with discussions on the comparison issues of productivity growth and levels between countries and across time. Gross output and value added output measures are compared. Using value added output, the relationship between multifactor productivity and labor productivity is derived. Changes in value-added-based labor productivity are shown to be the sum of labor productivity changes due to changes in capital-labor ratios and effects of multifactor productivity growth. In addition to capital-labor ratio and multifactor productivity growth, changes in gross-output-based labor productivity are also a function of the ratio between intermediate input and labor input. Multifactor productivity measures based on gross output are not comparable across different levels of aggregation due to interindustry transactions. Multifactor productivity measures based on value added are comparable across different levels of aggregation because interindustry flows are subtracted from the output measure. The authors point out that gross output and value added are useful complements. This document also contains an informative discussion on the interpretation of productivity measures.

Zoghi, Cindy. *Measuring Labor Composition: A Comparison of Alternate Methodologies*. Bureau of Labor Statistics. Washington, D.C., 2007.

This paper discusses the issues associated with calculating a labor composition index. Labor quality is often taken into account by sorting labor into types by education, experience, age, gender, occupation, and geographic region. It is not clear exactly which of these variables are the best to use to capture the difference in effectiveness of labor. What determines wage? Wage may not always reflect marginal productivity of labor. A number of theories are discussed. A second issue is regarding whether to use the actual wages as weights in labor input aggregation or to use the estimated wages from Mincer-type human capital wage regressions as weights. It is not possible to determine which approach is best regarding the choice of labor type categorizations and the use of estimated or actual wages.

Appendix C Sources of Construction Data Related to Productivity and Their Availability

This appendix provides a description of data sources that may be relevant to construction productivity measurement. It then describes classification systems, variables, and availability. These materials are tabulated for key sources of data.

C.1 Sources of Construction Data Related to Productivity

County Business Patterns (Census Bureau)

County Business Patterns contains annual data. The variables include number of employees, payroll, and number of establishments by NAICS codes. Number of establishments by employment-size class for NAICS categories is also reported. The online data is available for 1998 through 2006. Country Business Patterns does not cover the self employed.

Dodge Reports (McGraw-Hill Construction)

Dodge Reports are lists of construction projects and are available since 1967. Variables include value, month started, square footage, dwelling units (for residential only), state, county, project type, number of stories, and ownership (private and four public categorization). Note that the value associated with a project is an ex ante estimate. Whether a project is new construction, addition, or alteration is also indicated. Framing type is also reported. Examples of building types in the nonresidential sector include stores and restaurants, warehouses, office and bank buildings, parking garages and automotive services, manufacturing plants, warehouses, labs, schools, libraries, hospitals, government service buildings, religious buildings, amusement, social, and recreational buildings, hotels and motels, and dormitories. Nonbuilding categories include streets and highways, bridges, dams, reservoirs, river development, sewage and waste disposal systems, water supply systems, power plants, gas, and communication systems. While the Value Put in Place data have undergone a classification system change, the classification system of the Dodge Reports has remained the same since 1967.

Current Employment Statistics Survey

The BLS Current Employment Statistics (CES) program is used as the primary source of industry employment and hours data. The data are collected monthly and the employment levels are benchmarked yearly using data from State unemployment insurance programs, which covers about 98 % of all nonfarm employees.[203] The classification of industries in this survey is the NAICS system since 2003, and some of the historic data since 1990 were updated using the same

[203] Bureau of Labor Statistics, *Handbook of Methods* (Washington DC: Bureau of Labor Statistics, 1997).

classification system.[204] For industries that have the same or similar titles in the SIC and NAICS systems, there could still be some discrepancy in the data classified under these two systems. For example, under the SIC, auxiliary establishments were classified under the same code as the primary activity of the parent enterprise. Under NAICS, auxiliary establishments are classified based on their own primary activity.[205] In 2003, in addition to the new classification system, the CES also switched from a quota-based sampling method to a probability based sampling method.[206] The historic CES data that remain in the SIC classification system extend back to 1988, 1972, or 1958 for different segments of the construction industry. The longest time series is for the total number of all employees, the annual data for which extend back to 1919. The CES reports the number of all employees, the number of production workers, the number of women workers, the average weekly hours of production workers, the average weekly earnings of production workers, and the average weekly hours of overtime of production workers. In the case of the construction industry, the production workers include "workers, up through the level of working supervisors, who are engaged directly in a construction project, either at the site or in shops or yards, at jobs ordinarily performed by members of construction trades."[207] For non-production workers, which are executive and managerial personnel, professional and technical employees, and workers in routine office jobs, only employment data is available from this survey. One disadvantage of the CES data set is that hours paid, instead of hours worked are reported. Hours paid include vacation, paid sick leave, and holidays, in addition to hours worked. Hours at work includes paid time for traveling between jobs sites, coffee breaks, and machine downtime.[208] While some of the hours at work do not increase productivity, others do. One such example is activities that motivate workers and reduce shirking. Paid leave is best considered a benefit.[209] Work hours of non-production workers are not collected, and therefore would need to be estimated. The Current Employment Statistics Survey is also an establishment-level survey, and it does not contain information on the self-employed.

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[204] Teresa L. Morisi, "Recent Changes in the National Current Employment Statistics Survey," *Monthly Labor Review* June (2003): 3-13. For national series that had classifications with 90% or greater degree of interchangeability under SIC and NAICS, the historic data were reconstructed.

[205] *Ibid.*

[206] *Ibid.*

[207] Bureau of Labor Statistics, *Handbook of Methods. Op. cit.*

[208] *Ibid.*

[209] Lucy P. Eldridge, Marilyn E. Manser, and Phyllis Flohr Otto, "Alternative Measures of Supervisory Employee Hours and Productivity Growth," *Monthly Labor Review* April (2004): 9-28.

Current Population Survey (Census Bureau and Bureau of Labor Statistics)

The Current Population Survey (CPS) is a household survey. The CPS is used by the BLS to supplement the CES, for data on proprietors and unpaid family workers since self-employed individuals are not included in the CES. This is particularly a concern for the construction industry where a large proportion of the workers are self-employed. The CPS collects hours worked and weeks worked, in addition to industry and occupation information. The construction industry is included in the CPS as one category and is not further divided into subcategories. Number of workers, and average work hours are reported for wage and salary workers, self-employed workers and unpaid family workers. These data are available from 1994 to present.

One limitation of using the Current Population Survey to obtain information on the self employed is the sample size. Coding of industries and reporting are more accurate in establishment level surveys compared to household surveys. For this reason, data from the Current Employment Statistics program is used as a primary source of data, and data from the Current Population Survey is used as a supplemental source of data in BLS's productivity program.[210]

The Current Population Survey is also used by the BLS to derive annual ratios of supervisory (or nonproduction) worker average weekly hours to nonsupervisory (or production) worker average weekly hours, and subsequently nonproduction worker hours. The CPS asks respondents for their occupation and employment status. The information on occupation and employment status is used to sort the data into supervisory (nonproduction) and nonsupervisory (production) categories. CPS collects data on hours worked. Ratios of supervisory (nonproduction) worker average weekly hours to nonsupervisory (production) worker average weekly hours are calculated. These ratios are multiplied by nonsupervisory (production) worker average weekly hours from the CES. Note the hours data from the CES are for hours paid, and therefore some discrepancy is introduced. The ratios between hours worked and hours paid are available at major sector level, but not available at detailed industry level. The resultant number, supervisory (nonproduction) worker average weekly hours, is then multiplied by the number of supervisory workers to yield total supervisory worker weekly hours. Total supervisory worker hours are obtained by multiplying total supervisory worker weekly hours by 52. Total supervisory worker hours are then combined with total nonsupervisory worker hours from CES and total self-employed hours and unpaid family worker hours to yield total hours for an industry.

Economic Census (Census Bureau)

The Economic Census is an establishment survey and it covers establishments with payrolls. The focus of the Economic Census of the Construction Industries is establishments whose primary activity is construction. It is conducted every five years, in years ending with 2 or 7. It

[210] *Ibid.*

is classified under NAICS in recent years and under SIC in historic years. Many categories of the construction industry under SIC and NAICS are not comparable.[211] This change in classification system presents itself as a break in the time series of Economic Census data. The Economic Census defines value added for construction industries to be “the dollar value of business done less costs for construction work subcontracted to others and payments for materials, components, supplies, and fuels.”[212] All the components needed to calculate value added are collected in Economic Census surveys. In terms of labor input, the Economic Census contains data on number of construction workers employed and number of other employees.[213] There is, however, no information on the work hours or full-time vs. part-time status of the workers. The Economic Census does, however, collect data on labor costs. Percentage of construction work done in various project types, such as office building construction or tunnel construction, is also collected. Percentage of construction work done in different specialty trade activities, such as concrete work or structural steel erection, is also collected for contractors.

While the C30 reports or the Dodge reports contain data on gross output of the construction industry, the Economic Census is the only data source that enables the calculation of a value added measure of output. However, because the Economic Census covers both general contractors and subcontractors, there is a significant amount of double counting in terms of output. This is the reason why output data for the construction industry are not used in the input-output tables produced by the Bureau of Economic Analysis.[214] As the construction industry is one that wages often are paid in cash, labor wage data may be biased downward.[215] The Economic Census also does not cover the self-employed. Note also that there has been a change in the definition of value of construction work in the Economic Census surveys. The Economic Censuses for 1987-1997 collected value of construction work. In 2002 Economic Census, receipts, billings, or sales for construction work were collected to enhance the accuracy of estimates by respondents.[216]

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[211] http://www.census.gov/epcd/naics02/SICN02C.HTM#symbols

[212] 2002 Economic Census.

[213] In 1997 Economic Census, number of construction workers is not available, however, annual payroll costs for construction workers is available.

[214] Bureau of Economic Analysis, *Concepts and Methods of the U.S. Input-Output Accounts* (Washington DC: Bureau of Economic Analysis, 2009).

[215] *Ibid.*

[216] Census Bureau, 2002 Economic Census, Construction, Industry Series (Washington DC: Census Bureau, 2005).

Hours-at-Work Survey and National Compensation Survey (BLS)

BLS has been collecting annual establishment level data on actual hours worked for production and nonsupervisory workers (Hours-at-Work Survey) since 1981. Data from the Hours at Work Survey are used to derive ratios of hours at work to hours paid. This is done for 1-digit Standard Industrial Classification (SIC) industry groups on an annual basis. These ratios are then used to convert hours paid data from the establishment survey. Hours-at-Work Survey by itself, however, is not detailed enough to be used in industry-level productivity measurement. The BLS terminated the Hours at Work Survey in 2000, and replaced the HWS with the National Compensation Survey. The Employment Cost Index (ECI) from the National Compensation Survey is used to convert hours paid to hours worked. The Hours at Work Survey had a few limitations. Eventually, because of stringent data reporting requirements, the response rate decreased to the point where not enough data were usable. The ECI was designed to capture the hourly cost of wages and benefits, including paid leave. Ratios of hours at work to hours paid can also be constructed using the ECI data. These ratios are calculated using the ECI data since 2001. For the years before 2001, the ratios are based on Hours at Work Survey. The HWS survey included production and nonsupervisory workers in nonagricultural establishments. The National Compensation Survey, on the other hand, covers all workers. Another advantage of the National Compensation Survey is that it contains a bigger sample. The sample size is 37000 occupations within 8500 private establishments where as the HWS sampled fewer than 6000 establishments. The response rate associated with the NCS is also higher than that of the HWS.

Input-Output tables (Bureau of Economic Analysis)

The main data source of the input-output tables associated with the construction industry is the Value of Construction Put in Place data. Data from the Economic Census are generally not used to estimate output of the construction industry because of substantial double counting due to the inclusion of both general contractors and subcontractors.[217] Economic Census data, however, are used for inputs to construction industries. Generally, the I-O tables are organized using NAICS, but for the construction industry, activities are used due to data limitation.[218]

National Income and Product Accounts Fixed Investment and Fixed Assets Data (Bureau of Economic Analysis)

The BEA compiles data on private fixed investment by structure types and investment in government fixed assets by structure types. One data source the BEA uses is the C30 data from the Census Bureau. In addition to construction spending as defined by the Census Value of Construction Put in Place, BEA includes mining exploration, shafts, and wells, brokers'

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[217] Bureau of Economic Analysis, *Concepts and Methods of the U.S. Input-Output Accounts* (Washington DC: Bureau of Economic Analysis, 2009).

[218] *Ibid.*

commissions on the sale of new and used structures, mobile structures, manufactured homes, and net purchases of used structures. The data series start from 1929 and are available annually through the present. In 1997, the classification system changed. The pre-1997 classification system is based on building types. The new classification system is based on function (or end use). This change in classification system was preceded by the change in the classification in the C30 reports. In the 2009 Comprehensive Revision of the NIPAs, historic data were updated to conform to the new classification system.[219] For the private sector, real fixed investment is reported along with quantity index and price index. For the public sector, investment in fixed assets is reported in current dollars along with a quantity index. Data of investment by structure types could be used as a gross output measure in productivity analyses.

In addition to fixed investment by structure types, the BEA also compiles data on assets by industry. For the construction industry as a whole, net stocks, depreciation, and investment data are reported both in terms of current dollars and chain-type quantity indices. These data are reported annually by 32 equipment types and 15 structure types. Net stocks, depreciation, and investment data by industry are elements of capital in productivity analysis.

Nonemployer Statistics (Census Bureau)

The Nonemployer Statistics contains annual data and is based on administrative records. The universe of this survey is businesses with no paid employees. The variables include number of establishments and receipts by NAICS codes and by type of establishment (corporations, individual proprietorships, and partnerships). More aggregated NAICS classification is used to report the number of establishments and receipts by states.

Price Deflator (Fisher) Index of New One-Family Houses Under Construction (Census Bureau)

Price deflators for new one-family houses under construction are developed using a hedonic regression approach and are available monthly since 1964.

Price Deflator for New Multifamily Housing (Tabulated by the Census Bureau for the Bureau of Economic Analysis)

Price deflators for new multifamily housing are developed using a hedonic regression approach. This index was first developed in 1993 and extends back to 1978.[220]

Producer Price Indices (Bureau of Labor Statistics)

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[219] Eugene P. Seskin and Shelly Smith, "Improved Estimates of the National Income and Product Accounts: Results of the 2009 Comprehensive Revision" *Survey of Current Business* September (2009): 15-35.

[220] Frank de Leeuw, "A Price Index for New Multifamily Housing," *Survey of Current Business* February (1993):33-42.

The Bureau of Labor Statistics has recently developed producer price indices for the nonresidential sector of the construction industry. These producer price indices are a Laspeyres index, which holds quality constant. These price indices are based on prototypical buildings. Producer price indices are produced for the following new building construction categories: (1) new industrial building construction (NAICS 236211); (2) new warehouse building construction (NAICS 236221); (3) new school building construction (NAICS 236222); and (4) new office building construction (NAICS 236223). For each of the four building types, model buildings are developed. The buildings are comprised of a collection of assemblies, or production elements. The estimation of pricing for each assembly includes materials and labor. Sometimes machinery is also required. These costs are estimated by a cost-estimating firm. BLS surveys contractors regarding their margin (overhead and profits). BLS tracks both the costs and the margin. Producer price indices have also been developed for four types of special trades in the nonresidential setting (commercial and industrial): 1) concrete contractors (NAICS 23811), 2) roofing contractors (NAICS 23816), 3) electrical contractors (NAICS 23821), and 4) plumbing/HVAC contractors (NAICS 23822). The producer price indices for the specialty trades are for both new nonresidential building construction and nonresidential building maintenance and repair. Excluded from these producer price indices are residential work, additions, renovations, and non-building construction.

Producer Price Indices for Materials and Supply Inputs to Construction Industries (Bureau of Labor Statistics)

The BLS produces PPIs for materials and supply inputs to construction industries for different types of new construction (single-unit residential, multi-unit residential, non-residential buildings, highway and street construction, and other heavy construction) and for residential and non-residential maintenance and repair construction. These indices only include costs of materials and supplies and do not take into account labor costs, contractor overhead, and profits.

R.S. Means Square Foot Costs

Square Foot Costs data from R.S. Means are available since early 1980s. The BEA has used data from the more recent years along with the hedonic regression approach to develop price deflators for several building types. In the BEA's hedonic model, the natural logarithm of the cost per square foot is regressed on total square feet, dummy variables for combinations of exterior wall and interior supporting-frame type, and dummy variable for the year.[221]

Survey of Construction (Census Bureau)

The Survey of Construction focuses on new residential buildings. Data are monthly and include start date, completion date, and physical characteristics of each housing unit, such as square

[221] Carol E. Moylan and Brooks B. Robinson, "Preview of the 2003 Comprehensive Revision of the National Income and Product Accounts—Statistical Changes," *Survey of Current Business* September (2003): 17-32.

footage and number of bedrooms. These variables are collected for both new single-family and multifamily housing units. In addition, sales date and sales price are collected for one-family houses. Housing starts data have been collected since 1959, housing completions data have been collected since 1963, and housing completions data have been collected since 1968.

Value of Construction Put in Place (Census Bureau)

Value of Construction Put in Place is collected by Census Bureau's Manufacturing, Mining, and Construction Statistics (i.e., Current Construction Report, Series C30: Value of New Construction). Samples for the Value of Construction Put in Place Survey are drawn from the list of construction projects produced by McGraw-Hill Construction (Dodge Reports). Dodge Reports do not usually contain projects in nonpermit areas, and therefore projects in nonpermit areas are identified separately.[222] Value of Construction Put in Place includes architectural and engineering design, construction management, force-account construction, and secondary construction, in addition to construction services performed by the construction industry, as defined by the Economic Census. Since the Value of Construction Put in Place data are collected from owners, this data capture some construction activities not captured by the establishment-based Economic Census. Examples are construction by the self-employed, homeowner construction, and construction done as a secondary source of revenue by nonconstruction establishments.[223] The definitions of construction in the Value of Construction Put in Place and the Economic Census are also different. For instance, maintenance and repair is part of value of construction work in the Economic Census, but it is not included in the Value of Construction Put in Place. The value of land is excluded. For all sampled projects, a questionnaire is mailed to the owner of the project prior to the start of the project. Estimates of total construction cost, architectural, engineering, and miscellaneous costs are requested in the survey. Value of Construction Put in Place is collected monthly until the project is completed. The Census Bureau reports that about two thirds of Value Put in Place corresponds with work performed by the construction industry as defined by the Economic Census.[224] Data of Value of Construction Put in Place are reported monthly by building types. These data are not deflated, but they are reported with and without seasonal adjustment. Total construction cost, which is the sum of contract construction cost and owner supplied materials and labor, can be obtained from the microdata, but it is not published. Square footage information is reported on survey forms, but it is not published.

The classification system of the Value of Construction Put in Place data changed in 1993. The new system is based on project types by end usage while the older system is based on building

[222] Census Bureau, Construction Statistics Data Users' Conference. October 28, 1997. Washington, DC. Document issued March, 1999.

[223] Bureau of Economic Analysis, *Concepts and Methods of the U.S. Input-Output Accounts. Op. cit.*

[224] C30 Construction Spending Latest News, July 1, 2003.

and nonbuilding types. Data collected under the two classification systems are generally not comparable, particularly at a finer level. Some categories appear to be similar in both classification systems, but there are within-category changes that made the data incomparable. For instance, private medical offices were classified as office buildings in the old classification system, but they are classified under health care in the new classification system. Direct comparisons can only be made at the more aggregate levels, specifically for total, total private, total state and local, total federal, and total public levels for annual and not seasonally adjusted monthly data.[225]

C.2 Classification Systems, Variables, and Coverage

The Standard Industry Classification (SIC) of the construction industry is tabulated, in addition to the North American Industry Classification System (NAICS) 1997 and 2007. Data sources that are tabulated are: Current Employment Statistics Survey (Bureau of Labor Statistics) with SIC classification and with NAICS classification, GDP by Industry (Bureau of Economic Analysis), Producer Price Indices (Bureau of Labor Statistics), producer price indices for materials and supply inputs to construction industries (Bureau of Labor Statistics), Investment in government fixed assets and private fixed investment by structure type from National Income and Product Accounts (Bureau of Economic Analysis), Value of Construction Put in Place with old and new classification systems (Census Bureau), Economic Census of the Construction Industries (Census Bureau). For Economic Census of the Construction Industries, sub-industries under SIC or NAICS classifications are tabulated for 1992, 1997, and 2002. Variables and their availability are tabulated separately. This compilation of variables and their availability is based mainly on Industry Series of 1992, 1997, and 2002 and is therefore incomplete. Source data and price indices for BEA's annual estimates of private fixed investment in structures by type are also tabulated.

[225] *Ibid.*

Table C.1 Standard Industry Classification (SIC)

SIC code	Definition
15	Building Construction General Contractors And Operative Builders
152	General Building Contractors-Residential
1521	General Contractors-Single-Family Houses
1522	General Contractors-Residential Buildings, Other Than Single-Family
153	Operative Builders
1531	Operative Builders
154	General Building Contractors-nonresidential
1541	General Contractors-Industrial Building and Warehouses
1542	General Contractors-Nonresidential Buildings, Other Than Industrial Buildings and Warehouses
16	Heavy Construction Other Than Building Construction Contractors
161	Highway and Street Construction, Except Elevated Highways
1611	Highway and Street Construction, Except Elevated Highways
162	Heavy Construction, Except Highway and Street
1622	Bridge, Tunnel, and Elevated Highway Construction
1623	Water, Sewer, Pipeline, and Communications and Power Line Construction
1629	Heavy Construction, Not Elsewhere Classified
17	Construction Special Trade Contractors
171	Plumbing, Heating And Air-conditioning
1711	Plumbing, Heating and Air-Conditioning
172	Painting And Paper Hanging
1721	Painting and Paper Hanging
173	Electrical Work
1731	Electrical Work
174	Masonry, Stonework, Tile Setting, And Plastering
1741	Masonry, Stone Setting, and Other Stone Work
1742	Plastering, Drywall, Acoustical, and Insulation Work
1743	Terrazzo, Tile, Marble, and Mosaic Work
175	Carpentry And Floor Work
1751	Carpentry Work
1752	Floor Laying and Other Floor Work, Not Elsewhere Classified
176	Roofing, Siding, And Sheet Metal Work
1761	Roofing, Siding, and Sheet Metal Work
177	Concrete Work
1771	Concrete Work
178	Water Well Drilling
1781	Water Well Drilling
179	Miscellaneous Special Trade Contractors
1791	Structural Steel Erection
1793	Glass and Glazing Work
1794	Excavation Work
1795	Wrecking and Demolition Work
1796	Installation or Erection of Building Equipment, Not Elsewhere
1799	Special Trade Contractors, Not Elsewhere Classified

Table C.2 North American Industry Classification System (NAICS) 1997

NAICS code	Definition
23	Construction
233	Building, Developing, and General Contracting
2331	Land Subdivision and Land Development
23311	Land Subdivision and Land Development
2332	Residential Building Construction
23321	Single Family Housing Construction
23322	Multifamily Housing Construction
2333	Nonresidential Building Construction
23331	Manufacturing and Industrial Building Construction
23332	Commercial and Institutional Building Construction
234	Heavy Construction
2341	Highway, Street, Bridge, and Tunnel Construction
23411	Highway and Street Construction
23412	Bridge and Tunnel Construction
2349	Other Heavy Construction
23491	Water, Sewer, and Pipeline Construction
23492	Power and Communication Transmission Line Construction
23493	Industrial Nonbuilding Structure Construction
23499	All Other Heavy Construction
235	Special Trade Contractors
2351	Plumbing, Heating, and Air-Conditioning Contractors
23511	Plumbing, Heating, and Air-Conditioning Contractors
2352	Painting and Wall Covering Contractors
23521	Painting and Wall Covering Contractors
2353	Electrical Contractors
23531	Electrical Contractors
2354	Masonry, Drywall, Insulation, and Tile Contractors
23541	Masonry and Stone Contractors
23542	Drywall, Plastering, Acoustical, and Insulation Contractors
23543	Tile, Marble, Terrazzo, and Mosaic Contractors
2355	Carpentry and Floor Contractors
23551	Carpentry Contractors
23552	Floor Laying and Other Floor Contractors
2356	Roofing, Siding, and Sheet Metal Contractors
23561	Roofing, Siding, and Sheet Metal Contractors
2357	Concrete Contractors
23571	Concrete Contractors
2358	Water Well Drilling Contractors
23581	Water Well Drilling Contractors
2359	Other Special Trade Contractors
23591	Structural Steel Erection Contractors
23592	Glass and Glazing Contractors
23593	Excavation Contractors
23594	Wrecking and Demolition Contractors
23595	Building Equipment and Other Machinery Installation Contractors
23599	All Other Special Trade Contractors

Source: U.S. Census Bureau

Table C.3 North American Industry Classification System (NAICS) 2007

NAICS code	Definition
23	Construction
236	Construction of Buildings
2361	Residential Building Construction
23611	Residential Building Construction
236115	New Single-Family Housing Construction (except Operative Builders)
236116	New Multifamily Housing Construction (except Operative Builders)
236117	New Housing Operative Builders
236118	Residential Remodelers
2362	Nonresidential Building Construction
23621	Industrial Building Construction
236210	Industrial Building Construction
23622	Commercial and Institutional Building Construction
236220	Commercial and Institutional Building Construction
237	Heavy and Civil Engineering Construction
2371	Utility System Construction
23711	Water and Sewer Line and Related Structures Construction
237110	Water and Sewer Line and Related Structures Construction
23712	Oil and Gas Pipeline and Related Structures Construction
237120	Oil and Gas Pipeline and Related Structures Construction
23713	Power and Communication Line and Related Structures Construction
237130	Power and Communication Line and Related Structures Construction
2372	Land Subdivision
23721	Land Subdivision
237210	Land Subdivision
2373	Highway, Street, and Bridge Construction
23731	Highway, Street, and Bridge Construction
237310	Highway, Street, and Bridge Construction
2379	Other Heavy and Civil Engineering Construction
23799	Other Heavy and Civil Engineering Construction
237990	Other Heavy and Civil Engineering Construction
238	Specialty Trade Contractors
2381	Foundation, Structure, and Building Exterior Contractors
23811	Poured Concrete Foundation and Structure Contractors
238110	Poured Concrete Foundation and Structure Contractors
23812	Structural Steel and Precast Concrete Contractors
238120	Structural Steel and Precast Concrete Contractors
23813	Framing Contractors
238130	Framing Contractors
23814	Masonry Contractors
238140	Masonry Contractors
23815	Glass and Glazing Contractors
238150	Glass and Glazing Contractors
23816	Roofing Contractors
238160	Roofing Contractors
23817	Siding Contractors
238170	Siding Contractors
23819	Other Foundation, Structure, and Building Exterior Contractors
238190	Other Foundation, Structure, and Building Exterior Contractors

Table C.3 North American Industry Classification System (NAICS) 2007

NAICS code	Definition
2382	Building Equipment Contractors
23821	Electrical Contractors and Other Wiring Installation Contractors
238210	Electrical Contractors and Other Wiring Installation Contractors
23822	Plumbing, Heating, and Air-Conditioning Contractors
238220	Plumbing, Heating, and Air-Conditioning Contractors
23829	Other Building Equipment Contractors
238290	Other Building Equipment Contractors
2383	Building Finishing Contractors
23831	Drywall and Insulation Contractors
238310	Drywall and Insulation Contractors
23832	Painting and Wall Covering Contractors
238320	Painting and Wall Covering Contractors
23833	Flooring Contractors
238330	Flooring Contractors
23834	Tile and Terrazzo Contractors
238340	Tile and Terrazzo Contractors
23835	Finish Carpentry Contractors
238350	Finish Carpentry Contractors
23839	Other Building Finishing Contractors
238390	Other Building Finishing Contractors
2389	Other Specialty Trade Contractors
23891	Site Preparation Contractors
238910	Site Preparation Contractors
23899	All Other Specialty Trade Contractors
238990	All Other Specialty Trade Contractors

Source: Census Bureau

NAICS 2002 is very similar to NAICS 2007. The only difference is that under NAICS 2007, NAICS 23821 and NAICS 238210 are "Electrical Contractors and Other Wiring Installation Contractors," whereas, it is "Eletrical Contractors" under NAICS 2002.

Table C.4 Current Employment Statistics Survey with SIC Classification (Bureau of Labor Statistics)

SIC code	Category	Variable	Seasonal adjustment	Coverage
15-17	Construction	number of all employees	both	monthly from January 1939 to April 2003
15-17	Construction	number of all employees	no	annual from 1919
15-17	Construction	number of production workers	both	monthly from January 1947 to April 2003
15-17	Construction	average weekly hours of production workers	both	monthly from January 1947 to April 2003
15	General building contractors	number of all employees	both	monthly from January 1958 to April 2003
15	General building contractors	number of production workers	no	monthly from January 1964 to March 2003
15	General building contractors	average weekly hours of production workers	no	monthly from January 1958 to March 2003
15	Residential building construction	number of all employees	no	monthly from January 1972 to March 2003
152	Residential building construction	number of production workers	no	monthly from January 1972 to March 2003
152	Residential building construction	average weekly hours of production workers	no	monthly from January 1972 to March 2003
153	Operative builders	number of all employees	no	monthly from January 1958 ro March 2003
153	Operative builders	number of production workers	no	monthly from January 1972 ro March 2003
153	Operative builders	average weekly hours of production workers	no	monthly from January 1972 ro March 2003
154	Nonresidential building construction	number of all employees	no	monthly from January 1972 to March 2003
154	Nonresidential building construction	number of production workers	no	monthly from January 1972 to March 2003
154	Nonresidential building construction	average weekly hours of production workers	no	monthly from January 1972 to March 2003
16	Heavy construction, except building	number of all employees	both	monthly from January 1972 to April 2003
16	Heavy construction, except building	number of production workers	no	monthly from January 1972 to March 2003
16	Heavy construction, except building	average weekly hours of production workers	no	monthly from January 1972 to March 2003
161	Highway and street construction	number of all employees	no	monthly from January 1988 to March 2003
161	Highway and street construction	number of production workers	no	monthly from January 1988 to March 2003
161	Highway and street construction	average weekly hours of production workers	no	monthly from January 1988 to March 2003
162	Heavy construction, except highway	number of all employees	no	monthly from January 1972 to March 2003
162	Heavy construction, except highway	number of production workers	no	monthly from January 1972 to March 2003
162	Heavy construction, except highway	average weekly hours of production workers	no	monthly from January 1972 to March 2003
17	Special trade contractors	number of all employees	both	monthly from January 1972 to April 2003
17	Special trade contractors	number of production workers	no	monthly from January 1972 to March 2003
17	Special trade contractors	average weekly hours of production workers	no	monthly from January 1972 to March 2003
171	Plumbing, heating, and air-conditioning	number of all employees	no	monthly from January 1958 to March 2003
171	Plumbing, heating, and air-conditioning	number of production workers	no	monthly from January 1958 to March 2003
171	Plumbing, heating, and air-conditioning	average weekly hours of production workers	no	monthly from January 1958 to March 2003
172	Painting and paper hanging	number of all employees	no	monthly from January 1958 to March 2003
172	Painting and paper hanging	number of production workers	no	monthly from January 1958 to March 2003
172	Painting and paper hanging	average weekly hours of production workers	no	monthly from January 1958 to March 2003

Table C.4 Current Employment Statistics Survey with SIC Classification (Bureau of Labor Statistics)

SIC code	Category	Variable	Seasonal adjustment	Coverage
173	Eletrical work	number of all employees	no	monthly from January 1958 to March 2003
173	Eletrical work	number of production workers	no	monthly from January 1958 to March 2003
173	Eletrical work	average weekly hours of production workers	no	monthly from January 1958 to March 2003
174	Masonry, stonework, and plastering	number of all employees	no	monthly from January 1972 to March 2003
174	Masonry, stonework, and plastering	number of production workers	no	monthly from January 1972 to March 2003
174	Masonry, stonework, and plastering	average weekly hours of production workers	no	monthly from January 1972 to March 2003
175	Carpentry and floor work	number of all employees	no	monthly from January 1972 to March 2003
175	Carpentry and floor work	number of production workers	no	monthly from January 1972 to March 2003
175	Carpentry and floor work	average weekly hours of production workers	no	monthly from January 1972 to March 2003
176	Roofing, siding, and sheet metal work	number of all employees	no	monthly from January 1958 to March 2003
176	Roofing, siding, and sheet metal work	number of production workers	no	monthly from January 1958 to March 2003
176	Roofing, siding, and sheet metal work	average weekly hours of production workers	no	monthly from January 1958 to March 2003

Table C.5 Current Employment Statistics Survey with NAICS Classification (Bureau of Labor Statistics)

NAICS code	Category	Variable	Seasonal adjustment	Coverage
	Construction	number of all employees	both	monthly from January 1939
	Construction	number of production workers	both	monthly from January 1947
	Construction	average weekly hours of production workers	both	monthly from January 1948
236	Construction of buildings	number of all employees	both	monthly from January 1990
236	Construction of buildings	number of production workers	no	monthly from January 1990
237	Construction of buildings	average weekly hours of production workers	no	monthly from January 1990
2361	Construction of residential buildings	number of all employees	both	monthly from January 1985
2361	Construction of residential buildings	number of production workers	no	monthly from January 1990
2362	Construction of residential buildings	average weekly hours of production workers	no	monthly from January 1990
236115	New single-family general contractors	number of all employees	no	monthly from January 1990
236115	New single-family general contractors	number of production workers	no	monthly from January 1990
236115	New single-family general contractors	average weekly hours of production workers	no	monthly from January 1990
236116	New multifamily general contractors	number of all employees	no	monthly from January 1990
236118	Residential remodelers	number of all employees	no	monthly from January 1990
236118	Residential remodelers	number of production workers	no	monthly from January 1990
236118	Residential remodelers	average weekly hours of production workers	no	monthly from January 1990
2362	Construction of nonresidential buildings	number of all employees	both	monthly from January 1990
2362	Construction of nonresidential buildings	number of production workers	no	monthly from January 1990
2362	Construction of nonresidential buildings	average weekly hours of production workers	no	monthly from January 1990
23621	Construction of industrial buildings	number of all employees	no	monthly from January 1990
23621	Construction of industrial buildings	number of production workers	no	monthly from January 1990
23621	Construction of industrial buildings	average weekly hours of production workers	no	monthly from January 1990
23622	Construction of commercial buildings	number of all employees	no	monthly from January 1990
23622	Construction of commercial buildings	number of production workers	no	monthly from January 1990
23622	Construction of commercial buildings	average weekly hours of production workers	no	monthly from January 1990
237	Heavy and civil engineering construction	number of all employees	both	monthly from January 1990
237	Heavy and civil engineering construction	number of production workers	no	monthly from January 1990
237	Heavy and civil engineering construction	average weekly hours of production workers	no	monthly from January 1990
2371	Utility system construction	number of all employees	no	monthly from January 1990
2371	Utility system construction	number of production workers	no	monthly from January 1990
2371	Utility system construction	average weekly hours of production workers	no	monthly from January 1990
23711	Water and sewer system construction	number of all employees	no	monthly from January 1990
23711	Water and sewer system construction	number of production workers	no	monthly from January 1990
23711	Water and sewer system construction	average weekly hours of production workers	no	monthly from January 1990

Table C.5 Current Employment Statistics Survey with NAICS Classification (Bureau of Labor Statistics)

NAICS code	Category	Variable	Seasonal adjustment	Coverage
23712	Oil and gas pipeline construction	number of all employees	no	monthly from January 1990
23712	Oil and gas pipeline construction	number of production workers	no	monthly from January 1990
23712	Oil and gas pipeline construction	average weekly hours of production workers	no	monthly from January 1990
23713	Power and communication system construction	number of all employees	no	monthly from January 1990
23713	Power and communication system construction	number of production workers	no	monthly from January 1990
23713	Power and communication system construction	average weekly hours of production workers	no	monthly from January 1990
2372	Land subdivision	number of all employees	no	monthly from January 1990
2372	Land subdivision	number of production workers	no	monthly from January 1990
2372	Land subdivision	average weekly hours of production workers	no	monthly from January 1990
2373	Highway, street, and bridge construction	number of all employees	no	monthly from January 1990
2373	Highway, street, and bridge construction	number of production workers	no	monthly from January 1990
2373	Highway, street, and bridge construction	average weekly hours of production workers	no	monthly from January 1990
2379	Other heavy construction	number of all employees	no	monthly from January 1990
2379	Other heavy construction	number of production workers	no	monthly from January 1990
2379	Other heavy construction	average weekly hours of production workers	no	monthly from January 1990
238	Specialty trade contractors	number of all employees	both	monthly from January 1976
238	Specialty trade contractors	number of production workers	no	monthly from January 1976
238	Specialty trade contractors	average weekly hours of production workers	no	monthly from January 1976
part of 238	Residential specialty trade contractors	number of all employees	both	monthly from January 2001
part of 238	Nonresidential specialty trade contractors	number of all employees	both	monthly from January 2001
2381	Building foundation and exterior contractors	number of all employees	no	monthly from January 1990
2381	Building foundation and exterior contractors	number of production workers	no	monthly from January 1990
2381	Building foundation and exterior contractors	average weekly hours of production workers	no	monthly from January 1990
part of 2381	Residential building foundation and exterior contractors	number of all employees	no	monthly from January 2001
part of 2381	Nonresidential specialty trade contractors	number of all employees	no	monthly from January 2001
23811	Poured concrete structure contractors	number of all employees	no	monthly from January 1990
23811	Poured concrete structure contractors	number of production workers	no	monthly from January 1990
23811	Poured concrete structure contractors	average weekly hours of production workers	no	monthly from January 1990
23812	Steel and precast concrete contractors	number of all employees	no	monthly from January 1990
23812	Steel and precast concrete contractors	number of production workers	no	monthly from January 1990
23812	Steel and precast concrete contractors	average weekly hours of production workers	no	monthly from January 1990
23813	Framing contractors	number of all employees	no	monthly from January 1990
23813	Framing contractors	number of production workers	no	monthly from January 1990
23813	Framing contractors	average weekly hours of production workers	no	monthly from January 1990
23814	Masonry construction	number of all employees	no	monthly from January 1990
23814	Masonry construction	number of production workers	no	monthly from January 1990
23814	Masonry construction	average weekly hours of production workers	no	monthly from January 1990

Table C.5 Current Employment Statistics Survey with NAICS Classification (Bureau of Labor Statistics)

NAICS code	Category	Variable	Seasonal adjustment	Coverage
23815	Glass and glazing contractors	number of all employees	no	monthly from January 1990
23815	Glass and glazing contractors	number of production workers	no	monthly from January 1990
23815	Glass and glazing contractors	average weekly hours of production workers	no	monthly from January 1990
23816	Roofing contractors	number of all employees	no	monthly from January 1990
23816	Roofing contractors	number of production workers	no	monthly from January 1990
23816	Roofing contractors	average weekly hours of production workers	no	monthly from January 1990
23817	Siding contractors	number of all employees	no	monthly from January 1990
23819	Other building exterior contractors	number of all employees	no	monthly from January 1990
2382	Building equipment contractors	number of all employees	no	monthly from January 1990
2382	Building equipment contractors	number of production workers	no	monthly from January 1990
2382	Building equipment contractors	average weekly hours of production workers	no	monthly from January 1990
2382	Residential building equipment contractors	number of all employees	no	monthly from January 2001
part of 2382	Nonresidential building equipment contracotrs	number of all employees	no	monthly from January 2001
23821	Electrical contractors	number of all employees	no	monthly from January 1990
23821	Electrical contractors	number of production workers	no	monthly from January 1990
23821	Electrical contractors	average weekly hours of production workers	no	monthly from January 1990
23822	Plumbing and HVAC contractors	number of all employees	no	monthly from January 1990
23822	Plumbing and HVAC contractors	number of production workers	no	monthly from January 1990
23822	Plumbing and HVAC contractors	average weekly hours of production workers	no	monthly from January 1990
23829	Other building equipment contractors	number of all employees	no	monthly from January 1990
23829	Other building equipment contractors	number of production workers	no	monthly from January 1990
23829	Other building equipment contractors	average weekly hours of production workers	no	monthly from January 1990
2383	Building finishing contractors	number of all employees	no	monthly from January 1990
2383	Building finishing contractors	number of production workers	no	monthly from January 1990
2383	Building finishing contractors	average weekly hours of production workers	no	monthly from January 1990
part of 2383	Residential building finishing contractors	number of all employees	no	monthly from January 2001
part of 2383	Non residential building finishing contractors	number of all employees	no	monthly from January 2001
23831	Drywall and insulation contractors	number of all employees	no	monthly from January 1990
23831	Drywall and insulation contractors	number of production workers	no	monthly from January 1990
23831	Drywall and insulation contractors	average weekly hours of production workers	no	monthly from January 1990
23832	Painting and wall covering contractors	number of all employees	no	monthly from January 1990
23832	Painting and wall covering contractors	number of production workers	no	monthly from January 1990
23832	Painting and wall covering contractors	average weekly hours of production workers	no	monthly from January 1990

Table C.5 Current Employment Statistics Survey with NAICS Classification (Bureau of Labor Statistics)

NAICS code	Category	Variable	Seasonal adjustment	Coverage
23833	Flooring contractors	number of all employees	no	monthly from January 1990
23833	Flooring contractors	number of production workers	no	monthly from January 1990
23833	Flooring contractors	average weekly hours of production workers	no	monthly from January 1990
23834	Tile and terrazzo contractors	number of all employees	no	monthly from January 1990
23834	Tile and terrazzo contractors	number of production workers	no	monthly from January 1990
23834	Tile and terrazzo contractors	average weekly hours of production workers	no	monthly from January 1990
23835	Finish carpentry contractors	number of all employees	no	monthly from January 1990
23835	Finish carpentry contractors	number of production workers	no	monthly from January 1990
23835	Finish carpentry contractors	average weekly hours of production workers	no	monthly from January 1990
23839	Other building finishing contractors	number of all employees	no	monthly from January 1990
23839	Other building finishing contractors	number of production workers	no	monthly from January 1990
23839	Other building finishing contractors	average weekly hours of production workers	no	monthly from January 1990
2389	Other specialty trade contractors	number of all employees	no	monthly from January 1990
2389	Other specialty trade contractors	number of production workers	no	monthly from January 1990
2389	Other specialty trade contractors	average weekly hours of production workers	no	monthly from January 1990
part of 2389	Other residential trade contractors	number of all employees	no	monthly from January 2001
part of 2389	Other nonresidential trade contractors	number of all employees	no	monthly from January 2001
23891	Site preparation contractors	number of all employees	no	monthly from January 1990
23891	Site preparation contractors	number of production workers	no	monthly from January 1990
23891	Site preparation contractors	average weekly hours of production workers	no	monthly from January 1990
23899	All other specialty trade contractors	number of all employees	no	monthly from January 1990
23899	All other specialty trade contractors	number of production workers	no	monthly from January 1990
23899	All other specialty trade contractors	average weekly hours of production workers	no	monthly from January 1990

Table C.6 GDP by Industry (Bureau of Economic Analysis)

IO code	Description	Variables	Data availbility
230110	New residential 1-unit structures, nonfarm	gross output, quantity indexes, price indexes	annually from 1998-2007
230120	New multifamily housing structures, nonfarm	gross output, quantity indexes, price indexes	annually from 1998-2007
230130	New residential additions and alterations, nonfarm	gross output, quantity indexes, price indexes	annually from 1998-2007
230140	New farm housing units and additions and alterations	gross output, quantity indexes, price indexes	annually from 1998-2007
230210	Manufacturing and industrial buildings	gross output, quantity indexes, price indexes	annually from 1998-2007
230220	Commercial and institutional buildings	gross output, quantity indexes, price indexes	annually from 1998-2007
230230	Highway, street, bridge, and tunnel construction	gross output, quantity indexes, price indexes	annually from 1998-2007
230240	Water, sewer, and pipeline construction	gross output, quantity indexes, price indexes	annually from 1998-2007
230250	Other new construction	gross output, quantity indexes, price indexes	annually from 1998-2007
230310	Maintenance and repair of farm and nonfarm residential structures	gross output, quantity indexes, price indexes	annually from 1998-2007
230320	Maintenance and repair of nonresidential buildings	gross output, quantity indexes, price indexes	annually from 1998-2007
230330	Maintenance and repair of highways, streets, bridges, and tunnels	gross output, quantity indexes, price indexes	annually from 1998-2007
230340	Other maintenance and repair construction	gross output, quantity indexes, price indexes	annually from 1998-2007

Description	Variables	Data availability
construction	value added	annually from 1998-2008
construction	compensation to employees, wages and salaries, supplements to wages and salaries, gross operating surplus	annually from 1998-2007
construction	chain-type quantity indexes for energy inputs, chain-type quantity indexes for material inputs, chain-typ quantity indexes for purchased service inputs	annually from 1997-2007
construction	full-time and part-time employees	annually from 1948-1997

Table C.7 Producer Price Indices (Bureau of Labor Statistics)

Code	**Product**	**Coverage**
236211	New industrial building construction	monthly since June 2007
236221	New warehouse building construction	monthly since December 2004
236222	New school building construction	monthly since December 2005
236223	New office building construction	monthly since June 2006
23816	Roofing contractors, nonresidential work	monthly since December 2007
23811	Concrete contractors, nonresidential work	monthly since December 2007
23821	Electrical contractors, nonresidential work	monthly since December 2007
23822	Plumbing/HVAC contractors, nonresidential work	monthly since December 2007

Table C.8 Producer Price Indices for Materials and Supply Inputs to Construction Industries (Bureau of Labor Statistics)

Code	**Grouping**	**Coverage**
BCON	Inputs to construction industries	monthly from June 1986
BNEW	New construction	monthly from June 1986
BRS1	Single-unit residential	monthly from June 1986
BRSM	Multi-unit residential	monthly from June 1986
BBLD	Non-residential buildings	monthly from June 1986
BHWY	Highway and street construction	monthly from June 1986
BHVY	Other heavy construction	monthly from June 1986
BMRP	Maintenance and repair construction	monthly from June 1986
BMRS	Residential	monthly from June 1986
BMNR	Non-residential	monthly from June 1986

Table C.9 National Income and Product Accounts Private Fixed Investment by Structure Type (Bureau of Economic Analysis)

Category	**Variables**	**Coverage**
Private fixed investment in structures	real private fixed investment, quantity index and price index	annual since 1929
Nonresidential	real private fixed investment, quantity index and price index	annual since 1929
Commercial and healthcare	real private fixed investment, quantity index and price index	annual since 1929
Office	real private fixed investment, quantity index and price index	annual since 1929
Health care	real private fixed investment, quantity index and price index	annual since 1929
Hospitals and special care	real private fixed investment, quantity index and price index	annual since 1929
Hospitals	real private fixed investment, quantity index and price index	annual since 1929
Special care	real private fixed investment, quantity index and price index	annual since 1929
Medical buildings	real private fixed investment, quantity index and price index	annual since 1929
Multimerchandise shopping	real private fixed investment, quantity index and price index	annual since 1929
Food and beverage establishments	real private fixed investment, quantity index and price index	annual since 1929
Warehouses	real private fixed investment, quantity index and price index	annual since 1929
Other commercial	real private fixed investment, quantity index and price index	annual since 1929
Manufacturing	real private fixed investment, quantity index and price index	annual since 1929
Power and communication	real private fixed investment, quantity index and price index	annual since 1929
Power	real private fixed investment, quantity index and price index	annual since 1929
Electric	real private fixed investment, quantity index and price index	annual since 1929
Other Power	real private fixed investment, quantity index and price index	annual since 1929
Communication	real private fixed investment, quantity index and price index	annual since 1929
Mining exploration, shafts, and wells	real private fixed investment, quantity index and price index	annual since 1929
Petroleum and natural gas	real private fixed investment, quantity index and price index	annual since 1929
Mining	real private fixed investment, quantity index and price index	annual since 1929
Other structures	real private fixed investment, quantity index and price index	annual since 1929
Religious	real private fixed investment, quantity index and price index	annual since 1929
Educational and vocational	real private fixed investment, quantity index and price index	annual since 1929
lodging	real private fixed investment, quantity index and price index	annual since 1929
Amusement and recreation	real private fixed investment, quantity index and price index	annual since 1929
Transportation	real private fixed investment, quantity index and price index	annual since 1929
Air	real private fixed investment, quantity index and price index	annual since 1929
Land	real private fixed investment, quantity index and price index	annual since 1929
Farm	real private fixed investment, quantity index and price index	annual since 1929
Other	real private fixed investment, quantity index and price index	annual since 1929
Brokers' commission on sale of structures	real private fixed investment, quantity index and price index	annual since 1929
Net Purchases of used structures		

Table C.9 National Income and Product Accounts Private Fixed Investment by Structure Type (Bureau of Economic Analysis)

Category	Variables	Coverage
Residential	real private fixed investment, quantity index and price index	annual since 1929
Permanent site	real private fixed investment, quantity index and price index	annual since 1929
Single-family structures	real private fixed investment, quantity index and price index	annual since 1929
Multifamily structures	real private fixed investment, quantity index and price index	annual since 1929
Other structures	real private fixed investment, quantity index and price index	annual since 1929
Manufactured homes	real private fixed investment, quantity index and price index	annual since 1929
Dormitories	real private fixed investment, quantity index and price index	annual since 1929
Improvements	real private fixed investment, quantity index and price index	annual since 1929
Brokers' commission on sale of structures	real private fixed investment, quantity index and price index	annual since 1929
Net Purchases of used structures		
Addenda	real private fixed investment, quantity index and price index	annual since 1929
Private fixed investment in new structures	real private fixed investment, quantity index and price index	annual since 1929
Nonresidential structures	real private fixed investment, quantity index and price index	annual since 1929
Residential structures	real private fixed investment, quantity index and price index	annual since 1929

Table C.10 National Income and Product Accounts Investment in Government Fixed Assets (Bureau of Economic Analysis)

Category	Variables	Coverage
Government fixed assets	investment in government fixed assets (current dollars and chain-type quantity indexes)	annual from 1929
Equipment and software	investment in government fixed assets (current dollars and chain-type quantity indexes)	annual from 1929
Structures	investment in government fixed assets (current dollars and chain-type quantity indexes)	annual from 1929
Residential	investment in government fixed assets (current dollars and chain-type quantity indexes)	annual from 1929
Industrial	investment in government fixed assets (current dollars and chain-type quantity indexes)	annual from 1929
Office	investment in government fixed assets (current dollars and chain-type quantity indexes)	annual from 1929
Commercial	investment in government fixed assets (current dollars and chain-type quantity indexes)	annual from 1929
Health care	investment in government fixed assets (current dollars and chain-type quantity indexes)	annual from 1929
Educational	investment in government fixed assets (current dollars and chain-type quantity indexes)	annual from 1929
Public safety	investment in government fixed assets (current dollars and chain-type quantity indexes)	annual from 1929
Amusement and recreation	investment in government fixed assets (current dollars and chain-type quantity indexes)	annual from 1929
Transportation	investment in government fixed assets (current dollars and chain-type quantity indexes)	annual from 1929
Power	investment in government fixed assets (current dollars and chain-type quantity indexes)	annual from 1929
Highways and streets	investment in government fixed assets (current dollars and chain-type quantity indexes)	annual from 1929
Military facilities	investment in government fixed assets (current dollars and chain-type quantity indexes)	annual from 1929
Conservation and development	investment in government fixed assets (current dollars and chain-type quantity indexes)	annual from 1929
Other structures	investment in government fixed assets (current dollars and chain-type quantity indexes)	annual from 1929
Federal	investment in government fixed assets (current dollars and chain-type quantity indexes)	annual from 1929
National defense	investment in government fixed assets (current dollars and chain-type quantity indexes)	annual from 1929
Equipment and software	investment in government fixed assets (current dollars and chain-type quantity indexes)	annual from 1929
Aircraft	investment in government fixed assets (current dollars and chain-type quantity indexes)	annual from 1929
Missiles	investment in government fixed assets (current dollars and chain-type quantity indexes)	annual from 1929
Ships	investment in government fixed assets (current dollars and chain-type quantity indexes)	annual from 1929
Vehicles	investment in government fixed assets (current dollars and chain-type quantity indexes)	annual from 1929
Eletronics and software	investment in government fixed assets (current dollars and chain-type quantity indexes)	annual from 1929
Other equipment	investment in government fixed assets (current dollars and chain-type quantity indexes)	annual from 1929
Structures	investment in government fixed assets (current dollars and chain-type quantity indexes)	annual from 1929
Buildings	investment in government fixed assets (current dollars and chain-type quantity indexes)	annual from 1929
Residential	investment in government fixed assets (current dollars and chain-type quantity indexes)	annual from 1929
Industrial	investment in government fixed assets (current dollars and chain-type quantity indexes)	annual from 1929
Military facilities	investment in government fixed assets (current dollars and chain-type quantity indexes)	annual from 1929

Table C.10 National Income and Product Accounts Investment in Government Fixed Assets (Bureau of Economic Analysis)

Category	Variables	Coverage
Nondefense	investment in government fixed assets (current dollars and chain-type quantity indexes)	annual from 1929
Equipment and software	investment in government fixed assets (current dollars and chain-type quantity indexes)	annual from 1929
Structures	investment in government fixed assets (current dollars and chain-type quantity indexes)	annual from 1929
Office	investment in government fixed assets (current dollars and chain-type quantity indexes)	annual from 1929
Commercial	investment in government fixed assets (current dollars and chain-type quantity indexes)	annual from 1929
Health care	investment in government fixed assets (current dollars and chain-type quantity indexes)	annual from 1929
Educational	investment in government fixed assets (current dollars and chain-type quantity indexes)	annual from 1929
Public safety	investment in government fixed assets (current dollars and chain-type quantity indexes)	annual from 1929
Amusement and recreation	investment in government fixed assets (current dollars and chain-type quantity indexes)	annual from 1929
Transportation	investment in government fixed assets (current dollars and chain-type quantity indexes)	annual from 1929
Power	investment in government fixed assets (current dollars and chain-type quantity indexes)	annual from 1929
Highways and streets	investment in government fixed assets (current dollars and chain-type quantity indexes)	annual from 1929
Conservation and development	investment in government fixed assets (current dollars and chain-type quantity indexes)	annual from 1929
Other structures	investment in government fixed assets (current dollars and chain-type quantity indexes)	annual from 1929
State and local	investment in government fixed assets (current dollars and chain-type quantity indexes)	annual from 1929
Equipment and software	investment in government fixed assets (current dollars and chain-type quantity indexes)	annual from 1929
Structures	investment in government fixed assets (current dollars and chain-type quantity indexes)	annual from 1929
Residential	investment in government fixed assets (current dollars and chain-type quantity indexes)	annual from 1929
Office	investment in government fixed assets (current dollars and chain-type quantity indexes)	annual from 1929
Commercial	investment in government fixed assets (current dollars and chain-type quantity indexes)	annual from 1929
Health care	investment in government fixed assets (current dollars and chain-type quantity indexes)	annual from 1929
Educational	investment in government fixed assets (current dollars and chain-type quantity indexes)	annual from 1929
Public safety	investment in government fixed assets (current dollars and chain-type quantity indexes)	annual from 1929
Amusement and recreation	investment in government fixed assets (current dollars and chain-type quantity indexes)	annual from 1929
Transportation	investment in government fixed assets (current dollars and chain-type quantity indexes)	annual from 1929
Power	investment in government fixed assets (current dollars and chain-type quantity indexes)	annual from 1929
Highways and streets	investment in government fixed assets (current dollars and chain-type quantity indexes)	annual from 1929
Sewer systems	investment in government fixed assets (current dollars and chain-type quantity indexes)	annual from 1929
Water systems	investment in government fixed assets (current dollars and chain-type quantity indexes)	annual from 1929
Conservation and development	investment in government fixed assets (current dollars and chain-type quantity indexes)	annual from 1929
Other structures	investment in government fixed assets (current dollars and chain-type quantity indexes)	annual from 1929

Table C.10 National Income and Product Accounts Investment in Government Fixed Assets (Bureau of Economic Analysis)

Category	Variables	Coverage
Addenda:	investment in government fixed assets (current dollars and chain-type quantity indexes)	annual from 1929
General government fixed assets	investment in government fixed assets (current dollars and chain-type quantity indexes)	annual from 1929
Equipment and software	investment in government fixed assets (current dollars and chain-type quantity indexes)	annual from 1929
Structures	investment in government fixed assets (current dollars and chain-type quantity indexes)	annual from 1929
Government enterprise fixed assets	investment in government fixed assets (current dollars and chain-type quantity indexes)	annual from 1929
Equipment and software	investment in government fixed assets (current dollars and chain-type quantity indexes)	annual from 1929
Structures	investment in government fixed assets (current dollars and chain-type quantity indexes)	annual from 1929
Government nonresidential fixed assets	investment in government fixed assets (current dollars and chain-type quantity indexes)	annual from 1929
Equipment and software	investment in government fixed assets (current dollars and chain-type quantity indexes)	annual from 1929
Structures	investment in government fixed assets (current dollars and chain-type quantity indexes)	annual from 1929
Federal	investment in government fixed assets (current dollars and chain-type quantity indexes)	annual from 1929
Defense	investment in government fixed assets (current dollars and chain-type quantity indexes)	annual from 1929
Nondefense	investment in government fixed assets (current dollars and chain-type quantity indexes)	annual from 1929
State and local	investment in government fixed assets (current dollars and chain-type quantity indexes)	annual from 1929

Table C.11 Value of Construction Put in Place (C30 Data), Old Classification System (Census Bureau)

Category	Variable	Seasonal adjustment	Constant or current dollars	Coverage	Comparable with new classification system
Total construction	value of construction put in place	both	both	monthly from 1964 to 2002	yes for annual and not seaonally adjusted monthly data
Private construction	value of construction put in place	both	both	monthly from 1964 to 2002	yes for annual and not seaonally adjusted monthly data
Residential buildings	value of construction put in place	both	both	monthly from 1964 to 2002	no
New housing units	value of construction put in place	both	both	monthly from 1964 to 2002	no
1 unit	value of construction put in place	both	both	monthly from 1964 to 2002	no
2 or more units	value of construction put in place	both	both	monthly from 1964 to 2002	no
Improvements	value of construction put in place	both	both	annual from 1964 to 2002	no
Nonresidential buildings	value of construction put in place	both	both	monthly from 1964 to 2002	no
Industrial	value of construction put in place	both	both	monthly from 1964 to 2002	no
Office	value of construction put in place	both	both	monthly from 1964 to 2002	no
Hotels, motels	value of construction put in place	both	both	monthly from 1964 to 2002	no
Other commercial	value of construction put in place	both	both	monthly from 1964 to 2002	no
Religious	value of construction put in place	both	both	monthly from 1964 to 2002	no
Educational	value of construction put in place	both	both	monthly from 1964 to 2002	no
Hospital and institutional	value of construction put in place	both	both	monthly from 1964 to 2002	no
Miscellaneous	value of construction put in place	both	both	monthly from 1964 to 2002	no
Farm nonresidential	value of construction put in place	both	both	annual from 1964 to 2002	no
Public utilities	value of construction put in place	both	both	annual from 1964 to 2002	no
Telecommunications	value of construction put in place	both	both	monthly from 1964 to 2002	no
Railroad	value of construction put in place	both	both	annual from 1964 to 2002	no
Electric light and power	value of construction put in place	both	both	annual from 1964 to 2002	no
Gas	value of construction put in place	both	both	annual from 1964 to 2002	no
Petroleum pipelines	value of construction put in place	both	both	annual from 1964 to 2002	no
All other private	value of construction put in place	both	both	monthly from 1964 to 2002	no
Public construction	value of construction put in place	both	both	monthly from 1964 to 2002	yes for annual and not seaonally adjusted monthly data
Buildings	value of construction put in place	both	both	monthly from 1964 to 2002	no
Housing and redevelopment	value of construction put in place	both	both	monthly from 1964 to 2002	no
Industrial	value of construction put in place	both	both	monthly from 1964 to 2002	no
Educational	value of construction put in place	both	both	monthly from 1964 to 2002	no
Hospital	value of construction put in place	both	both	monthly from 1964 to 2002	no
Other	value of construction put in place	both	both	monthly from 1964 to 2002	no
Highways and streets	value of construction put in place	both	both	monthly from 1964 to 2002	no
Military facilities	value of construction put in place	both	both	monthly from 1964 to 2002	no
Conservation and development	value of construction put in place	both	both	monthly from 1964 to 2002	no

Table C.11 Value of Construction Put in Place (C30 Data), Old Classification System (Census Bureau)

Category	Variable	Seasonal adjustment	Constant or current dollars	Coverage	Comparable with new classification system
Other public construction	value of construction put in place	both	both	monthly from 1964 to 2002	no
Sewer systems	value of construction put in place	both	both	monthly from 1964 to 2002	no
water supply facilities	value of construction put in place	both	both	monthly from 1964 to 2002	no
Miscellaneous nonbuilding	value of construction put in place	both	both	monthly from 1964 to 2002	no
Total public construction	value of construction put in place	both	both	monthly from 1964 to 2002	yes for annual and not seaonally adjusted monthly data
State and local construction	value of construction put in place	both	both	monthly from 1964 to 2002	yes for annual and not seaonally adjusted monthly data
Total building	value of construction put in place	both	both	monthly from 1964 to 2002	no
Housing and redevelopment	value of construction put in place	both	both	monthly from 1964 to 2002	no
Educational	value of construction put in place	both	both	monthly from 1964 to 2002	no
Hospital	value of construction put in place	both	both	monthly from 1964 to 2002	no
Other	value of construction put in place	both	both	monthly from 1964 to 2002	no
Highways and streets	value of construction put in place	both	both	monthly from 1964 to 2002	no
Conservation and development	value of construction put in place	both	both	monthly from 1964 to 2002	no
Other state and local construction	value of construction put in place	both	both	monthly from 1964 to 2002	no
Sewer systems	value of construction put in place	both	both	monthly from 1964 to 2002	no
Water supply facilities	value of construction put in place	both	both	monthly from 1964 to 2002	no
Miscellaneous nonbuilding	value of construction put in place	both	both	monthly from 1964 to 2002	no
Federal construction	value of construction put in place	both	both	monthly from 1964 to 2002	yes for annual and not seaonally adjusted monthly data
Total building	value of construction put in place	both	both	monthly from 1964 to 2002	no
Housing	value of construction put in place	both	both	monthly from 1964 to 2002	no
Industrial	value of construction put in place	both	both	monthly from 1964 to 2002	no
Educational	value of construction put in place	both	both	monthly from 1964 to 2002	no
Hospital	value of construction put in place	both	both	monthly from 1964 to 2002	no
Other federal buildings	value of construction put in place	both	both	monthly from 1964 to 2002	no
Highways and streets	value of construction put in place	both	both	annual from 1964 to 2002	no
Military Facilities	value of construction put in place	both	both	monthly from 1964 to 2002	no
Conservation and development	value of construction put in place	both	both	monthly from 1964 to 2002	no
Miscellaneous nonbuilding	value of construction put in place	both	both	monthly from 1964 to 2002	no

Total private construction includes public safety, highway and street, sewage and waste disposal, water supply, and conservation and development, which are not reported separately.

Table C.12 Value of Construction Put in Place (C30 Data), New Classification System (Census Bureau)

Category	Variable	Seasonal adjustment	Constant or current dollars	Coverage	Comparable with old classification system
Total construction	value of construction put in place	both	current dollars	monthly since 1993	yes for annual and not seaonally adjusted monthly data
Residential	value of construction put in place	both	current dollars	monthly since 2002	no
Nonresidential	value of construction put in place	both	current dollars	monthly since 2002	no
Lodging	value of construction put in place	both	current dollars	monthly since 2002	no
Office	value of construction put in place	both	current dollars	monthly since 2002	no
Commercial	value of construction put in place	both	current dollars	monthly since 2002	no
Health care	value of construction put in place	both	current dollars	monthly since 2002	no
Educational	value of construction put in place	both	current dollars	monthly since 2002	no
Religious	value of construction put in place	both	current dollars	monthly since 2002	no
Public safety	value of construction put in place	both	current dollars	monthly since 2002	no
Amusement and recreation	value of construction put in place	both	current dollars	monthly since 2002	no
Transportation	value of construction put in place	both	current dollars	monthly since 2002	no
Communication	value of construction put in place	both	current dollars	monthly since 2002	no
Power	value of construction put in place	both	current dollars	monthly since 2002	no
Highway and street	value of construction put in place	both	current dollars	monthly since 2002	no
Sewage and waste disposal	value of construction put in place	both	current dollars	monthly since 2002	no
Water supply	value of construction put in place	both	current dollars	monthly since 2002	no
Conservation and development	value of construction put in place	both	current dollars	monthly since 2002	no
Manufacturing	value of construction put in place	both	current dollars	monthly since 2002	no
Total private construction	value of construction put in place	both	current dollars	monthly since 1993	yes for annual and not seaonally adjusted monthly data
Residential	value of construction put in place	both	current dollars	monthly since 1993	no
Nonresidential	value of construction put in place	both	current dollars	monthly since 1993	no
Lodging	value of construction put in place	both	current dollars	monthly since 1993	no
Office	value of construction put in place	both	current dollars	monthly since 1993	no
Commercial	value of construction put in place	both	current dollars	monthly since 1993	no
Health care	value of construction put in place	both	current dollars	monthly since 1993	no
Educational	value of construction put in place	both	current dollars	monthly since 1993	no
Religious	value of construction put in place	both	current dollars	monthly since 1993	no
Amusement and recreation	value of construction put in place	both	current dollars	monthly since 1993	no
Transportation	value of construction put in place	both	current dollars	monthly since 1993	no
Communication	value of construction put in place	both	current dollars	monthly since 1993	no
Power	value of construction put in place	both	current dollars	monthly since 1993	no
Manufacturing	value of construction put in place	both	current dollars	monthly since 1993	no

Table C.12 Value of Construction Put in Place (C30 Data), New Classification System (Census Bureau)

Category	Variable	Seasonal adjustment	Constant or current dollars	Coverage	Comparable with old classification system
Total public construction	value of construction put in place	both	current dollars	monthly since 1993	yes for annual and not seaonally adjusted monthly data
Residential	value of construction put in place	both	current dollars	monthly since 2002	no
Nonresidential	value of construction put in place	both	current dollars	monthly since 2002	no
Office	value of construction put in place	both	current dollars	monthly since 2002	no
Commercial	value of construction put in place	both	current dollars	monthly since 2002	no
Health care	value of construction put in place	both	current dollars	monthly since 2002	no
Educational	value of construction put in place	both	current dollars	monthly since 2002	no
Public safety	value of construction put in place	both	current dollars	monthly since 2002	no
Amusement and recreation	value of construction put in place	both	current dollars	monthly since 2002	no
Transportation	value of construction put in place	both	current dollars	monthly since 2002	no
Power	value of construction put in place	both	current dollars	monthly since 2002	no
Highway and street	value of construction put in place	both	current dollars	monthly since 2002	no
Sewage and waste disposal	value of construction put in place	both	current dollars	monthly since 2002	no
Water supply	value of construction put in place	both	current dollars	monthly since 2002	no
Conservation and development	value of construction put in place	both	current dollars	monthly since 2002	no

Total private construction includes public safety, highway and street, sewage and waste disposal, water supply, and conservation and development, which are not reported separately.

Total public construction includes lodging, religious, communication and manufacturing, which are not reported separately.

Table C.13 Industry Series of the 1992 Economic Census

SIC code	Description
1521	General Contractors— Single-Family Houses
1522	General Contractors— Residential Buildings, Other Than Single-Family Houses
1531	Operative Builders
1541	General Contractors— Industrial Buildings and Warehouses
1542	General Contractors— Nonresidential Buildings, Other Than Industrial Buildings and Warehouses
1611	Highway and Street Construction Contractors, Except Elevated Highways
1622	Bridge, Tunnel, and Elevated Highway Construction Contractors
1623	Water, Sewer, Pipeline, and Communications and Power Line Construction
1629	Heavy Construction Contractors, Not Elsewhere Classified
1711	Plumbing, Heating, and Air-Conditioning Special Trade Contractors
1721	Painting and Paper Hanging Special Trade Contractors
1731	Electrical Work Special Trade Contractors
1741	Masonry, Stone Setting, and Other Stone Work Special Trade Contractors
1742	Plastering, Drywall, Acoustical and Insulation Work Special Trade Contractors
1743	Terrazzo,Tile,Marble, and Mosaic Work Special Trade Contractors
1751	Carpentry Work Special Trade Contractors
1752	Floor Laying and Other Floor Work Special Trade Contractors, Not Elsewhere Classified
1761	Roofing, Siding, and Sheet Metal Work Special Trade Contractors
1771	Concrete Work Special Trade Contractors
1781	Water Well Drilling Special Trade Contractors
1791	Structural Steel Erection Special Trade Contractors
1793	Glass and Glazing Work Special Trade Contractors
1794	Excavation Work Special Trade Contractors
1795	Wrecking and Demolition Work Special Trade Contractors
1796	Installation or Erection of Building Equipment Special Trade Contractors, Not Elsewhere Classified
1799	Special Trade Contractors, Not Elsewhere Classified

Table C.14 Industry Series of the 1997 Economic Census

NAICS code	SIC code	Description
233110		Land Subdivision and Land Development
	655200	Land subdividers and developers, except cemeteries
233210		Single-Family Housing Construction
	152100	General contractors--single-family houses
	153110	Operative builders (pt)
	874121	Management services (pt)
233220		Multifamily Housing Construction
	152220	General contractors--residential buildings, other than single-family
	153120	Operative builders (pt)
	874122	Management services (pt)
233310		Manufacturing and Industrial Building Construction
	153130	Operative builders (pt)
	154120	General contractors--industrial buildings and warehouses
	874123	Management services (pt)
233320		Commercial and Institutional Building Construction
	152210	General contractors--residential buildings, other than single-family (pt)
	153140	Operative builders (pt)
	154110	General contractors--industrial buildings and warehouses (pt)
	154200	General contractors--nonresidential buildings, except industrial buildings and warehouses
	874124	Management services (pt)
234110		Highway and Street Construction
	161100	Highway and street construction contractors, except elevated highways
	874131	Management services (pt)
234120		Bridge and Tunnel Construction
	162200	Bridge, tunnel, and elevated highway construction contractors
	874132	Management services (pt)
234910		Water, Sewer, Pipeline Construction
	162310	Water, sewer, pipeline, and communication and power line construction (pt)
	874133	Management services (pt)
234920		Power and Communication Transmission Line Construction
	162320	Water, sewer, pipeline, and communication and power line construction (pt)
	874134	Management services (pt)
234930		Industrial Nonbuilding Structure Construction
	162910	Heavy construction, not elsewhere classified (pt)
	874135	Management services (pt)
234990		All Other Heavy Construction
	162920	Heavy construction, not elsewhere classified (pt)
	735320	Heavy construction, equipment rental (pt)
	874136	Management services (pt)
235110		Plumbing, Heating, and Air-Conditioning Contractors
	171100	Plumbing, heating, and air-conditioning special trade contractors
235210		Painting and Wall Covering Contractors
	172100	Painting and paper hanging special trade contractors
	179910	Special trade contractors, not elsewhere classified (pt)
235310		Electrical Contractors
	173100	Electrical work special trade contractors

Table C.14 Industry Series of the 1997 Economic Census

NAICS code	SIC code	Description
235410		Masonry and Stone Contractors
	174100	Masonry, stone setting, and other stone work special trade contractors
235420		Drywall, Plastering, Acoustical, and Insulation Contractors
	174200	Plastering, drywall, acoustical, and insulation work special trade contractors
	174310	Terrazzo, tile, marble, and mosaic work special trade contractors
	177110	Concrete work special trade contractors (pt)
235430		Tile, Marble, Terrazzo, and Mosaic Contractors
	174320	Terrazzo, tile, marble, and mosaic work special trade contractors (pt)
235510		Carpentry Contractors
	175100	Carpentry work special trade contractors
235520		Floor Laying and Other Floor Contractors
	175200	Floor laying and other floor work special trade contractors, not elsewhere classified
235610		Roofing, Siding, and Sheet Metal Contractors
	176100	Roofing, siding, and sheet metal work special trade contractors
235710		Concrete Contractors
	177120	Concrete work special trade contractors (pt)
235810		Water Well Drilling Contractors
	178100	Water well drilling special trade contractors
235910		Structural Steel Erection Contractors
	179100	Structual steel erection special trade contractors
235920		Glass and Glazing Contractors
	179300	Glass and glazing work special trade contractors
	179920	Special trade contractors, not elsewhere classified (pt)
235930		Excavation Contractors
	179400	Excavation work special trade contractors
235940		Wrecking and Demolition Contractors
	179500	Wrecking and demolition work special trade contractors
235950		Building Equipment and Other Machinery Installation Contractors
	179600	Install or erection of building equipment, special trade contractors, not elseswhere classified
235990		All Other Special Trade Contractors
	179940	Special trade contractors, not elsewhere classified (pt)

Table C.15 Industry Series of the 2002 Economic Census

NAICS code	Description
236	**Construction of Buildings**
236115	New Single-Family Housing Construction (except Operative Builders)
236116	New Multifamily Housing Construction (except Operative Builders)
236117	New Housing Operative Builders
236118	Residential Remodelers
236210	Industrial Building Construction
236220	Commercial and Institutional Building Construction
237	**Heavy and Civil Engineering Construction**
237110	Water and Sewer Line and Related Structures Construction
237120	Oil and Gas Pipeline and Related Structures Construction
237130	Power and Communication Line and Related Structures Construction
237210	Land Subdivision
237310	Highway, Street, and Bridge Construction
237990	Other Heavy and Civil Engineering Construction
238	**Specialty Trade Contractors**
238110	Poured Concrete Foundation and Structure Contractors
238120	Structural Steel and Precast Concrete Contractors
238130	Framing Contractors
238140	Masonry Contractors
238150	Glass and Glazing Contractors
238160	Roofing Contractors
238170	Siding Contractors
238190	Other Foundation, Structure, and Building Exterior Contractors
238210	Electrical Contractors
238220	Plumbing, Heating, and Air-Conditioning Contractors
238290	Other Building Equipment Contractors
238310	Drywall and Insulation Contractors
238320	Painting and Wall Covering Contractors
238330	Flooring Contractors
238340	Tile and Terrazzo Contractors
238350	Finish Carpentry Contractors
238390	Other Building Finishing Contractors
238910	Site Preparation Contractors
238990	All Other Specialty Trade Contractors

Table C.16 Variables Reported by Economic Census

Variables	How values are reported	Availability	Notes
Number of establishments	U.S. total	1977, 1982, 1987, 1992, 1997, 2002	
	by state (location of establishment)	1992, 1997, 2002	
	by size of establishment (number of employees)	1992, 1997, 2002	
	by size of establishment (value of business done)	1992, 1997, 2002	
	by project-type specialization	1992, 1997, 2002	
	by kind-of-business specialization	1997, 2002	
Proprietors and working partners	U.S. total	1977, 1982, 1987, 1992	
Total number of employees	U.S. total	1977, 1982, 1987, 1992, 1997, 2002	
	by state (location of establishment)	1987, 1992, 1997, 2002	
	by size of establishment (number of employees)	1987, 1992, 1997, 2002	
	by size of establishment (value of business done)	1987, 1992, 1997, 2002	
	by project-type specialization	1992, 1997, 2002	
	by kind-of-business specialization	1997, 2002	
Number of construction workers	U.S. total	1977, 1982, 1987, 1992, 1997, 2002	
	by state (location of establishment)	1992, 1997, 2002	
March	U.S. total	1977, 1982, 1987, 1992, 1997, 2002	
	by state (location of establishment)	1992, 1997, 2002	
May	U.S. total	1977, 1982, 1987, 1992, 1997, 2002	
	by state (location of establishment)	1992, 1997, 2002	
August	U.S. total	1977, 1982, 1987, 1992, 1997, 2002	
	by state (location of establishment)	1992, 1997, 2002	
November	U.S. total	1977, 1982, 1987, 1992, 1997, 2002	
	by state (location of establishment)	1997, 2002	
Number of other employees	U.S. total	1987, 1992, 1997, 2002	
	by state (location of establishment)	1997, 2002	
March	U.S. total	1977, 1982, 1987, 1997, 2002	
	by state (location of establishment)	1997, 2002	
May	U.S. total	1987, 1992, 1997, 2002	
	by state (location of establishment)	1997, 2002	
August	U.S. total	1987, 1992, 1997, 2002	
	by state (location of establishment)	1997, 2002	
November	U.S. total	1987, 1992, 1997, 2002	
	by state (location of establishment)	1997, 2002	
Total payroll	U.S. total	1977, 1982, 1987, 1992, 1997, 2002	
	by state (location of establishment)	1992, 1997, 2002	
	by size of establishment (number of employees)	1992, 1997, 2002	
	by size of establishment (value of business done)	1992, 1997, 2002	
	by project-type specialization	1992, 1997, 2002	
	by kind-of-business specialization	1997, 2002	
Construction workers	U.S. total	1977, 1982, 1987, 1992, 1997, 2002	
	by state (location of establishment)	1992, 1997, 2002	
Other employees	U.S. total	1977, 1982, 1987, 1992, 1997, 2002	
	by state (location of establishment)	1997, 2002	
First-quarter payroll, all employees	U.S. total	1977, 1982, 1987, 1992, 1997, 2002	
Fringe benefits, all employees	U.S. total	1977, 1982, 1987, 1992, 1997, 2002	
Legally required expenditures	U.S. total	1977, 1982, 1987, 1992, 1997, 2002	
Voluntary expenditures	U.S. total	1977, 1982, 1987, 1992, 1997, 2002	

Table C.16 Variables Reported by Economic Census

Variables	How values are reported	Availability	Notes
Value of business done	U.S. total	1977, 1982, 1987, 1992, 1997, 2002	
	by size of establishment (number of employees)	1992, 1997, 2002	
	by size of establishment (value of business done)	1992, 1997, 2002	
	by type of business	1987, 1992, 1997, 2002	
Value of construction work	U.S. total	1977, 1982, 1987, 1992, 1997, 2002	
	by state (location of establishment)	1987, 1992, 1997, 2002	
	by state (location of construction work)	1987, 1992, 1997, 2002	
	by size of establishment (number of employees)	1987, 1992, 1997, 2002	
	by size of establishment (value of business done)	1987, 1992, 1997, 2002	
	by project-type specialization	1992, 1997, 2002	
	by kind-of-business specialization	1997	
Value of construction work on government owned projects	U.S. total	1977, 1982, 1987, 1992, 1997, 2002	
Value of construction work on federally owned projects	U.S. total	1987, 1992, 1997, 2002	
Value of construction work on state and locally owned projects	U.S. total	1987, 1992, 1997, 2002	
Value of construction work on privately owned projects	U.S. total	1977, 1982, 1987, 1992, 1997, 2002	
Other business receipts	U.S. total	1997, 2002	
Cost of construction work subcontracted out to others	U.S. total	1977, 1982, 1987, 1992, 1997, 2002	
	by state (location of establishment)	1992, 1997, 2002	
	by size of establishment (number of employees)	1992, 1997, 2002	
	by size of establishment (value of business done)	1992, 1997, 2002	
	by project-type specialization	1992, 1997, 2002	
	by kind-of-business specialization	1997, 2002	
Value of construction work subcontracted in from others	U.S. total	1977, 1982, 1987, 1992	
	by state (location of establishment)	1992	
Net value of construction work	U.S. total	1977, 1982, 1987, 1992, 1997, 2002	
	by state (location of establishment)	1992, 1997, 2002	
	by size of establishment (number of employees)	1992, 1997, 2002	
	by size of establishment (value of business done)	1992, 1997, 2002	
	by project-type specialization	1992, 1997, 2002	
	by kind-of-business specialization	1997, 2002	
Value added	U.S. total	1977, 1982, 1987, 1992, 1997, 2002	
	by state (location of establishment)	1987, 1992, 1997, 2002	
	by size of establishment (number of employees)	1987, 1992, 1997, 2002	
	by size of establishment (value of business done)	1987, 1992, 1997, 2002	
	by project-type specialization	1992, 1997, 2002	
	by kind-of-business specialization	1997, 2002	
Value of construction work			
New construction	U.S. total and by project type	1987, 1992, 1997, 2002	
Additions, alterations, or reconstruction	U.S. total and by project type	1987, 1992, 1997, 2002	
Maintenance and repair	U.S. total and by project type	1987, 1992, 1997, 2002	
Selected costs	U.S. total	1977, 1982, 1987, 1992, 1997, 2002	
Materials, components, supplies, and fuel	U.S. total	1992, 1997, 2002	
	by state (location of establishment)	1992, 1997, 2002	
	by size of establishment (number of employees)	1992, 1997, 2002	
	by size of establishment (value of business done)	1992, 1997, 2002	
Materials, parts, and supplies	U.S. total	1977, 1982, 1987, 1992, 1997, 2002	
Power, fuels, and lubricants	U.S. total	1977, 1982, 1987, 1992, 1997, 2002	
Purchased eletricity	U.S. total	1977, 1982, 1987, 1992, 1997, 2002	
Natural gas and manufactured gas	U.S. total	1977, 1982, 1987, 1992, 1997, 2002	
Gasoline and diesel fuel	U.S. total	1977, 1982, 1987, 1992, 1997, 2002	
On-highway use of gasoline and diesel fuel	U.S. total	1987, 1992, 1997, 2002	
Off-highway use of gasoline and diesel fuel	U.S. total	1987, 1992, 1997, 2002	
All other fuels and lurbicants	U.S. total	1977, 1982, 1987, 1992, 1997, 2002	

Table C.16 Variables Reported by Economic Census

Variables	How values are reported	Availability	Notes
End-of-year gross book value of depreciable assets	U.S. total	1987, 1992, 1997, 2002	Buildings and structures vs. machinery and equipments are also reported separately for 1987 and 1998
	by state (location of establishment)	1992, 1997, 2002	Buildings and structures vs. machinery and equipments are also reported separately for 1987 and 1999
	by size of establishment (number of employees)	1992	
	by size of establishment (value of business done)	1992	
Depreciation charges during year	U.S. total	1987, 1992, 1997, 2002	Buildings and structures vs. machinery and equipments are also reported separately for 1987 and 2000
Number of establishments with inventories	U.S. total	1992, 1997, 2002	
Value of construction work for establishments with inventories	U.S. total	1992, 1997, 2002	
End-of-year (Economic Census year), inventories of materials and supplies	U.S. total	1992, 1997, 2002	
End-of-year (one year before Economic Census year), inventories of materials and supplies	U.S. total	1992, 1997, 2002	
Number of establishments with no inventories	U.S. total	1992, 1997, 2002	
Value of construction work for establishments with no inventories	U.S. total	1992, 1997, 2002	
Establishments not reporting inventories	U.S. total	1992, 1997, 2002	
Value of construction work for establishments not reporting inventories	U.S. total	1992, 1997, 2002	

The above variables are reported by the Economic Census for SIC/NAICS categories. This compilation is an incomplete list.

Table C.17 Source Data and Price Indices for BEA's Annual Estimates of Private Fixed Investment in Structures by Type

Component	Major source data	Price index used to deflate the estimates	Description of the price index
Private fixed investment in structures			
Nonresidential			
Commerical and health care			
Office	Census Bureau monthly construction survey (C30)	BEA price index for office buildings	This quality-adjusted index measures changes in costs and is derived using ordinary least squares hedonic regressions based on square foot costs data from the R.S. Means Company.
Healthcare			
Hospitals and special care			
Hospitals	Census Bureau monthly construction survey (C30)	An unweighted average of Census Bureau's single-family houses under construction index and a Turner Construction Company building cost index	The Census Bureau index measures quality-adjusted changes in the price of new single-family homes under construction. The building cost index is a price index for national building construction costs based on current cost.
Special care	Census Bureau monthly construction survey (C30)	Same as those for hospitals	
Medical buildings	Census Bureau monthly construction survey (C30)	Same as those for hospitals	
Multimerchandise shopping	Census Bureau monthly construction survey (C30)	BLS PPI for warehouses	This PPI measures the quality-adjusted cost for new warehouse construction.
Food and beverage establishments	Census Bureau monthly construction survey (C30)	Same as those used for multimerchandise shopping	
Warehouses	Census Bureau monthly construction survey (C30)	Same as those used for multimerchandise shopping	
Other Commercial	Census Bureau monthly construction survey (C30) and judgemental trend	Same as that used for warehouses and BLS price index for mobile structures	This PPI measures changes in the prices of new residential mobile homes.

Table C.17 Source Data and Price Indices for BEA's Annual Estimates of Private Fixed Investment in Structures by Type

Component	Major source data	Price index used to deflate the estimates	Description of the price index
Manufacturing	Census Bureau monthly construction survey (C30)	BEA price index for factories	This quality-adjusted index measures changes in costs. It is derived using ordinary least squares hedonic regressions based on square foot costs data from the R.S. Means Company.
Power and communication			
Power			
Electric	Census Bureau monthly construction survey (C30)	Weighted average of Handy-Whitman price indexes for eletric light and power plants and utility buildings	These indexes are based on prices for materials, labor costs, and prices of mechanical and electrical equipment for steam operated electric plants in six regions and for reinforced concrete buildings and brick buildings in six regions.
Other power	Census Bureau monthly construction survey (C30)	Handy-Whitman price index for has plants	This index is based on prices for materials, labor costs, and prices of mechanical and electrical equipment for gas plants in six regions.
Communication	Census Bureau monthly construction survey (C30)	AUS Telephone Plant index	This index is derived from data from operating companies and suppliers on construction methods, plant investment, and component costs.
Mining exploration, shafts, and wells			
Petroleum and natural gas	Footage drilled and cost per foot from trade sources extrapolated by BLS producer price index for oil and gas wells.	Weighted average of BLS PPIs for drilling oil and gas wells and for oil and gas field services	These indexes measure changes in prices received by domestics producers.
Mining	Census Bureau annal capital expenditures survey	Same as those used for hospitals	

Table C.17 Source Data and Price Indices for BEA's Annual Estimates of Private Fixed Investment in Structures by type

Component	Major source data	Price index used to deflate the estimates	Description of the price index
Other structures			
Religious	Census Bureau monthly construction survey (C30)	Same as those used for hospitals	
Educational and vocational	Census Bureau monthly construction survey (C30)	BLS PPI for new school construction	This PPI measures the quality-adjusted cost for new school construction.
Lodging	Census Bureau monthly construction survey (C30)	Same as those used for hospitals	
Amusement and recreation	Census Bureau monthly construction survey (C30)	Same as those used for hospitals	
Transportation			
Air	Census Bureau monthly construction survey (C30)	Same as those used for hospitals	
Land	Census Bureau monthly construction survey (C30)	Weighted average of BLS employment cost index (ECI) for construction industry, Bureau of Reclamation construction cost trends for bridges and for power plants, the BLS PPIs for material and supply inputs into construction industries, BLS PPI for other communication equipment, and the price indexes used for hospitals.	The BLS employment cost index measures labor costs. The Bureau of Reclamation construction cost trends index tracks costs such as contractor labor and equipment costs for the Bureau's construction projects. The PPI for material and supply inputs measures prices of input commodities, and the PPI for other communication equipment measures prices of signal equipment.
Farm	Census Bureau monthly construction survey (C30)	Same as those used for hospitals	
Other	Census Bureau monthly construction survey (C30)	An unweighted average of the Handy-Whitman water utility plant index, Federal Highway Administration Composite index for highways, and those used for hospitals	The Handy-Whitman water utility plant index is based on prices for materials, labor costs, and prices of mechanical and electrical equipment for water utilities in six regions.
Brokers' commissions on sale of structures	Trend-based estimates	BLS PPI for real estate brokage, nonresidential property sales and rental including land sales and rental	This PPI measures changes in real estate brokerage fees received from nonresidential property sales and rental.
Net purchases of used structures	BEA government fixed asset accounts	An unweighted average of the implicit price deflators for nonresidential buildings, for utilities, for farm buildings, and for other private structures	These implicit price deflators reflect the types of buildings bought and sold by the private sector.

Table C.17 Source Data and Price Indices for BEA's Annual Estimates of Private Fixed Investment in Structures by Type

Component	Major source data	Price index used to deflate the estimates	Description of the price index
Residential			
Permanent site			
Single-family structures	Census Bureau monthly construction survey	Census Bureau price index for single-family houses under construction index	This index measures changes in the price of new single-family homes under construction.
Multifamily structures	Census Bureau monthly construction survey	Census Bureau price index for multifamily houses under construction	This index measures changes in the price of new multi-family homes under construction.
Other structures			
Manufactured homes	Shipments from trade source and average retail price from Census Bureau monthly survey	BLS PPI for mobile structures	This PPI measures changes in the prices of new mobile homes.
Dormitories	Census Bureau monthly construction survey	Same as that used for single family structures	
Improvements	Census Bureau survey of residential alterations and repair and survey of consumer expenditures	Average of the Census Bureau index for single-family houses under construction, BLS PPI for home maintenance and repair, and BLS employment cost index for construction industry	See single-family structures for a description of the Census Bureau index. The BLS employment cost index measures labor costs in the construction industry. The PPI measures the cost of residential home maintenance and repair.
Brokers' commissions on sale of structures	Number of single-family houses sold and mean sales price from Census Bureau monthly construction survey and trade source	BLS PPI for real estate brokerage, residential property sales and rental	This PPI measures changes in real estate brokerage fees received from residential property sales and rental.
Net purchases of used structures	BEA government fixed asset accounts	Same as that used for single family structures	

Source: Paul R. Lally, "How BEA Accounts for Investment in Private Structures," Survey of Current Business February 2009: 9-15.

Table C.18 Web Links to Key Sources

Table Number	Web Link (URL)
C.1	http://www.osha.gov/pls/imis/sic_manual.html
C.2	http://www.census.gov/eos/www/naics/
C.3	http://www.census.gov/eos/www/naics/
C.4	http://www.bls.gov/ces/cesbtabs.htm
C.5	http://www.bls.gov/ces/
C.6	http://www.bea.gov/industry/gdpbyind_data.htm
C.7	http://www.bls.gov/ppi/
C.8	http://www.bls.gov/ppi/
C.9	http://www.bea.gov/national/nipaweb/SelectTable.asp?Selected=N
C.10	http://www.bea.gov/national/nipaweb/SelectTable.asp?Selected=N
C.11	http://www.census.gov/const/www/c30index.html
C.12	http://www.census.gov/const/www/c30index.html
C.13	http://www.census.gov/epcd/www/92result.html
C.14	http://www.census.gov/epcd/www/ec97stat.htm
C.15	http://www.census.gov/econ/census02/guide/INDRPT23.HTM
C.16	See Economic Censuses for specific years.
C.17	http://www.bea.gov/scb/pdf/2009/02%20February/0209_briefing_structures.pdf

Appendix D Glossary of Selected Terms

Automation and integration technologies:

> **Automation technologies**: Automation technologies focus on the degree to which individual work functions are automated (e.g., supply management and project management).
>
> **Integration technologies**: Integration technologies focus on the ability to exchange information between work functions and their associated databases (e.g., exchanges of information among supply management and project management functions).

Deflation: The meaning of deflation is the division of the value of some aggregate by a price index - described as a "deflator" - in order to revalue its quantities at the prices of the price reference period or to revalue the aggregate at the general price level of the price reference period.[226]

Establishment: An establishment is a business or industrial unit at a single physical location that produces or distributes goods or performs services.[227]

Free-rider: A person or organization who benefits from a public good, but neither provides it nor contributes to the cost of collective provision. They thus free ride on the efforts of others. The free-rider problem means that many public goods are under-provided, or have to be provided by governments which can collect taxes or pay for them.[228]

Intermediate inputs: Goods and services, other than fixed assets, used as inputs into the production process of an establishment that are produced elsewhere in the economy or are imported. They may be either transformed or used up by the production process. Land, labor, and capital are primary inputs and are not included among intermediate inputs.[229]

Nominal prices: Prices charged by providers of general government services such as health and education and prices that are heavily subsidized through government funding or regulated by

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[226] OECD Glossary of Statistical Terms. http://stats.oecd.org/glossary/detail.asp?ID=3019. Accessed September 3, 2009.

[227] Census Bureau web page on Economic Census. http://factfinder.census.gov/jsp/saff/SAFFInfo.jsp?_pageId=sp2_economic

[228] John Black, *Oxford Dictionary of Economics*. (Oxford and New York: Oxford University Press, 2002).

[229] OECD Glossary of Statistical Terms. http://stats.oecd.org/glossary/detail.asp?ID=1395. Accessed September 3, 2009.

government policy. Such prices are not economically significant and therefore do not provide signals of market driven inflation.[230]

Price index: A price index reflects an average of the proportionate changes in the prices of a specified set of goods and services between two periods of time. Usually a price index is assigned a value of 100 in some selected base period and the values of the index for other periods are intended to indicate the average percentage change in prices compared with the base period.[231]

Productivity: The basic concept underlying construction productivity measures is a comparison of the output of a task, project, or industry with the corresponding factors of production (inputs) required to generate that output.

Three dimensions of productivity:

> **Task**: Tasks refer to specific construction activities such as concrete placement or structural steel erection.
>
> **Project**: Projects are the collection of tasks required for the construction of a new facility or renovation of an existing constructed facility.
>
> **Industry**: Industry measures are based on the North American Industrial Classification (NAICS) codes for the construction sector and represent the total portfolio of projects.

Quantity index: A measure reflecting the average of the proportionate changes in the quantities of a specified set of goods and services between two periods of time. Usually a quantity index is assigned a value of 100 in some selected base period and the values of the index for other periods are intended to indicate the average percentage change in quantities compared with the base period. A quantity index is built up from information on quantities such as the number or total weight of goods or the number of services; the quantity index has no meaning from an economic point of view if it involves adding quantities that are not commensurate, although it is often used as a proxy for a volume index.[232]

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[230] OECD Glossary of Statistical Terms. http://stats.oecd.org/glossary/detail.asp?ID=5660. Accessed September 3, 2009.

[231] OECD Glossary of Statistical Terms. http://stats.oecd.org/glossary/detail.asp?ID=2110. Accessed September 3, 2009.

[232] OECD Glossary of Statistical Terms. http://stats.oecd.org/glossary/detail.asp?ID=2221. Accessed September 3, 2009.

Real terms: Attempts to reduce changes in economic variables to changes in quantities. Real GDP, for example, is the value of gross national product, measured at current prices, deflated by a GDP deflator, or price index.[233]

Sustainability: Sustainability is defined as "meeting the needs of the present generation without compromising the ability of future generations to meet their own needs."[234]

Value added for the construction industry: Value added for the construction industry is defined as the dollar value of business done less costs for construction work subcontracted to others and payments for materials, components, supplies, and fuels.[235]

Value of construction put in place: The value of construction put in place is a measure of the value of construction installed or erected at the site during a given period. For an individual project, this includes (1) cost of materials installed or erected, (2) cost of labor (both by contractors and force account) and a proportionate share of the cost of construction equipment rental, (3) contractor's profit, (4) cost of architectural and engineering work, (5) miscellaneous overhead and office costs chargeable to the project on the owner's books, and (6) interest and taxes paid during construction (except for state and locally owned projects).[236]

Workface Planning: Workface Planning is the process of organizing and delivering all the elements necessary, before work is started, to enable craft persons to perform quality work in a safe, effective and efficient manner.[237]

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[233] John Black, *Oxford Dictionary of Economics. Op. cit.*

[234] Brundtland GH, editor. 1987. Our common future: Report of the UN Commission on Environment and Development. http://www.un-documents.net/wced-ocf.htm. Accessed September 3, 2009.

[235] Economic Census 2002.

[236] Census Bureau Construction Spending Methodology. http://www.census.gov/const/C30/definitions.pdf

[237] Construction Owners Association of Alberta (COAA) Best Practices XVI Conference – Workface Planning (WFP) Plenary Presentation. 2003. http://www.workfaceplan.com/archive.htm. Accessed September 4, 2009.