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INDUSTRY-LEVEL PRODUCTIVITY MEASUREMENT AND THE 2008 SYSTEM OF NATIONAL ACCOUNTS

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The 2008 System of National Accounts recognizes capital services as the conceptually correct way to measure the input of capital into production. This allows setting up an integrated system of industry-level and aggregate productivity accounts that are consistent with the 2008 SNA. The paper discusses the new aspects in the 2008 SNA and sets out such an integrated system, based on Jorgenson's aggregate production possibility frontier and gross output-based industry productivity measures. Recent results for industry productivity measures for the United States complete the picture.

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1. INTRODUCTION

Implicitly or explicitly, productivity measurement has long been linked to the national accounts. National accounts data have constituted the key source for the components of productivity statistics—measures of the volume of outputs produced and the volume of inputs used in an economy, a sector, or an industry. The 1993 System of National Accounts (United Nations *et al.*, 1993) acknowledged the link to productivity measures but in a cursory way only and with reference to measures of labor productivity rather than multi-factor productivity.

A particular conceptual gap was the absence of the notion of capital services. This is the idea that there is not only a flow of labor services and intermediate inputs but also a flow of capital services into production. This flow can be measured as an integral part of the national accounts, very much in the same way as labor (at least in its simplified measure of hours worked) has long made its way into the national accounts. The 2008 System of National Accounts (2008 SNA) (United Nations *et al.*, 2009) made a decisive step by recognizing capital services as an integral element in the new system of national accounts, thereby

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opening the way for fully articulated sets of output, input, and productivity statistics.[1]

In so doing, the SNA as an official accounting standard follows a path that has long been pursued by the academic community. Landmarks of these efforts include Kendrick (1961),Christensen and Jorgenson (1973), and Jorgenson *et al.* (1987). More recently, Jorgenson and Landefeld (2006) have presented a prototype system that integrates the U.S. national income and product accounts with productivity statistics generated by the U.S. Bureau of Labor Statistics and balance sheets produced by the Federal Reserve Board. Jorgenson and Landefeld's prototype system describes the accounting relations at the aggregate level of the economy and for the main institutional sectors. The prototype system has been updated by Jorgenson (2009b).

Jorgenson *et al.* (1987) provide the framework for industry-level productivity accounts and their link to aggregate measures of productivity change. Fraumeni *et al.* (2006) take this discussion forward and show how industry and productivity accounts in U.S. statistical agencies can be integrated into a consistent set. Disaggregating the production account by industrial sector requires an integrated system of input–output accounts and accounts for gross product originating by industry, described by Lawson *et al.* (2006) and Moyer *et al.* (2006). Donahoe *et al.* (2010) present data for the U.S. system of industry accounts for 1998–2008 on the basis of the North American Industry Classification System (NAICS).

Our own contribution builds on this work and sets out an integrated system of industry and economy-wide productivity accounts in compliance with 2008 SNA accounting standards. The reference to the terminology and concepts of the 2008 SNA should encourage researchers and statistical offices to develop industry and aggregate productivity accounts as they implement the new standard. We discuss some of the limitations for productivity measurement that arise from the conventions adopted in the 2008 SNA, such as the treatment of consumer durables and capital service measures for government-owned assets. The paper concludes with a set of industry-level results for the United States.

The Canadian Productivity Accounts, published by Statistics Canada, provide a leading example of productivity accounts integrated with a system of national accounts.[2] The industry accounts are based on the NAICS and incorporate a time series of input–output tables for the period 1961–2007. The input–output tables are integrated with the production, income, and expenditure side of the Canadian System of National Accounts[3] and these tables are consistent with measures of capital and labor inputs, as well as multifactor productivity.[4] Since

[1]A companion product to the 2008 SNA, the new OECD (2009) *Manual on Measuring Capital* provides the necessary reference for the computation of capital and capital services measures. It complements the OECD (2001) *Manual on Measuring Productivity* that describes in some detail the construction of productivity statistics at the aggregate and industry levels.

[2]See Baldwin *et al.* (2010) for a recent summary of the Canadian Productivity Accounts. An early example for official productivity statistics, but not necessarily integrated with the national accounts, is BLS (1983).

[3]See Wilson (2006) for details on the Canadian System of National Accounts and its relationship to the 1993 SNA (United Nations *et al.*, 1993).

[4]Integration of productivity measures with the Canadian System of National Accounts is discussed by Baldwin and Harchaoui (2006).

2007 Statistics Netherlands has published a system of industry-level productivity accounts that is integrated with system of national accounts for The Netherlands.[5] Statistical agencies in Australia, Belgium, Denmark, Finland, and Italy also publish industry-level productivity statistics within the framework of the national accounts.

2. Industry-Level: Accounting Relationships

We start by setting out the accounting relationships at the industry level, i.e., for a set of producing units (for instance, establishments) grouped by their primary activity along an industry classification such as the International Standard Industry Classification or the North American Industry Classification. Establishments may produce one or more products but their primary product determines the allocation to a particular industry. We consider a set of N_J different industries and a set of N_I products that are produced domestically or imported from abroad. On the output side of the production account of industry j one has the sum over the value of all outputs produced,[6] the value itself being the product of the prices and quantities of each product. In the national accounts, output is valued at basic prices, excluding taxes raised on products sold but including any subsidies received by the producer.

On the input side of the industry production account one finds the value of intermediate products entering production and value added, itself composed of compensation of employees, gross operating surplus (profits), mixed income (the income of self-employed persons), and (other) taxes minus subsidies that are raised on production. Intermediate inputs can be purchased either from establishments within the industry or from other industries in the country, or can be imported from abroad. The valuation of inputs is at purchasers' prices, reflecting all taxes levied on these products and all subsidies paid on these products. More formally, the industry-level production account[7] can be presented as:

$$(1)\qquad P_jQ_j = \tilde{P}_jX_j + VA_j \text{ with } j = 1, 2, \ldots N_J \text{ industries and}$$
$$P_jQ_j \equiv \sum_i^{N_I} P_{ij}Q_{ij}$$
$$\tilde{P}_jX_j \equiv \sum_i^{N_I} \tilde{P}_{ij}X_{ij}$$
$$VA_j \equiv CE_j + GOS_j + MI_j + TP_j$$

where:

Q_{ij}: quantity (volume) of product i produced in industry j

P_{ij}: basic price of product i produced in industry j

[5]See van der Bergen *et al.* (2007).

[6]These outputs are within the production boundary of the SNA. By convention, and mainly for practical reasons, they exclude some activity that would qualify as production on purely conceptual grounds, in particular the services produced by households for their own consumption such as child care, cooking, or cleaning.

[7]To be precise, the SNA distinguishes between the production account and the primary distribution of income account, but to keep things simple and without much loss of information, we combine these two accounts into one "production account."

P_jQ_j: value of industry j's gross output at basic prices
X_{ij}: quantity (volume) of product i used in industry j, comprising both imported and domestically-produced products
$\tilde{P}_{ij}$: purchasers' price of product i used in industry j
$\tilde{P}_j X_j$: value of industry j's intermediate inputs at purchasers' prices
VA_j: value added (at basic prices) of industry j
CE_j: compensation of employees in industry j
GOS_j: gross operating surplus in industry j
MI_j: mixed income in industry j
TP_j: taxes on production minus subsidies on production levied in industry j

From the first line in equation (1) it can easily be seen that value added equals gross output minus intermediate inputs. Value added is designed to reflect the value created by a process of production. It is also a measure of primary income that combines labor income, income generated from the use of capital in production, and net taxes on production. A crucial step in the development of productivity measures will be the decomposition of these income components into a price and a quantity or volume component, of which more later.

3. Supply–Use Tables: Accounting Relationships Across Industries and Products

The above accounting relationships can be brought together in supply–use tables. Today, an increasing number of countries use supply–use tables as the organizing and balancing framework for their national accounts. The key merit of such tables is that they systematically track flows of products through the economy, along with the value added generated in their production. As will be shown below, supply–use tables are also a key element in the construction of industry-level productivity measures and their links to aggregate productivity indicators. Much can be said about the construction and methodology of supply–use tables, but for the purpose at hand it suffices to indicate that the supply table shows which domestic industry produces which products and which products are imported, and the use table shows whether these products are delivered to other industries (and if so to which industries) or whether these products go to final demand (and if so, whether it is the consumption, investment or export component of final demand).[8]

The supply table (Figure 1, upper panel) is best presented as a matrix with products along rows and industries producing them along columns. To domestically produced outputs have to be added imported products Q_{Mi} at prices P_{Mi} to characterize total supply for each type of product,[9] the sum of each row

[8]For more details, see Beutel (2008).

[9]See Chapter 14 of the 2008 SNA for a discussion how to convert statistical information on imports from trade classifications to product classifications.

Supply of products

		Industry				Total supply from domestic production	Imports	Taxes on products	Trade and transport margins	Total supply at purchasers' prices
		1	2	…	N_J					
Product	1	$P_{11}Q_{11}$			$P_{1N_J}Q_{1N_J}$	$\sum_{j=1}^{N_J} P_{1j}Q_{1j}$	$P_{M1}Q_{M1}$	T_1	TM_1	$\sum_{j=1}^{N_J} P_{1j}Q_{1j} + P_{M1}Q_{M1} + T_1 + TM_1$
	2									
	.									
	.									…
	.									
	N_I	$P_{N_I1}Q_{N_I1}$			$P_{N_IN_J}Q_{N_IN_J}$	$\sum_{j=1}^{N_J} P_{N_Ij}Q_{N_Ij}$	$P_{MN_I}Q_{MN_I}$	T_{N_I}	TM_{N_I}	$\sum_{j=1}^{N_J} P_{N_Ij}Q_{N_Ij} + P_{MN_I}Q_{MN_I} + T_{N_I} + TM_{N_I}$
Gross output		P_1Q_1			$P_{N_J}Q_{N_J}$		P_MQ_M		0	$\sum_{i=1}^{N_I}\left(\sum_{j=1}^{N_J} P_{ij}Q_{ij} + P_{Mi}Q_{Mi} + T_i\right)$

Use of products

	Total supply at purchasers' prices		Deliveries to Industry				Deliveries to final demand
			1	2	…	N_J	
Product	$\sum_{j=1}^{N_J} P_{i1}Q_{i1} + P_{M1}Q_{M1} + T_1 + TM_1$	1	$\tilde{P}_{11}X_{11}$			$\tilde{P}_{1N_J}X_{1N_J}$	$\tilde{P}_1Q_{FD1}$
		2					
		.					
	…	.					
		.					
	$\sum_{j=1}^{N_J} P_{N_Ij}Q_{N_Ij} + P_{MN_I}Q_{MN_I} + T_{N_I} + TM_{N_I}$	N_I	$\tilde{P}_{N_I1}X_{N_I1}$			$\tilde{P}_{N_IN_J}X_{N_IN_J}$	$\tilde{P}_{N_I}Q_{FD\,N_I}$
	$\sum_{i=1}^{N_I}\left(\sum_{j=1}^{N_J} P_{ij}Q_{ij} + P_{Mi}Q_{Mi} + T_i\right)$	Intermediate inputs	$\sum_{i=1}^{N_I} \tilde{P}_{i1}X_{i1}$			$\sum_{i=1}^{N_I} \tilde{P}_{iN_J}\tilde{X}_{iN_J}$	
		Value-added:	VA_1			VA_{N_J}	
		Compensation of employees	CE_1	…		CE_{N_J}	
		Gross operating surplus	GOS_1	…		GOS_{N_J}	
		Mixed income	MI_1	…		MI_{N_J}	
		Taxes on production	TP_1	…		TP_{N_J}	
		Gross output	P_1Q_1			$P_{N_J}Q_{N_J}$	

Figure 1. Supply and Use Tables

of the supply matrix. Each industry's total production is given by the sum of each column of the supply matrix

(2)	Total domestic supply of product i at basic prices	$= \sum_{j=1}^{N_J} P_{ij}Q_{ij}; i = 1, 2, \ldots N_I$ products
	Imports: supply from abroad at basic prices	$= \sum_{i=1}^{N_I} P_{Mi}Q_{Mi}$
	Total domestic supply by industry j at basic prices	$= \sum_{i=1}^{N_I} P_{ij}Q_{ij}; j = 1, 2, \ldots N_J$ industries

It was mentioned earlier that output (and therefore supply) of products is valued at basic prices whereas inputs (and therefore demand) are valued at purchasers' prices, one of the differences being net taxes on products. To ensure balance of supply and use of products, the value of net taxes on products has thus to be added to the value of supply.

There is another item that needs to be taken into account in order to ensure a balance between the supply and use of products, namely trade and transport margins: the purchaser's price includes any transportation charges needed for delivery at the required time and place. If such transportation costs are paid separately by the purchasers, they form part of the purchaser's price but not part of the basic price, i.e., the price relevant for the supplier. Transport margins reflect the value of a service and along with taxes and subsidies on produ2cts they have to be added to the value of production at basic prices to obtain a measure of total supply of a product at purchasers' prices. However, as distinct from net taxes on products $\{T_i\}$, transportation margins are only reallocated across products and their sum remains zero.

The use table (Figure 1, lower panel) starts from total supply at purchasers' prices which equals total demand at purchasers' prices and then tracks the destination of each product in the economy. For every type of product (the rows of the use matrix), the different destinations are shown in the columns of the use matrix: intermediate inputs and final demand (consumption, investment, and exports at purchasers' prices), denoted $\sum_{i=1}^{N_I} \tilde{P}_i Q_{FDi}$ in equation (3) below.

(3)	Total supply of product i at basic prices	$\sum_{j=1}^{N_J} P_{ij}Q_{ij} + P_{Mi}Q_{Mi}$
	+ net taxes + trade and transport margins	$+ \sum_{j=1}^{N_J} T_{ij} + TM_i$
	= Total demand of product i at purchasers' prices for $i = 1, 2, \ldots N_I$ products	$= \sum_{j=1}^{N_J} \tilde{P}_{ij} X_{ij} + \sum_{i=1}^{N_I} \tilde{P}_i Q_{FDi}$

Each column in the use matrix further reproduces the industry-level production account as in equation (1): intermediate inputs at purchasers' prices plus value added at basic prices equals gross output at basic prices. For the economy as a whole, GDP is the sum over industry value added at basic prices plus net taxes on products.

(4)	Gross output minus intermediate inputs	$\sum_{i=1}^{N_I}\sum_{j=1}^{N_J} P_{ij}Q_{ij} - \sum_{i=1}^{N_I}\sum_{j=1}^{N_J} \tilde{P}_{ij}X_{ij}$
	= Value added at basic prices	$= \sum_{j=1}^{N_J} VA_j$
	= Final demand at purchasers' prices minus imports at basic prices minus net taxes on products	$= \sum_{i=1}^{N_I} \tilde{P}_i Q_{FDi} - \sum_{i=1}^{N_I} P_{Mi}Q_{Mi} - T$
	= Final demand at purchasers' prices minus imports at purchasers' prices minus net taxes on domestic products	$= \sum_{i=1}^{N_I} \tilde{P}_i Q_{FDi} - \sum_{i=1}^{N_I} \tilde{P}_{Mi}Q_{Mi} - (T - T_M)$

4. Industry-Level Volume Measures of Outputs, Inputs, and Productivity

All the relationships so far have been defined in current prices and are accounting identities. However, productivity measurement deals with the volumes of outputs, inputs, and how they relate to each other; consistent measurement of volume and price aggregates requires some backing in production theory. At the industry level, we evoke the existence of a period t industry production function f_j that relates the aggregate volume of industry[10] output Q_j to labor input L_j, capital input K_j, and intermediate inputs X_j. More specifically, f_j is the maximum output Q_j producible in period t, given a set of labor, capital, and intermediate inputs:

(5) $$Q_j = f_j\,(L_j, K_j, X_j, t) \quad \text{for } j = 1, 2, \ldots N_J \text{ industries.}$$

The volume of output Q_j is itself a function g_j of the various products produced by industry j: $Q_j = g_j(Q_{1j}, Q_{2j}, \ldots Q_{N_Ij})$. More specifically, if g_j is the minimum amount of aggregate input[11] required to produce the vector of outputs $(Q_{1j}, Q_{2j}, \ldots Q_{N_Ij})$, the set of efficient production possibilities at the industry level can be represented as

(6) $$g_j(Q_{1j}, Q_{2j}, \ldots, Q_{N_Ij}) = f_j\,(L_j, K_j, X_j, t) \quad \text{for } j = 1, 2, \ldots N_J \text{ industries.}$$

The production possibilities sets at industry-level form the starting block for the specifications of indices of outputs, inputs, and productivity. We consider these in turn.

[10]"Industry" is understood in the sense of the 2008 SNA, i.e., as the aggregate over a set of establishments engaged in the same, or similar kind of activities.

[11]For the mathematical properties of this factor requirements function, see Diewert (1976); for a discussion in the context of deriving an output price index, see Diewert (2009).

4.1. *Outputs*

For industry gross output, the first step in volume measurement consists of applying a producer price index (PPI) to the value change of gross output at the most disaggregated product level. PPIs are typically developed by product but—at the lowest level of aggregation—not necessarily with an industry-specific component. It is therefore common practice to apply the same rate of price change across a single row of the supply table. In other words, the assumption is made that the price change of the same type of product is independent of the industry where it is produced.[12] In terms of the present set-up, this implies that the volume change of industry j's gross output of product type i between period $t-1$ and t, is obtained by deflating the value change of industry output by the product-specific PPI,[13] $P_i^t / P_i^{t-1}: Q_{ij}^t / Q_{ij}^{t-1} = \left(P_{ij}^t Q_{ij}^t / P_{ij}^{t-1} Q_{ij}^{t-1}\right) / \left(P_i^t / P_i^{t-1}\right)$.

Given a set of volume changes for each industry-product combination, $\{Q_{ij}^t / Q_{ij}^{t-1}\}$ and the production values for each of these combinations, the question arises which index number formula to choose in the construction of an industry-level volume index of gross output. Christensen and Jorgenson (1973) were the first to consistently apply Törnqvist or translog quantity indices in measuring the changes in the volume of output, input, and productivity. In terms of the production theoretic set-up above, this means that the change in the output aggregator g_j is measured as

$$\text{(7)} \qquad \Delta \ln Q_j = \sum_{i=1}^{N_I} \bar{s}_{Qij} \Delta \ln Q_{ij} \quad \text{for } j = 1, 2, \ldots N_J \text{ industries}$$

where $\bar{s}_{Qij} \equiv 0.5\left(s_{Qij}^t + s_{Qij}^{t-1}\right)$ and $s_{Qij}^t \equiv \dfrac{P_{ij}^t Q_{ij}^t}{P_j^t Q_j^t}$ for $i = 1, 2, \ldots N_I$ products.

The aggregation weights s_{Qij}^t reflect the share of product type i in industry j's total gross output. The translog aggregation formula has a number of desirable properties. In particular, Diewert (1976) showed that if g_j has a translog functional form, and given revenue maximizing behavior of producers, the translog aggregation formula is superlative in that it exactly represents the shift in g_j. Note also that the translog functional form allows for different degrees of substitution between products produced by an industry.[14] Using translog formulae raises, however, an issue of consistency with current national accounts practice: in concept, both the 1993 and the 2008 SNA favor the use of superlative index numbers although the focus in the SNA is on the Fisher Ideal Index rather than on the translog or

[12]This is a weaker assumption than assuming that the same price applies across industries. Note also that even if an industry-specific deflator were available for each type of product, it would still be impossible to set up a fully consistent deflation procedure for the supply *and* the use table unless there is information about the demand destination of each element of industry–product specific supply. A fully-fledged information set requires a set of satellite matrices that map the product-specific delivery structure between industries. This is developed in much greater detail by E. Diewert in Chapter 18 of IMF (2004) and in Diewert (2006, 2007). He provides a similar treatment with an emphasis on foreign trade, which can be found in Chapter 20 of IMF (2009).

[13]This may entail a bias when the actual product composition below the most detailed level at which PPIs are used in the supply–use tables varies strongly between industries and when component prices below this level exhibit different price changes.

[14]The translog functional form was introduced by Christensen *et al.* (1973).

Törnqvist index number formula. This would appear to be a minor empirical issue as it has been shown that the translog and the Fisher Index approximate each other closely (Diewert, 1978).

Only a minority of countries actually *use* Fisher Ideal Index numbers in their national accounts. A much more pervasive formula is the chained Laspeyres Index for volume measures. In the comparison between periods t and $t-1$, the Laspeyres Index uses period $t-1$ weights only and its results can diverge from those of superlative index number formulae. We are thus facing a situation where aggregates of outputs (and inputs—see below) derived for purposes of productivity measurement may differ from the same aggregates shown in the national accounts. There is no general rule about the quantitative importance of this difference. If relative prices change little between comparison periods, differences may turn out to be small. If, on the other hand, there are large shifts in relative prices, the ensuing bias from the use of a simple Laspeyres-type index may turn out to be sizeable.

4.2. *Inputs*

On the input side, before disentangling price from volume changes, some extra work on current price data is necessary. It will be remembered that total costs consist of intermediate inputs, compensation of employees, mixed income, gross operating surplus, and (other) net taxes on production. While compensation of employees is without doubt a payment for labor services, and while gross operating surplus will largely or entirely reflect payment for capital services, this is less clear for mixed income and for net taxes on production. Mixed income being essentially the income of self-employed persons, some of it will be compensation of labor services and some will be compensation of capital services. A common method is to assume that average remuneration of the self-employed in an industry equals the average remuneration of other workers of similar qualification in the same industry.[15] Similarly, other taxes on production have to be allocated to either labor or capital. In some cases this may be possible by examining the nature of taxes (for example, a property tax would be added to gross operating surplus as it concerns structures or land, or a payroll tax would be allocated to compensation of employees) but in some cases this will not be possible.

A case can be made to assume that all income that does not directly accrue to labor accrues to capital. The value of capital services is then measured residually. In terms of the notation adopted earlier, the value of total labor input in industry j is then defined as $P_{Lj}L_j = CE_j + \alpha_j MI_j + \beta_j TP_j$ where α_j is the share of mixed income that has been allocated to labor and β_j is the share of other taxes on production that has been allocated to labor. The residual value-added then equals the value of capital services: $P_{Kj}K_j = VA_j - P_{Lj}L_j = GOS_j + (1 - \alpha_j)MI_j + (1 - \beta_j)TP_j$. Alternatively, a case can be made to produce an independent measure for the value of capital services. As a consequence, the sum of labor and capital income will not necessary equal value-added and a residual term arises in the form of a windfall profit or loss. Over longer periods, this may in particular be the case if output

[15]See, for example, Jorgenson *et al.* (2005, ch. 6), or OECD (2001).

markets are not fully competitive.[16] For the present exposition we shall stick with the first case and construct capital income residually so that value-added decomposes exactly into a labor and capital component as shown in equation (8) below.[17]

$$VA_j = P_{Lj}L_j + P_{Kj}K_j \quad \text{for } j = 1, 2, \ldots N_J \text{ industries.} \tag{8}$$

Total costs in industry j are the sum of primary inputs and intermediate inputs and they equal the value of gross output:

$$P_jQ_j = P_{Lj}L_j + P_{Kj}K_j + \tilde{P}_jX_j \quad \text{for } j = 1, 2, \ldots N_J \text{ industries.} \tag{9}$$

4.2.1. Volume of Intermediate Inputs

Intermediate inputs are an industry's purchase of outputs from other establishments. In our supply–use framework they correspond to cell entries $\tilde{P}_{ij}X_{ij}$ for each of the $i = 1, 2, \ldots N_I$ products and $j = 1, 2, \ldots N_J$ industries. Intermediate inputs are valued at purchasers' prices, i.e., they include net taxes on products. This is consistent with an input perspective by producers using intermediate inputs and constitutes the theoretically correct valuation in productivity accounts.[18] But the implication is also that, at least in principle, there should be separate deflators for each $\tilde{P}_{ij}$, a condition rarely met in practice where often a single deflator is used across entire rows of the supply–use tables. We construct a volume aggregator of intermediate inputs $X_j = X_j(X_{1j}, X_{2j}, \ldots X_{NIj})$ purchased by industry j and apply the same reasoning as in the case of output aggregation[19] to obtain a translog index of intermediate inputs:

$$\Delta \ln X_j = \sum_{i=1}^{N_I} \bar{s}_{Xij} \Delta \ln X_{ij} \quad \text{for } j = 1, 2, \ldots N_J \text{ industries} \tag{10}$$

where $\bar{s}_{Xij} \equiv 0.5\left(s^t_{Xij} + s^{t-1}_{Xij}\right)$ and $s^t_{Xij} \equiv \dfrac{\tilde{P}^t_{ij}X^t_{ij}}{\tilde{P}^t_jX^t_j}$

$i = 1, 2, \ldots N_I$ products and $j = 1, 2, \ldots N_J$ industries.

4.2.2. Volume of Labor Input

Neither capital nor labor are homogenous inputs, and measuring labor input by simply adding hours worked ignores differences in labor quality that arise as a

[16]For a discussion, see OECD (2009), Diewert and Nakamura (2007), or Schreyer (2012).

[17]With an independent "exogenous" measure of capital services (labeled $P'_{Kj}K_j$ in what follows), value-added comprises labor, capital, and a residual remuneration R_j. While R_j constitutes residual profits or losses, it is conceptually different from *entrepreneurial income* as defined in the SNA. The latter corresponds to GOS minus interest payments, rents (payments for the use of non-produced assets), and adding property income receivable. Conceptually, entrepreneurial income is close to the concept of profits or losses as understood in business accounts.

[18]See Jorgenson *et al.* (1987) and OECD (2001) for details on the construction of industry-level productivity accounts. Details on the construction of a time series of input–output tables are given by Jorgenson *et al.* (2005, ch. 4).

[19]The aggregator X_j is taken as a homogenous translog function in its components and producers behave as cost minimizers.

consequence of education, skills, or work experience.[20] L_j should therefore be understood as an aggregator across N_L different types of labor: $L_j = L_j(L_{1j}, L_{2j}, \ldots L_{NLj})$ and the total value of compensation as the sum of compensation across different types of labor: $P_{Lj}L_j = \sum_{i=1}^{N_L} P_{Lij}L_{ij}$ in every industry $j = 1, 2, \ldots N_J$. Here, P_{Lij} is the hourly compensation of the i-th type of labor in industry j and L_{ij} is the corresponding number of hours. By applying the same reasoning as in the case of output aggregation, the quantity change of labor input can be measured as a translog index of the volume changes of different types of labor input:

$$\Delta \ln L_j = \sum_{i=1}^{N_L} \bar{s}_{Lij} \Delta \ln L_{i,j} \quad \text{for } j = 1, 2, \ldots N_J \text{ industries} \tag{11}$$

where $\bar{s}_{Lij} \equiv 0.5\left(s_{Lij}^t + s_{Lij}^{t-1}\right)$ and $s_{Lij}^t \equiv \dfrac{P_{Lij}^t L_{ij}^t}{P_{Lj}^t L_j^t}$

for $i = 1, 2, \ldots N_L$ types of labor and $j = 1, 2, \ldots N_J$ industries.

The index number (11) can also be interpreted as the quantity index of labor income. The log difference between the quantity index of labor income and a simple index of hours worked that does not account for different types of labor quality is an index of labor quality. Labor quality captures changes in the composition of the work force by the characteristics of individual workers, as suggested by BLS (1993). A detailed description of the sources and methods for estimates of labor quality can be found in Jorgenson *et al.* (2005, ch. 6).

4.2.3. Volume of Capital Input

For a long time national accounting standards treated labor and capital differently—there was explicit recognition of a price and quantity of labor input but no such recognition of a price and quantity of capital input. This changed with the 2008 SNA, which explicitly acknowledges capital services, thereby permitting a price–volume split of all income components.[21] Akin to labor input, it is recognized that there are different types of capital services, each proportional to different types of capital stocks. Aggregate capital input into industry j, K_j combines N_K different types of capital: $K_j = K_j(K_{1j}, K_{2j}, \ldots K_{NKj})$ and the total value of compensation for capital services is the sum of compensation across different types of capital: $P_{Kj}K_j = \sum_{i=1}^{N_K} P_{Kij}K_{ij}$. Here, P_{Kij} is the price of the i-th type of capital services in industry j per unit of K_{ij}, the corresponding quantity. By applying the same reasoning as in the case of labor, the quantity change of capital input can be measured as a translog index of the volume changes of different types of capital input:

$$\Delta \ln K_j = \sum_{i=1}^{N_K} \bar{s}_{Kij} \Delta \ln K_{ij} \quad \text{for } j = 1, 2, \ldots N_J \text{ industries} \tag{12}$$

[20]See Jorgenson *et al.* (1987, ch. 3, 8; 2005, ch. 6).
[21]For a recent discussion, see Vanoli (2010) and Jorgenson *et al.* (2010).

where $\bar{s}_{Kij} \equiv 0.5\left(s_{Kij}^{t}+s_{Kij}^{t-1}\right)$ and $s_{Kij}^{t} \equiv \dfrac{P_{Kij}^{t}K_{ij}^{t}}{P_{Kj}^{t}K_{j}^{t}}$.
for $i = 1, 2, \ldots N_K$ types of capital and $j = 1, 2, \ldots N_J$ industries.

We shall only briefly dwell on capital measurement; for more detail, the reader is referred to Jorgenson (1963), Hulten (1990), Jorgenson *et al.* (2005, ch. 5), OECD (2009), Chapter 20 of the 2008 SNA, or Diewert and Schreyer (2008). But two main features of capital measurement merit mentioning here. The first relates to the construction of time series of industry and asset-specific capital stocks $\{K_{ij}^{t}\}$. For most purposes, these are developed by cumulating time series of industry and asset-specific investment expenditure, deflated such that they are expressed in constant quality units of investment. To each investment series, an age–efficiency and retirement profile is applied that takes account of the loss of productive capacity of capital goods and of their scrapping as they age. In the simplest case, the combined age–efficiency/retirement profile exhibits a geometric form, i.e., the cohort of assets loses efficiency and retires at a constant rate. With time series of industry- and asset-specific capital stocks at hand, the assumption is made that the flow of capital services is proportional to the size of the individual stocks. Proportionality implies that the index of capital input as in (12) constitutes the index of capital service flows.

The second main ingredient of capital services measurement is the price of these services. Capital service prices are rental prices and they may be observable when owners of capital goods rent them out to users for one or several periods of time. Given such data on market rental prices by class of asset, the implicit rental values paid by owners for the use of their property can be imputed by applying these rental rates as prices. This method is often used to estimate the rental value of owner-occupied dwellings. The main obstacle to broader application of this method is the lack of data on market rental prices. An alternative approach for imputation of rental prices is to extend the perpetual inventory method to include prices of capital services. For each type of capital perpetual inventory, estimates are prepared for asset prices, service prices, depreciation, and revaluation. Under the assumption of geometrically declining relative efficiency of capital goods, the asset prices decline geometrically with vintage.[22] A common specification for the capital service price P_{Kij} is:

(13) $$P_{Kij} = \tilde{P}_{ij}\left(r_j + \delta_{ij}(1+i_{ij}) - i_{ij}\right) \quad \text{for } i = 1, 2, \ldots N_K \text{ types of assets and } j = 1, 2, \ldots N_J \text{ industries,}$$

where $\tilde{P}_{ij}$ is the purchaser's price, at the beginning of a period, of a new asset of type i acquired by industry j, r_j is the nominal rate of return prevailing for industry j, δ_{ij} is the constant rate of depreciation for asset type i in industry j, and i_{ij} is the rate of inflation in the purchase price of new capital goods between the beginning and the end of the period. Service prices for each class of assets held by each industry typically comprise machinery, equipment, residential and non-residential structures, land, and several other types of natural resources (see the discussion on

[22]See Fraumeni (1997) for the computation of depreciation in the U.S. national accounts and OECD (2009) for a general discussion.

the scope of capital below). More elaborate versions of the user cost expression include terms for income taxes and depreciation allowances and we refer to Jorgenson and Yun (2001) for a more detailed exposition.

In principle, all the terms in (13) are observable except for the rate of return r_j (and the expected rate of asset price change i_{ij} if (13) is interpreted as an *ex-ante* term). OECD (2009) and Oulton (2007) provide a discussion on the various alternatives for estimating these terms. For reasons of space, we only refer to one of them here. This approach is based on *ex-post* price changes and computes the rate r_j "endogenously" for a given $P_{Kj}K_j$.

(14) $$P_{Kj}K_j = \sum_{i=1}^{N_K} \tilde{P}_{ij}\left(r_j + \delta_{ij}(1+i_{ij}) - i_{ij}\right)K_{ij} \quad \text{for } j = 1, 2, \ldots N_J \text{ industries.}$$

The alternative approach consists in selecting a rate r_j', for instance a market interest rate and then computing the value of capital services $P_{Kj}' K_j$ ("exogenous" approach). As indicated earlier, a consequence of this procedure is the appearance of a difference between the sum of the values of labor and capital services and value added.

4.2.4. Assets Used by Non-Market Producers, Consumer Durables, and R&D

Note a complication in the case of industries with non-market producers, in particular government. As non-market producers offer their products at a price that covers only part or none of the costs of production, revenues cannot serve as a measure of the value of output. The SNA therefore foresees that the value of output is estimated as the sum of costs incurred in its production. However, according to the SNA, capital costs for government producers are solely measured as the value of depreciation, thus ignoring that part of costs of capital services which reflect the opportunity costs of capital and revaluation, namely $\sum_{i=1}^{N_K} \tilde{P}_{ij}\left(r_j - i_{ij}\right)K_{ij}$. The main reason for this convention lies in the fact that any such imputation directly affects GDP and national income and that there is a broad spectrum of possible imputations. That said, Jorgenson and Landefeld (2006), Jorgenson and Yun (2001), and OECD (2009) show alternatives for dealing with this complication. From the perspective of productivity measurement, the asymmetric treatment of assets used in market and in non-market production results in an incomplete estimate of capital inputs and in an asymmetric treatment of the same asset, depending on the sector affiliation of the asset owner. For analytical applications it may therefore be considered deviating from the national accounts convention. An example for such an application is Mas *et al.* (2006) who examine the contribution of infrastructure capital, largely held by government entities, to economic growth in Spain.

The scope of assets belonging to government is often large and includes produced and non-produced assets. For example, natural resources are often government-owned and can account for an important part in the total wealth of the public sector. Note, however, that when government owns a non-produced, non-financial asset such as land or a subsoil resource and leaves its exploitation to another unit, the act of renting is not itself considered production. As a consequence, the income associated with using the asset appears in the using or extracting industry whereas the asset itself is allocated to the industry of its owner. For the purposes of productivity studies then, capital services provided by land and subsoil assets should be registered with the users of assets.

Another national accounts convention is the treatment of consumer durables as final consumption expenditure and not as investment. On conceptual grounds, certain consumer durables constitute capital goods that provide a flow of capital services, in particular in the production of services that households produce for their own consumption, for instance washing machines in the process of laundering. By convention, this production is however outside the SNA production boundary and accordingly, consumer durables are outside the SNA asset boundary. Jorgenson and Landefeld (2006) show how prices and quantities of capital services for *all* productive assets can be included in a national accounts framework and this includes a consistent treatment of consumer durables and government assets. It is of note that recognition of the capital services of consumer durables implies not only expanded measures of capital services but also an expanded measure of output. While such an extension of the production and the asset boundaries are useful for several analytical purposes, they would seem to add little by way of analyzing productivity. The main reason being that, for want of other information, the volume of household output produced with household labor and services from consumer durables is typically measured by the volume of these inputs, thus defining away any productivity change.

A major innovation of the 2008 SNA is the recognition of research and development (R&D) as an asset. Thus, rather than being treated as current expenditure, resources spent on R&D are now treated as capital formation. While economically sensible, there are empirical challenges. Key questions relate to the choice of the depreciation profile and to the choice of the asset price index. A first assessment of these issues can be found in OECD (2010) and Fraumeni and Okubo (2005).

4.3. *Industry-Level Productivity Measures*

Having dealt with the measurement of aggregates of inputs and outputs, it is now only a short step toward the measurement of industry productivity. The starting point is (6) and we define the family of multi-factor productivity indices of industry j as the shift in the production possibility efficient set over time, given a reference set of inputs:

$$\ln \pi_j = \partial \ln f_j \big/ \partial t \quad \text{for } j = 1, 2, \ldots N_J \text{ industries.} \tag{15}$$

Diewert (1976) showed that if the input and output aggregators in (6) are translog functional forms, if the technology exhibits constant returns to scale and if producers act as cost minimizers and revenue maximizers under competitive conditions, an exact representation of the discrete counterpart to (15) is the Törnqvist or translog productivity index:

$$\text{(16)}\quad \ln \pi_j = \Delta \ln Q_j - \bar{v}_{Kj} \Delta \ln K_j - \bar{v}_{Lj} \Delta \ln L_j - \bar{v}_{Xj} \Delta \ln X_j$$
$$\text{with } \bar{v}_{Kj} \equiv 0.5\left(v_{kj}^t + v_{kj}^{t-1}\right), \bar{v}_{Lj} \equiv 0.5\left(v_{Lj}^t + v_{Lj}^{t-1}\right); \bar{v}_{Xj} \equiv 0.5\left(v_{Xj}^t + v_{Xj}^{t-1}\right) \text{ and}$$
$$v_{Kj}^t \equiv \frac{P_{Kj}^t K_j^t}{P_j^t Q_j^t}; v_{Lj}^t \equiv \frac{P_{Lj}^t L_j^t}{P_j^t Q_j^t}; v_{Xj}^t \equiv \frac{\tilde{P}_{Xj}^t X_j^t}{P_j^t Q_j^t} \quad \text{for } j = 1, 2, \ldots N_J \text{ industries.}$$

This productivity measure is based on gross output and allows for substitution between primary and intermediate inputs. Productivity growth is thus defined as the capacity to produce a larger bundle of gross output given a set of primary and intermediate inputs.[23] When the value of capital services is not derived residually, and consequently the sum of inputs does not exactly add to gross output, a modified productivity measure is called for (see Schreyer, 2012). The difference lies in the weights that attach to inputs—these constitute cost shares rather than shares in the value of output. Such modified input shares would carry through the remaining derivations, including the links to total economy productivity measures.

Noting that industry value added equals industry gross output minus intermediate inputs consumed by the industry, a volume index of value added in industry j, $\Delta \ln V_j$, is implicitly defined through the decomposition of the volume index of gross output into a volume index of value added and a volume index of intermediate inputs:[24]

$$\text{(17)}\quad \Delta \ln Q_j = \bar{v}_{VAj} \Delta \ln V_j + \bar{v}_{Xj} \Delta \ln X_j \text{ or}$$
$$\Delta \ln V_j = \frac{1}{\bar{v}_{VAj}} \Delta \ln Q_j - \frac{\bar{v}_{Xj}}{\bar{v}_{VAj}} \Delta \ln X_j$$
$$\text{with } \bar{v}_{VAj} \equiv 0.5\left(v_{VAj}^t + v_{VAj}^{t-1}\right) \text{ and } v_{VAj}^t \equiv \frac{VA_j^t}{P_j^t Q_j^t} \quad \text{for } j = 1, 2, \ldots N_J \text{ industries.}$$

Expressions (16) and (17) can now be combined to yield a decomposition of the rate of growth of real value added in industry $j = 1, 2, \ldots N_J$:

$$\text{(18)}\quad \Delta \ln V_j = \frac{1}{\bar{v}_{VAj}} \left(\bar{v}_{Kj} \Delta \ln K_j + \bar{v}_{Lj} \Delta \ln L_j + \ln \pi_j\right).$$

5. Total Economy Productivity Measure

The starting point for linking industry-level productivity measures to economy-wide productivity measures is Jorgenson's (1966) production possibility frontier (PPF). The PPF relates an economy's output to the set of inputs available

[23]An alternative formulation of productivity change is in terms of value added and a shift of a primary input function over time. While the two types of productivity measures can be linked, they represent different assumptions about technology and, more specifically, different assumptions about the path-independence of productivity change (see Hulten, 1973; Balk, 2003). For a comprehensive review of various approaches toward productivity measurement, see Balk (1998).

[24]This is the logarithmic version of double deflation of value-added as described in the SNA.

in the economy. The key feature of the PPF is the explicit role it provides for changes in the relative prices of components of output. In what follows, we shall employ a value-added based PPF.

We characterize a value-added based PPF as the efficient set of volume measures of value added, produced by the set of primary inputs labor and capital available in the economy.[25]

$$H\left(V_1, V_2, \ldots, V_{N_J}\right) = Z(L, K, t) \tag{19}$$

Expressions (4) and (8) provide the current-price accounting relationship in accordance with (19):

$$VA = \sum_{j=1}^{N_J} VA_j = P_L L + P_K K \tag{20}$$

If H and Z are approximated by translog functional forms, and assuming profit-maximizing behavior of producers, competitive markets, and constant returns to scale, the discrete-time equivalent to the shift in the production possibility frontier $\ln\rho = \delta \ln Z / \delta t$ can be represented by the difference between a translog index of the volume of value added and a translog index of the volume of labor and capital inputs. The resulting expression is a widely-used measure of economy-wide growth of multi-factor productivity, originally introduced by Jorgenson and Griliches (1967):

(21) $\ln\rho = \Delta\ln V - \bar{w}_L \Delta\ln L - \bar{w}_K \Delta\ln K$ where:

$\Delta\ln V = \sum_{j=1}^{N_J} \bar{w}_{VAj} \Delta\ln V_j$: share-weighted growth of industry value added,

$\Delta\ln K = \sum_{i=1}^{N_K} \bar{w}_{Ki} \Delta\ln K_i$: share-weighted growth of different types of capital,

$\Delta\ln L = \sum_{i=1}^{N_L} \bar{w}_{Li} \Delta\ln L_i$: share-weighted growth of different types of labor,

with:

$$\bar{w}_L \equiv 0.5\left(w_L^t + w_L^{t-1}\right), w_L^t \equiv \frac{P_L^t L^t}{VA^t}, P_L^t L^t = \sum_{i=1}^{N_L} P_{Li}^t L_i^t,$$

$P_{Lij}^t = P_{Li}^t$ for $i = 1, 2, \ldots N_L$ types of labor and $j = 1, 2, \ldots N_J$ industries,

$$\bar{w}_K \equiv 0.5\left(w_K^t + w_K^{t-1}\right), w_K^t \equiv \frac{P_K^t K^t}{VA^t}, P_K^t K^t = \sum_{i=1}^{N_K} P_{Ki}^t K_i^t,$$

$P_{Kij}^t = P_{Ki}^t$ for $i = 1, 2, \ldots N_K$ types of capital and $j = 1, 2, \ldots N_J$ industries,

[25]Assume $Z(L, K, t)$ is a positive, linear homogenous and convex function in L and K and assume that $H(V)$ is a positive aggregator function of different volumes of industry value-added.

$$\bar{w}_{VAj} \equiv 0.5\left(w_{VAj}^{t} + w_{VAj}^{t-1}\right) \text{ and } w_{VAj}^{t} \equiv \frac{VA_j^t}{VA^t} \quad \text{for } j = 1, 2, \ldots N_J \text{ industries,}$$

$$\bar{w}_{Ki} \equiv 0.5\left(w_{Ki}^{t} + w_{Ki}^{t-1}\right) \text{ and } w_{Ki}^{t} \equiv \frac{P_{Ki}^t K_i^t}{P_K^t K^t} \quad \text{for } i = 1, 2, \ldots N_K \text{ types of capital,}$$

$$\bar{w}_{Li} \equiv 0.5\left(w_{Li}^{t} + w_{Li}^{t-1}\right) \text{ and } w_{Li}^{t} \equiv \frac{P_{Li}^t L_i^t}{P_L^t L^t} \quad \text{for } i = 1, 2, \ldots N_L \text{ types of labor.}$$

We follow Jorgenson *et al.* (2005, ch. 8), and compute the economy-wide labor and capital shares w_L^t and w_K^t as well as the share-weighted growth of labor and capital input under the assumption of a single price for a particular type of input, independent of the industry in which it is used. This is tantamount to a top-down computation without any industry-specific information. The assumption of a single input price constitutes a benchmark, achievable under full mobility of factors in competitive factor markets. This benchmark can then be compared with input aggregates that allow for input-specific input prices, giving rise to a "reallocation" term. Importantly, the assumption of a single price does not carry over to the output side—the price of value added is allowed to vary across industries as there is no reason to assume that each industry produces the same type of value added. Indeed, the industry-specific price of value added is a central feature of Jorgenson's (1966) production possibility frontier.

When (18) is inserted into (21), we obtain the link between economy-wide productivity growth as defined through the value-added based production possibility frontier and industry-level gross output-based productivity growth:

$$\ln \rho = \sum_{j=1}^{N_J} \frac{\bar{w}_{VAj}}{\bar{v}_{VAj}} \ln \pi_j + REALL_L + REALL_K, \tag{22}$$

with

$$REALL_L = \sum_{j=1}^{N_J} \bar{w}_{VAj} \frac{\bar{v}_{Lj}}{\bar{v}_{VAj}} \Delta \ln L_j - \bar{w}_L \sum_{i=1}^{N_L} \bar{w}_{Li} \Delta \ln L_i,$$

$$REALL_K = \sum_{j=1}^{N_J} \bar{w}_{VAj} \frac{\bar{v}_{Kj}}{\bar{v}_{VAj}} \Delta \ln K_j - \bar{w}_K \sum_{i=1}^{N_L} \bar{w}_{Ki} \Delta \ln K_i.$$

Equation (22) is identical to expression (31) in Jorgenson *et al.* (2005, ch. 8), with three sources of economy-wide productivity growth and similar to the expression for value added-based productivity growth in Aulin-Ahmavaara and Pakarinen (2007). The first source is a weighted average of industry productivity growth rates. Each industry's productivity growth gets weighted by two coefficients: w_{VAj}, the industry share in total value added; and v_{VAj}, each industry's value-added

Corrections added on 12 December 2012 after initial online publication on 7 August 2012: some minor errors in the definitions following equation (21) have been corrected in this version of the article.

share in gross output. One divided by the other corresponds to the ratio of industry gross output to economy-wide value added, the set of Domar (1961) weights. These weights sum to more than unity and pick up the fact that productivity increase in an industry that delivers intermediate products to another industry has both direct and indirect effects on economy-wide productivity growth.

Two reallocation effects can also be identified through equation (22). They quantify the departure from the assumptions on inputs required for the production possibility frontier: the first item in the reallocation terms captures aggregate labor or capital input when aggregation is carried out across industries, allowing for industry-specific prices of labor or capital services. The second item is aggregate labor or capital input under the assumption of equal input prices across industries. The reallocation term will be positive if inputs grow quicker in those industries that pay higher prices for these inputs than other industries.

6. Total Economy and Industry-Level Productivity and the U.S. National Accounts

To illustrate the concepts presented in this paper we give prototype total-economy and industry-level production accounts for the U.S. National Income and Product Accounts (NIPAs) for the period 1947–2010. To simplify the presentation we focus on the value-added based production possibility frontier and industry-level gross-output-based productivity growth presented in (22) above.[26] We have sub-divided the time period at 1995 and 2000 to focus on the IT investment boom of 1995–2000, which ended with the dot-com crash of 2000.

We define the contribution of an industry to U.S. economic growth as the growth rate of real value added in the industry, weighted by the share of the industry in the GDP. Table 1 gives the contributions of nine major industry groups to economic growth during the period 1947–2010. Table 2 presents the underlying growth rates and shares in nominal value-added for all eight groups. The contributions of four of these groups increased during the IT investment boom of 1995–2000, relative to the period 1947–95, while the contributions of eight groups decreased during the period of slower growth following the dot-com crash of 2000.

The prices of capital inputs are essential for assessing the contribution of IT equipment and software to economic growth. This contribution is the relative share of IT equipment and software in the value of output, multiplied by the rate of growth of IT capital input. A substantial part of the growing contribution of capital input in the U.S. can be traced to the change in composition of investment associated with the growing importance of information technology. The contributions of college-educated and non-college-educated workers to U.S. economic growth is given by the relative shares of these workers in the value of output, multiplied by the growth rates of their hours worked.

Table 1 shows that the growth of productivity was far less important than the contributions of capital and labor inputs as sources of U.S. economic growth for

[26]This illustration employs the 65-sector classification of industries based on NAICS and presented in the NIPAs. A detailed breakdown of the IT-producing sectors is provided by Jorgenson *et al.* (2010). This is essential for analyzing the economic impact of information technology.

TABLE 1

Growth in Aggregate Value-Added and the Sources of Growth, United States Addregate Prodution Possibility Frontier, Average Annual Perentage Change

	1947–2010	1947–1973	1973–1995	1995–2000	2000–2005	2005–2010	1995–2010 Less 1947–1995
			Contributions				
Value-added	2.95	3.56	2.63	4.35	2.11	0.54	–0.80
Agriculture, forestry, fishing, hunting and mining	0.07	0.09	0.06	0.04	–0.03	0.09	–0.05
Transportation, warehousing, utilties	0.15	0.22	0.11	0.15	0.06	0.05	–0.08
Construction	0.07	0.18	0.03	0.16	–0.09	–0.30	–0.19
Manufacturing	0.65	1.05	0.41	0.91	0.20	–0.10	–0.42
Trade	0.52	0.58	0.50	0.95	0.32	0.00	–0.12
Information	0.19	0.16	0.21	0.21	0.37	0.09	0.04
Finance, insurance, real estate, rental and leasing	0.61	0.63	0.60	0.89	0.61	0.27	–0.03
Other services	0.51	0.40	0.55	0.96	0.59	0.37	0.17
Government	0.18	0.24	0.18	0.10	0.09	0.08	–0.13
Capital input	1.31	1.47	1.24	1.79	0.95	0.68	–0.23
IT capital	0.41	0.28	0.44	1.00	0.49	0.35	0.26
Non-IT capital	0.90	1.20	0.81	0.78	0.45	0.33	–0.49
Labor input	0.96	1.01	1.18	1.48	0.19	0.01	–0.53
Callege labor	0.59	0.46	0.80	0.86	0.34	0.38	–0.08
Non-college labor	0.37	0.56	0.38	0.62	–0.15	–0.37	–0.45
Aggregate TFP	0.67	1.07	0.21	1.09	0.98	–0.15	–0.04
			Quality and stock contributions				
Contribution of capital quality	0.39	0.49	0.33	0.75	0.20	0.03	–0.09
Contribution of capital stock	0.92	0.99	0.92	1.04	0.75	0.65	–0.14
Contribution of labor quality	0.33	0.38	0.29	0.24	0.25	0.38	–0.05
Contribution of labor hours	0.64	0.63	0.89	1.24	–0.06	–0.37	–0.48

Source: Jorgenson *et al*. (2012).

TABLE 2

Growth and Shares of Aggregate Variables, United States Aggregate Production Possibility Frontier, Average Annual Percentage Change

	1947–2010	1947–1973	1973–1995	1995–2000	2000–2005	2005–2010	1995–2010 Less 1947–1995
		Growth rates					
Value-added	2.95	3.56	2.63	4.35	2.11	0.54	–0.80
Agriculture, forestry, fishing, hunting, and mining	1.30	1.10	1.72	1.22	–1.11	2.98	–0.36
Transportation, warehousing, utilities	2.43	3.25	1.88	2.94	1.35	1.13	–0.82
Construction	1.49	3.97	0.70	3.56	–1.89	–6.55	–4.09
Manufacturing	3.06	4.18	2.28	5.88	1.68	–0.77	–1.04
Trade	4.28	4.63	4.22	8.37	2.98	–0.03	–0.67
Information	5.09	4.89	5.30	4.94	8.45	1.97	0.04
Finance, insurance, real estate, rental and leasing	3.79	4.53	3.56	4.42	2.85	1.26	–1.24
Other services	2.90	3.03	2.97	4.02	2.30	1.39	–0.44
Government	1.28	1.68	1.23	0.73	0.69	0.58	–0.81
Capital input	3.71	4.16	3.57	5.03	2.63	1.78	–0.74
IT capital	15.51	18.07	15.16	19.65	8.77	6.30	–5.17
Non-IT capital	2.73	3.52	2.51	2.58	1.49	1.02	–1.36
Labor input	1.49	1.58	1.80	2.29	0.30	0.03	–0.81
College labor	3.45	3.94	3.94	3.15	1.16	1.27	–2.08
Non-college labor	0.76	1.07	0.90	1.66	–0.42	–1.20	–0.98
		Shares					
Value-added	100.0	100.0	100.0	100.0	100.0	100.0	0.0
Agriculture, forestry, fishing, hunting, and mining	4.9	6.7	4.3	2.4	2.3	2.9	–3.1
Transportation, warehousing, utilities	6.0	6.9	5.9	5.1	4.6	4.5	–1.7
Construction	4.6	4.7	4.5	4.5	4.9	4.5	0.0
Manufacturing	20.4	25.4	19.0	15.5	13.1	12.1	–8.9
Trade	11.9	12.7	11.8	11.3	10.7	10.1	–1.6
Information	3.7	3.2	4.0	4.3	4.4	4.4	0.8
Finance, insurance, real estate, rental and leasing	16.7	13.9	17.2	20.0	21.4	21.4	5.5
Other services	17.8	12.8	18.6	23.8	25.5	26.7	9.8
Government	14.0	13.8	14.7	13.3	13.2	13.5	–0.9
Capital input	35.5	35.4	34.9	35.5	36.0	38.2	1.4
IT capital	2.9	1.3	2.9	5.1	5.6	5.5	3.3
Non-IT capital	32.7	34.1	32.0	30.5	30.4	32.7	–1.9
Labor input	64.5	64.6	65.1	64.5	64.0	61.8	–1.4
College labor	19.2	11.8	21.0	27.4	29.7	30.7	13.2
Non-college labor	45.3	52.7	44.1	37.1	34.2	31.1	–14.6

Source: Jorgenson *et al*. (2012).

the period 1947–2010. Productivity growth accounts for about 20 percent of U.S. economic growth, somewhat higher than the 15 percent of growth for 1945–65 estimated by Jorgenson and Griliches (1967). The contribution of capital input accounts for 45 percent of growth during the period 1947–2010, while labor input accounts for 33 percent.

In the Domar (1961) weighting scheme the productivity growth rate of each industry is weighted by the ratio of the industry's gross output to aggregate value added. A distinctive feature of Domar weights is that they sum to more than one, reflecting the fact that an increase in the rate of growth of the industry's productivity has two effects. The first is a direct effect on the industry's output and the second an indirect effect via the output delivered to other industries as intermediate inputs. The rate of growth of aggregate productivity also depends on the reallocations of capital and labor inputs among industries.

Table 3 gives the decomposition of the rate of growth of productivity presented in Table 1. The Domar-weighted sum of industry productivity growth rates for the period 1947–2010 is 0.67 percent, the same as the aggregate productivity growth rate in Table 1. Reallocation effects of capital input contribute positively but by a small amount to aggregate productivity growth, whereas the reallocation effect of labor input is about zero for the period as a whole. We conclude that the industry-level rates of productivity growth are the main sources of aggregate productivity growth over long periods of time, as shown by Jorgenson *et al*. (1987, ch. 9). For the relatively short sub-periods of 1995–2000 and 2000–10, the reallocations are quantitatively more significant and are not mutually offsetting.

Table 4 gives contributions of the 65 individual industries to aggregate value added, using value-added weights, and productivity growth for the total economy, using Domar weights. Real estate, wholesale trade, and retail trade are the largest contributors to value added, reflecting their large shares in value added. The computer and electronic products industry is a major contributor to both value added and productivity growth, despite its relatively modest share in value added and its small Domar weight.

7. Conclusions

By recognizing capital services as an integral element, the 2008 SNA has cleared the way to the incorporation of productivity into systems of national accounts. This resolves long-standing controversies and has led to a very significant convergence of views. The OECD (2009) manual on *Measuring Capital* provides detailed methodology for the construction of measures of capital services, using data available from the national accounts. This complements the OECD (2001) manual on *Measuring Productivity*, presenting the methodology for constructing productivity statistics at the industry and economy-wide levels.

Incorporation of industry-level and total economy measures of productivity into the national accounts has the advantages of international standardization that have long accrued to measures of output and income. Statistical offices, led by Canada and The Netherlands and including Australia, Belgium, Denmark, Finland, and Italy, are producing industry-level and total-economy estimates of productivity within the framework of the national accounts. Standardization rests

TABLE 3

Decomposition of Aggregate Productivity Growth, United States Average Annual Percentage Change

	1947–2010	1947–1973	1973–1995	1995–2000	2000–2005	2005–2010	1995–2010 Less 1947–1995
Aggregate production possibility frontier vs. direct aggregation across industries							
Aggregate TFP	0.67	1.07	0.21	1.09	0.98	–0.15	–0.04
Domar-weighted productivity	0.63	0.98	0.18	1.20	0.90	–0.05	0.07
Agriculture, forestry, fishing, hunting, and mining	0.04	0.10	0.00	0.05	–0.01	0.03	–0.03
Transportation, warehousing, utilities	0.07	0.15	0.00	0.05	0.04	0.02	–0.04
Construction	–0.02	0.08	–0.05	–0.05	–0.19	–0.16	–0.15
Manufacturing	0.35	0.46	0.21	0.59	0.47	0.02	0.01
Trade	0.24	0.25	0.21	0.60	0.18	–0.01	0.03
Information	0.05	0.03	0.05	–0.11	0.33	0.07	0.06
Finance, insurance, real estate, rental and leasing	0.09	0.09	0.01	0.23	0.17	0.21	0.15
Other services	–0.11	–0.03	–0.21	–0.09	–0.02	–0.12	0.04
Government	–0.09	–0.14	–0.03	–0.05	–0.07	–0.10	0.02
Reallocation of capital input	0.04	0.02	0.11	–0.05	0.03	–0.09	–0.10
Reallocation of labor input	0.00	0.07	–0.08	–0.07	0.04	0.00	–0.01

Notes: The contribution of an output or input is the growth rate multiplied by the average value share. Domar weights are the ratio of gross output over value-added.

Source: Jorgenson *et al*. (2012).

TABLE 4

Industry Contributions to Aggregate Value-Added and TFP Growth, United States 1947–2010

	Value-Added			Productivity		
	V-A Weight	V-A Growth	Contribution to Aggregate V-A	Domar Weight	TFP Growth	Contribution to Aggregate TFP
Farms	0.027	2.56	0.060	0.053	1.68	0.090
Forestry fishing and related activities	0.003	1.47	0.005	0.007	–0.80	–0.006
Oil and gas extraction	0.011	–0.49	–0.001	0.018	–1.72	–0.035
Mining except oil and gas	0.006	0.51	–0.003	0.012	0.28	–0.002
Support activities for mining	0.002	2.57	0.005	0.006	0.05	–0.002
Utilities	0.021	2.66	0.052	0.036	0.22	0.000
Construction	0.046	1.49	0.066	0.106	–0.21	–0.019
Wood products	0.004	1.47	0.007	0.014	0.45	0.005
Nonmetalic mineral products	0.007	1.05	0.012	0.014	0.24	0.004
Primary metals	0.014	–1.37	–0.008	0.040	–0.32	–0.017
Fabricated metal products	0.017	1.57	0.033	0.040	0.31	0.013
Machinery	0.019	2.58	0.057	0.038	0.41	0.013
Computer and electronic products	0.015	13.69	0.223	0.037	4.44	0.190
Electrical equipment applicances and comp	0.008	0.29	0.005	0.017	–0.53	–0.011
Motor vehicles bodies and trailers and part	0.016	1.82	0.048	0.059	0.30	0.020
Other transportation equipment	0.012	1.43	0.024	0.028	0.02	0.000
Furniture and related products	0.004	1.81	0.009	0.009	0.70	0.006
Miscellaneous manufacturing	0.006	4.27	0.026	0.015	1.18	0.018
Food and beverage and tobacco products	0.022	1.10	0.036	0.096	0.07	0.017
Textil mills and textile product mills	0.007	2.16	0.022	0.022	1.12	0.026
Apparel and leather and allied products	0.008	0.45	0.019	0.024	0.74	0.020
Paper products	0.009	1.58	0.019	0.024	0.14	0.003
Printing and related support activities	0.005	1.84	0.011	0.013	0.31	0.004
Petroleum and coal products	0.006	7.18	0.024	0.034	0.60	0.012
Chemical products	0.019	3.36	0.066	0.049	0.44	0.018
Plastics and rubber products	0.007	3.40	0.026	0.016	0.41	0.007
Wholesale trade	0.051	5.46	0.282	0.073	1.67	0.122
Retail trade	0.068	3.39	0.234	0.109	1.04	0.114
Air transportation	0.004	9.27	0.032	0.010	2.13	0.017
Rail transportation	0.010	–0.56	–0.009	0.015	1.17	0.020
Water transportation	0.001	4.70	0.006	0.005	1.33	0.005
Truct transportation	0.010	4.47	0.043	0.019	1.12	0.021
Transit and ground passenger transportation	0.003	–0.49	–0.006	0.005	–0.24	–0.003
Pipeline transportation	0.001	4.48	0.005	0.003	1.12	0.003

Table 4 continued on next page

TABLE 4 (*continued*)

	Value-Added			Productivity		
	V-A Weight	V-A Growth	Contribution to Aggregate V-A	Domar Weight	TFP Growth	Contribution to Aggregate TFP
Other transportation and support activities	0.007	2.23	0.017	0.011	0.41	0.005
Warehousing and storage	0.002	3.57	0.009	0.003	1.15	0.003
Publishing industries (includes software)	0.009	4.73	0.042	0.019	0.76	0.016
Motion picture and sound recording industration	0.004	1.51	0.003	0.006	–0.42	–0.004
Broadcasting and telecommunications	0.022	6.00	0.131	0.035	1.38	0.045
Information and data processing services	0.003	4.67	0.015	0.005	–1.11	–0.003
Federal reserve banks credit intermediation	0.026	3.83	0.093	0.042	–0.81	–0.035
Securities commodity contracts and inverstr	0.006	8.56	0.068	0.013	1.02	0.034
Insurance carriers and related activities	0.019	3.66	0.064	0.036	–0.34	–0.011
Funds trusts and other financial vehicles	0.001	1.12	0.001	0.005	–0.83	–0.005
Real estate	0.105	3.32	0.339	0.137	1.01	0.133
Rental and leasing services and lessors of in	0.010	4.45	0.043	0.014	–1.82	–0.027
Legal services	0.010	2.72	0.021	0.014	–1.29	–0.020
Computer systems design and related serviced	0.005	6.57	0.035	0.007	–0.75	0.001
Miscellaneous professional scientific and te	0.025	4.65	0.104	0.038	0.27	–0.003
Management of companies and enterprises	0.015	2.35	0.034	0.023	–0.60	–0.015
Administrative and support services	0.014	5.17	0.065	0.021	0.22	0.005
Waste management and remediation services	0.002	3.90	0.008	0.005	0.70	0.003
Educational services	0.007	3.04	0.019	0.012	–0.53	–0.007
Ambulatory health care services	0.021	3.58	0.071	0.032	–0.39	–0.012
Hospitals nursing and residential care factilture	0.019	2.92	0.046	0.031	–1.04	–0.031
Socia assistance	0.003	5.84	0.014	0.005	1.00	0.002
Performing arts spectator sports muserums a	0.003	3.39	0.010	0.006	0.60	0.003
Amusements gambling and recreation indus	0.004	2.90	0.011	0.006	0.07	–0.001
Accommodation	0.007	3.32	0.022	0.011	0.73	0.007
Food services and drinking places	0.016	0.56	0.009	0.037	–0.50	–0.020
Other services except government	0.027	1.48	0.041	0.043	–0.36	–0.016
Federal general government	0.053	–0.05	–0.010	0.086	–0.57	–0.054
Federal government enterprises	0.007	0.72	0.006	0.009	–0.35	–0.002
S&L government enterprises	0.007	1.77	0.013	0.013	–1.29	–0.014
S&L general government	0.073	2.67	0.176	0.102	–0.08	–0.017
Sum	1.000		2.945	1.887		0.631

Notes: Growth rates are average annual rates of change. The contribution of an output or input is the growth rate multiplied by the average value share. Domar weights are the ratio of gross output over value-added.

Source: Jorgenson *et al*. (2012).

on an extensive body of conceptual and empirical research. We have contributed to this effort by setting out a system of productivity accounts within the framework of the 2008 SNA.

Jorgenson *et al.* (2010), the EU (European Union) KLEMS (capital, labor, energy, materials, and services) project described by Timmer *et al.* (2010), Jorgenson *et al.* (2007), and the studies presented in Jorgenson (2009a) have presented industry-level data on productivity within the framework of national accounts. The EU KLEMS study was completed in June 2008. This landmark study presents productivity measurements for 25 of the 27 EU members, as well as Australia, Canada, Japan, and Korea, and the U.S.[27] Efforts are underway to extend the EU KLEMS framework to important developing and transition economies, including Argentina, Brazil, Chile, China, India, Indonesia, Mexico, Russia, Turkey, and Taiwan.[28]

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[27]For current information on the participating countries, see the EU KLEMS website at http://www.euklems.net/.

[28]Additional information is available on the World KLEMS website at http://www.worldklems.net/.

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