INDUSTRY-LEVEL PRODUCTIVITY MEASUREMENT AND THE NATIONAL ACCOUNTS

by
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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 acknowledged the link to productivity measures but in a cursory way only and with reference to measures of labour 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 labour 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 labour (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 recognising capital services as an integral element in the new system of national accounts, thereby opening the way for fully articulated sets of output, input and productivity statistics[2].

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, Gollop, and Fraumeni (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

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[2] 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.

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, Gollop, and Fraumeni (1987) provide the framework for industry-level productivity accounts and their link to aggregate measures of productivity change. Fraumeni, Harper, Powers, and Yuscavage (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, Moyer, Okubo, and Planting (2006), and Moyer, Reinsdorf, and Yuskavage (2006). Donahoe, Morgan, Muck, and Stewart (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 adds to it in two ways. First, we set 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. Since we limit ourselves to the boundaries and conventions of the 2008 SNA, this puts us at variance with Jorgenson and Landefeld's (2006) prototype accounting system in the treatment of consumer durables and in capital service measures for government-owned assets.

Our second contribution consists in linking and interpreting two variants of Jorgenson's (1966) production possibility frontier. We show how aggregate productivity measures defined under both variants relate to each other and to measures of industry-level productivity growth. A particular point in this context, noted by other authors as well, arises from the existence of taxes on products that drive a wedge between the total value of outputs and the total value of inputs. We deal with this wedge by treating taxes as the price of a fixed input and show how it can be taken into the account in the de-composition of economy-wide productivity growth.

The Canadian Productivity Accounts, published by Statistics Canada, provide a leading example of productivity accounts integrated with a system of national accounts.[3] The industry accounts are based on NAICS and incorporate a time series of input-output tables for the period 1961-2007. The input-output tables are integrated with the expenditure side of the Canadian System of National Accounts[4] and these tables are consistent with measures of capital and labour inputs, as well as multifactor productivity.[5] Since 2007 Statistics Netherlands has published a system of industry-level productivity accounts that is integrated with system of national accounts for The Netherlands.[6] Statistical agencies in Australia, Belgium, Denmark, Finland, and Italy also publish industry-level productivity statistics within the framework of the national accounts.

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[3] See Baldwin, Gu, and Macdonald (2010) for a recent summary of the Canadian Productivity Accounts.

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

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

[6] See van der Bergen, van Rooijen-Horsten, de Haan, and Balk (2010).

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 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, 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, 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 taxes that are raised on production. Intermediate inputs can either be purchased 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] is then presented as:

$$P_jQ_j = \tilde{P}_jX_j + VA_j \quad \text{with } j = 1,2,...N_J \text{ industries and} \tag{1}$$

$$P_jQ_j \equiv \sum_i^{N_I} P_{ij}Q_{ij}$$

$$\tilde{P}_jX_j \equiv \sum_i^{N_I} \tilde{P}_{ij}X_{ij}$$

$$VA_j \equiv CE_j + GOS_j + MI_j + TP_j$$

where

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

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

X_{ij}: Quantity (volume) of product i used in industry j

$\tilde{P}_{ij}$: Purchasers' price of product i produced in industry j

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 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 a measure of primary income that combines labour income, property income and taxes on production. A crucial step in the development of productivity measures will be the

[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'.

decomposition of these income components into a price and a quantity or volume component, of which more later.

Supply-use tables: accounting relationships across industries and products

The above accounting relationships can be brought together in supply-use tables (also called make-use tables). Today, an increasing number of countries use supply-use tables as the organising 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 industry produces which products, 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 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 $Q_{M,i}$ at prices $P_{M,i}$ to characterise total supply for each type of product[9], the sum of each row of the supply matrix. Each industry's total production is given by the sum of each column of the supply matrix

$$\text{Total domestic supply of product i at basic prices} = \sum_{j=1}^{N_J} P_{ij}Q_{ij};\ i = 1,2,...N_I \text{ products} \quad (2)$$

$$\text{Imports: supply from abroad at basic prices (c.i.f.)} = \sum_{i=1}^{N_I} P_{Mi}Q_{Mi}$$

$$\text{Total domestic supply by industry j at basic prices} = \sum_{i=1}^{N_I} P_{ij}Q_{ij};\ j = 1,2,...N_J \text{ industries}$$

It was mentioned earlier that output (and therefore supply) of products are 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, 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 on products 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 taxes on products $\{T_i\}$, transportation margins are only re-allocated across industries and their sum remains zero.

The use table 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 to other industries and final demand (consumption, investment and exports), denoted $\{FD_i\}$ in equation (3) below.

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[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.

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

Each column in the use matrix further reproduces the industry-level production account as in equation in (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 at basic prices is the sum over industry value added at basic prices. In turn, GDP at basic prices equals final demand at purchasers' prices minus the value of imports minus net taxes on products.

Gross output minus intermediate inputs	$\sum_{i=1}^{N_I}\sum_{j=1}^{N_J} P_{ij}Q_{ij} - \sum_{i=1}^{N_I}\sum_{j=1}^{N_J} \tilde{P}_{ij}X_{ij}$	(4)
= Value added (GDP) at basic prices	$=\sum_{j=1}^{N_J} VA_j$	
= Final demand minus imports minus net taxes	$=\sum_{i=1}^{N_I} FD_i - \sum_{i=1}^{N_I} P_{Mi}Q_{Mi} - \sum_{i=1}^{N_I} T_i$	

Figure 1 Supply and use tables

		Industry				Total supply from domestic production	Imports	Taxes on products	Trade and transport margins	Total supply at purchasers' prices
		1	2	…	N_J					
	1					$\sum_{j=1}^{N_J} P_{1,j}Q_{1,j}$	$P_{M,1}Q_{M,1}$	T_1	TM_1	$\sum_{j=1}^{N_J} P_{1,j}Q_{1,j} + P_{M,1}Q_{M,1} + T_1 + TM_1$
	2									
Product	.		$\{P_{ij}Q_{ij}\}$							
	.									…
	.									
	N_I					$\sum_{j=1}^{N_J} P_{N_J,j}Q_{N_J,j}$	$P_{M,Nj}Q_{M,Nj}$	T_{NI}	TM_{NI}	$\sum_{j=1}^{N_J} P_{N_I,j}Q_{N_I,j} + P_{M,N_I}Q_{M,N_I} + T_{N_I} + TM_{N_I}$
Gross output		$P_1Q_1 = \sum_{i=1}^{N_I} P_{i,1}Q_{i,1}$			$P_{N_J}Q_{N_J} = \sum_{i=1}^{N_I} P_{i,N_J}Q_{i,N_J}$		$P_MQ_M = \sum_{i=1}^{N_I} P_{M,i}Q_{M,i}$		0	$\sum_{i=1}^{N_I}\sum_{j=1}^{N_J} P_{ij}Q_{ij} + P_{M,i}Q_{M,i} + T_i + TM_i$

	Total supply at purchasers' prices		Deliveries to Industry				Deliveries to final demand
			1	2	…	N_I	
	$\sum_{j=1}^{N_J} P_{i1}Q_{i1} + P_{M1}Q_{M1} + T_1 + TM_1$	1					FD_1
		2					
Product		.		$\{\tilde{P}_{ij}X_{ij}\}$			
	…	.					
		.					
	$\sum_{j=1}^{N_J} P_{N_I,j}Q_{N_I,j} + P_{M,N_I}Q_{M,N_I} + T_{N_I} + TM_{N_I}$	N_J					FD_{NI}
	$\sum_{i=1}^{N_I}\sum_{j=1}^{N_J} P_{ij}Q_{ij} + P_{M,i}Q_{M,i} + T_i + TM_i$	Intermediate inputs	$\sum_{i=1}^{N_I}\tilde{P}_{i,1}X_{i,1}$			$\sum_{i=1}^{N_I}\tilde{P}_{i,N_J}\tilde{X}_{i,N_J}$	
		Value-added:	VA_1			VA_{NJ}	
		Compensation of employees	CE_1	…		CE_{NJ}	
		Gross operating surplus	GOS_1	…		GOS_{NJ}	
		Mixed income	MI_1	…		MI_{NJ}	
		Taxes on production	TP_1	…		TP_{NJ}	
		Gross output	P_1Q_1			$P_{NJ}Q_{NJ}$	

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 and 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^t that relates the aggregate volume of industry output Q_j to labour input L_j, capital input K_j and intermediate inputs X_j. More specifically, f_j^t is the maximum output Q_j producible in period t, given a set of labour, capital and intermediate inputs:

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

The volume of output Q_j is itself a function g_j of the various products produced by industry j: $Q_j = g_j(Q_{1j}, Q_{2j}, ... Q_{N_I j})$. More specifically, if g_j is the minimum amount of aggregate input[10] required to produce the vector of outputs $(Q_{1j}, Q_{2j}, ... Q_{N_I j})$, the set of efficient production possibilities at the industry level can be represented as

[10] For the mathematical properties of this factor requirements function see Diewert (1976).

$$g_j(Q_{1j}, Q_{2j}, ..., Q_{N_1 j}) = f_j^t(L_j, K_j, X_j) \text{ for } j=1,2,...N_J \text{ industries.} \quad (6)$$

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.

Output

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 price index 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[11]. 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[12], 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 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

$$\Delta \ln Q \equiv \ln\left(\frac{g_j(Q_{1j}^t, Q_{2j}^t, ..., Q_{N_1 j}^t)}{g_j(Q_{1j}^{t-1}, Q_{2j}^{t-1}, ..., Q_{N_1 j}^{t-1})}\right) = \sum_{i=1}^{N_1} \bar{s}_{Qij} \Delta \ln Q_{ij} \quad \text{for } j=1,2,...N_J \text{ industries} \quad (7)$$

where $\bar{s}_{ij} \equiv 0.5\left(s_{ij}^t + s_{ij}^{t-1}\right)$ and $s_{ij}^t \equiv \dfrac{P_{ij}^t Q_{ij}^t}{P_j^t Q_j^t}$.

The aggregation weights s_{ij}^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 maximising behaviour 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.[13] Using translog formulae raises, however, an issue of consistency with current national accounts

[11] Note 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 in Chapter 18 of IMF (2004). A similar treatment with an emphasis on foreign trade can be found in Chapter 20 of IMF (2009).

[12] 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.

[13] The translog functional form was introduced by Christensen, Jorgenson, and Lau (1973).

practice: in concept, both the 1993 and the 2008 SNA favour the use of superlative index numbers the focus in the SNA is on the Fisher Ideal Index rather than on the translog or 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 *uses* 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-1weights 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.

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 taxes on production. While compensation of employees is without doubt a payment for labour services, and while gross operating surplus will largely or entirely reflect payment for capital services, this is less clear for mixed income and for taxes on production. Mixed income being essentially the income of self-employed persons, some of it will be compensation of labour 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[14]. Similarly, taxes on production have to be allocated to either labour 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 pay-roll tax would be allocated to compensation of employees) but in some cases the allocation will remain somewhat arbitrary.

Consideration has also to be given to gross operating surplus. A case can be made to assume that all of GOS is remuneration for capital services but a case can also be made to split GOS up into remuneration for capital and into residual or windfall profit or loss, in particular if markets are not taken as fully competitive[15]. For the present exposition we shall assume that GOS plus any added values from mixed income and from taxes on production exactly equal remuneration of capital services.

In terms of the notation adopted earlier, we shall denote the value of total labour input in industry j as $W_jL_j=CE_j+\alpha_jMI_j+\beta_jTP_j$ where α_j is the share of mixed income that has been allocated to labour and where β_j is the share of net taxes on production that has been allocated to labour. Similarly, we shall denote the value of total capital services in industry j as $P_{K,j}K_j= GOS_j+(1-\alpha_j)MI_j+(1-\beta_j)TP_j$. It follows that value added at basic prices in industry j corresponds to the sum of labour and capital income:

$$VA_j = P_{L_j}L_j + P_{Kj}K_j \text{ for } j=1,2,...N_J \text{ industries.} \qquad (8)$$

[14] See, for example Jorgenson, Ho, and Stiroh (2005), Chapter 6, or OECD (2001).

[15] For a discussion, see OECD (2009), Diewert and Nakamura (2007) or Schreyer (20XX).

In (8), P_{Lj} stands for the price of labour input L_j, and $P_{K,j}$ stands for the price of the flow of capital services K_j. VA_j was introduced earlier and denotes current-price value added in industry j. Total costs in industry j are the sum of primary inputs and intermediate inputs and they equal the value of gross output:

$$P_jQ_j = P_{Lj}L_j + P_{Kj}K_j + \tilde{P}_{Xj}X_j \equiv TC_j \text{ for j=1,2,...}N_J \text{ industries} \quad (9)$$

Volume of intermediate inputs

Intermediate inputs are an industry's purchase of outputs from other industries. In our supply-use framework they correspond to cell entries $\tilde{P}_{ij}X_{ij}$ for each of the i=1,2,..N_I products and j=1,2,..N_J industries. Intermediate inputs as well as primary inputs are valued at purchaser's 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[16]. 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 $X_j=X_j(X_{1j},X_{2j},...X_{NI,j})$ purchased by industry j and apply the same reasoning as in the case of output aggregation[17] to obtain a translog index of intermediate inputs:

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

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

Volume of labour input

Neither capital nor labour are homogenous inputs, and measuring labour input by simply adding hours worked ignores differences in labour quality that arise as a consequence of education, skills, or work experience.[18] L_j should therefore be understood as an aggregator across N_L different types of labour: $L_j=L_j(L_{1j}, L_{2j}, ...L_{NL,j})$ and the total value of compensation as the sum of compensation across different types of labour: $P_{Lj}L_j = \sum_{i=1}^{N_L} P_{Lij}L_{ij}$. Here, P_{Lij} is the hourly compensation of the i-th type of labour 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 labour input can be measured as a translog index of the volume changes of different types of labour input:

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

[16] See Jorgenson, Gollop and Fraumeni (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, Ho, and Stiroh (2005), Chapter 4.

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

[18] See Jorgenson, Gollop, and Fraumeni (1987), Chapters 3 and 8, and Jorgenson, Ho, and Stiroh (2005), Chapter 6.

where $\bar{s}_{L,ij} \equiv 0.5\left(s_{L,ij}^{t} + s_{L,ij}^{t-1}\right)$ and $s_{L,ij}^{t} \equiv \frac{P_{Lij}^{t} L_{ij}^{t}}{P_{Lj}^{t} L_{j}^{t}}$.

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

Volume of capital input

For a long time national accounting standards treated labour and capital differently – there was explicit recognition of a price and quantity of labour 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. Akin to labour input, it is recognised 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 stocks: $K_j=K_j(K_{1j}, K_{2j}, ...K_{NK,j})$ 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 output aggregation, the quantity change of capital input can be measured as a translog index of the volume changes of different types of capital input:

$$\Delta \ln K_j = \sum_{i=1}^{N_K} \bar{s}_{Kij} \Delta \ln K_{ij} \qquad \text{for j=1,2,...}N_J \text{ industries} \qquad (12)$$

where $\bar{s}_{K,ij} \equiv 0.5\left(s_{K,ij}^{t} + s_{K,ij}^{t-1}\right)$ and $s_{K,ij}^{t} \equiv \frac{P_{Kij}^{t} K_{ij}^{t}}{P_{Kj}^{t} K_{j}^{t}}$.

We shall only briefly dwell on the main features of capital measurement, for more detail, the reader is referred to Hulten (1990), Jorgenson, Ho, and Stiroh (2005), Chapter 5, OECD (2009), SNA 2008 (2009), Chapter 20, or Diewert and Schreyer (2009). The first question 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) can be interpreted as an 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[19]. For a sector not subject to either direct or indirect taxes, a common specification for the capital service price P_K^t is:

$$P_{Kij}^{t} = \widetilde{P}_{ij}^{t}\left(r_j^t + \delta_{ij}(1+i_{ij}^t) - i_{ij}^t\right) \quad \text{for asset type i and j=1,2,...}N_J \text{ industries,} \qquad (13)$$

where $\widetilde{P}_{ij}^{t}$ is the purchaser's price, at the beginning of period t, of a new asset of type i acquired by industry j, r_j^t 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 $i_{ij}^t \equiv \widetilde{P}_{ij}^{t+1} / \widetilde{P}_{ij}^{t}$ is the rate of inflation in the acquisition price of new capital goods between the beginning and the end of period t. Service prices for each class of assets held by each industry comprise machinery, equipment, residential and nonresidential structures, land and several other types of natural resources (see the discussion on 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^t (and the expected rate of asset price change i_{ij}^t if (13) is interpreted as an *ex-ante* term). OECD (2009) provides 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^t after equating the remuneration of capital with gross operating surplus and the capital part of mixed income:

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

Note two complications 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. Concerning capital remuneration, no observable measure of gross operating surplus exists so r_j^t cannot be computed as in (14). Jorgenson and Landefeld (2006), Jorgenson and Yun (2001) and OECD (2009) show alternatives for dealing with this complication. A second, more serious issue arises from the fact that the 2008 SNA recognizes capital services for assets owned by market producers but not by non-market producers. Capital costs for government producers are solely measured as the value of depreciation, thus ignoring that part of costs of capital services that reflect the opportunity costs of capital and revaluation: $\sum_{i=1}^{N_K} \widetilde{P}_{ij}^{t}\left(r_j^t - i_{ij}^t\right) K_{ij}^t$. The asymmetric treatment of assets used in market and in non-market production results either in an incomplete estimate of capital inputs or in a deviation from national accounts conventions.

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. For mainly practical reasons, this production is 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

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

Industry-level productivity measures

Having dealt with the measurement of aggregates of inputs and outputs, it is now only a short step towards 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 between periods t and t-1, given a reference set of inputs:

$$\pi_j = f_j^t(K_j, L_j, X_j) / f_j^{t-1}(K_j, L_j, X_j) \qquad \text{for j=1,2,...N}_J \text{ industries.} \tag{15}$$

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 minimisers and revenue maximisers under competitive conditions, an exact representation of (15) is the Törnqvist or translog productivity index:

$$\ln \pi_j = \Delta \ln Q_j - \bar{v}_{Kj} \Delta \ln K_j - \bar{v}_{Lj} \Delta \ln L_j - \bar{v}_{Xj} \Delta \ln X_j \qquad \text{for j=1,2,...N}_J \text{ industries.} \tag{16}$$

with $\bar{v}_{Kj} \equiv 0.5\left(v_{kj}^t + v_{kj}^{t-1}\right), \bar{v}_{Lj} \equiv 0.5\left(v_{Lj}^t + v_{Lj}^{t-1}\right); \bar{v}_{Xj} \equiv 0.5\left(v_{Xj}^t + v_{Xj}^{t-1}\right)$ and

$$v_{kj}^t \equiv \frac{P_{Kj}^t K_j^t}{P_j^t Q_j^t};\ v_{Lj}^t \equiv \frac{P_{Lj}^t L_j^t}{P_j^t Q_j^t};\ v_{Xj}^t \equiv \frac{\tilde{P}_{Xj}^t X_j^t}{P_j^t Q_j^t}.$$

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[20]. 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 de-composition of the volume index of gross output into a volume index of value added and a volume index of intermediate inputs:

$$\Delta \ln Q_j = \bar{v}_{VAj} \Delta \ln V_j + \bar{v}_{Xj} \Delta \ln X_j \ \text{ or} \tag{17}$$

$$\Delta \ln V_j = \frac{1}{\bar{v}_{VAj}} \Delta \ln Q_j - \frac{\bar{v}_{Xj}}{\bar{v}_{VAj}} \Delta \ln X_j$$

with $\bar{v}_{VAj} \equiv 0.5\left(v_{VAj}^t + v_{VAj}^{t-1}\right)$ and $v_{VAj}^t \equiv \dfrac{VA_j^t}{P_j^t Q_j^t}$ for j=1,2,...N_J industries.

Expressions (16) and (17) can now be combined to yield a de-composition of the rate of growth of real value added in industry j:

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

[20] 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).

Total economy productivity measures

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 of final demand products (consumption, investment, exports) to the set of inputs available in the economy. The key feature of the PPF is the explicit role it provides for changes in the relative prices of final demand components. In what follows, we shall present two types of the PPF, each corresponding to somewhat different assumptions about the economy's technology.

Value-added based production possibility frontier

We characterise a value-added based PPF as the efficient set of volume measures of value added, produced by the set of primary inputs labour and capital available in the economy:

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

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^t are approximated by translog functional forms, and assuming profit-maximising behaviour of producers, competitive markets and constant returns to scale, the shift in the value-added based production possibility frontier $\rho = Z^t(L,K)/Z^{t-1}(L,K)$ is exactly represented by the difference between a translog index of the volume of value added and a translog index of the volume of labour 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):

$$\ln\rho = \Delta\ln V - \overline{w}_L \Delta\ln L - \overline{w}_K \Delta\ln K \text{ where} \tag{21}$$

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

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

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

with

$\overline{w}_L \equiv 0.5\left(w_L^t + w_L^{t-1}\right)$, $w_L^t \equiv \frac{P_L^t L^t}{VA^t}$, $P_L L = \sum_{i=1}^{N_L} P_{Li} L_i$, $P_{Lij} = P_{Li}$ for j=1,2,...N_I industries

$\overline{w}_K \equiv 0.5\left(w_K^t + w_K^{t-1}\right)$, $w_K^t \equiv \frac{P_K^t K^t}{VA^t}$, $P_K K = \sum_{i=1}^{N_K} P_{Ki} K_i$ $P_{Kij} = P_{Ki}$ for j=1,2,...N_I industries

$\overline{w}_{VAj} \equiv 0.5\left(w_{VAj}^t + w_{VAj}^{t-1}\right)$ and $w_{VAj}^t \equiv \frac{VA_j^t}{VA^t}$ for j=1,2,...N_I industries,

$\overline{w}_{Ki} \equiv 0.5\left(w_{Ki}^t + w_{Ki}^{t-1}\right)$ and $w_{Ki}^t \equiv \frac{P_{Ki}^t K_i^t}{VA^t}$ for i=1,2,...N_K types of capital,

$\overline{w}_{Li} \equiv 0.5\left(w_{Li}^t + w_{Li}^{t-1}\right)$ and $w_{Li}^t \equiv \frac{P_{Li}^t L_i^t}{VA^t}$ for i=1,2,...N_L types of labour.

We follow Jorgenson, Ho and Stiroh (2005), Chapter 8, and compute the economy-wide labour and capital shares w_L^t and w_K^t as well as the share-weighted growth of labour 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. Below this benchmark will 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:

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

with

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

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

Equation (22) is identical to expression (31) in Jorgenson, Ho, and Stiroh (2005), Chapter 8, with three sources of economy-wide productivity growth. 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 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 labour or capital input when aggregation is carried out across industries, allowing for industry-specific prices of labour or capital services. The second item is aggregate labour 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.

Final products-based production possibility frontier

An alternative path towards characterising technology in the economy is to define the PPF as the efficient set of the volume of final products, produced by primary inputs labour and capital as well as by imports available in the economy. Note the symmetry of this set-up with our specification of the industry-level production technology: in both cases, output is understood as deliveries of products to units outside the 'sector', and input is understood as all purchases of products and primary factors of production entering the 'sector'. For the economy as a whole, output is the set of final products $\{Q_{FD}\}$, composed of consumption goods and services, investment goods and exports. Inputs comprise labour, capital and imports.

$$h(Q_{FD1}, Q_{FD2}, ..., Q_{FD,N_J}) = z^t(L, K, Q_M) \tag{23}$$

To derive the accounting identities in accordance with this specification, we start by expressing the vector of final demand deliveries – measured at purchasers' prices in the supply-use table above – in basic prices. This is necessary because purchasers' prices reflect an input perspective. In the present specification, final demand products are considered the economy's output and should thus be valued at basic prices (just as value added, the alternative output measure in (19) was valued at basic prices). Let $\{P_{FD}\}$ stand for the basic prices of final products, $\{\tilde{P}_{FD}\}$ for the purchasers' prices of final products, $\{T_{FD}\}$ for the net taxes on final products and $\{TM_{FD}\}$ for the transportation margins on final products, then the following relation holds:

$$FD = \sum_{i=1}^{N_I} \tilde{P}_{FDi} Q_{FDi} = \sum_{i=1}^{N_I} P_{FDi} Q_{FDi} + \sum_{i=1}^{N_I} \left(T_{FDi} + TM_{FDi}\right) \tag{24}$$

Expression (4) can now be employed to relate the value of final demand to value added and to the set of primary inputs:

$$FD = \sum_{j=1}^{N_J} VA_j + \sum_{i=1}^{N_I} T_i + \sum_{i=1}^{N_I} P_{Mi} Q_{Mi} \tag{25}$$

$$\sum_{i=1}^{N_I} P_{FDi} Q_{FDi} + \sum_{i=1}^{N_I} \left(T_{FDi} + TM_{FDi}\right) = \sum_{j=1}^{N_J} VA_j + \sum_{i=1}^{N_I} T_i + \sum_{i=1}^{N_I} P_{Mi} Q_{Mi} \text{ and}$$

$$\sum_{i=1}^{N_I} P_{FDi} Q_{FDi} = \sum_{i=1}^{N_K} P_{Ki} K_i + \sum_{i=1}^{N_L} P_{Li} L_i + \sum_{i=1}^{N_I} \tilde{P}_{Mi} Q_{Mi} + \sum_{i=1}^{N_I} T_{DXi}$$

Where $\sum_{i=1}^{N_I} T_{DXi} \equiv \sum_{i=1}^{N_I} T_i - \left(T_{FDi} + TM_{FDi} + T_{Mi} + TM_{Mi}\right)$

In the last line of (25) we used (20) to express economy-wide value added as the sum of payments to capital and labour and we used T_{DX} as a shorthand for the product taxes and transport margins on domestic intermediate products: T_{DX} equals total taxes on products plus transportation margins minus taxes and transportation margins on final demand products (T_{FD}+TM_{FD}) minus taxes and transportation margins on imports (T_M+T_{MM}). Imports are considered an input in the present set-up of the production possibility frontier and hence have to be valued at purchasers' prices. The third line in expression (25) is the accounting identity at current prices that corresponds to the PPF (24).

However, a comparison of the input side of the production possibility frontier with the accounting relationship (25) shows that the tax term T_{DX} has no quantity correspondence as an input into production. To deal with this cost item, we re-define the production possibility frontier with an additional fixed input[21] whose quantity is equal to one and whose price is equal to T_{DX}:

$$h(Q_{FD1}, Q_{FD2}, ..., Q_{FD,N_J}) = \tilde{z}^t(L, K, Q_M, 1) \tag{26}$$

We are now ready to formulate the measure of productivity growth that corresponds to this characterisation of technology. Applying the same reasoning as before, we find that if h and $\tilde{z}^t$ are approximated by a translog functional form, and if we assume profit-maximising behaviour of producers, competitive markets and constant returns to scale in the final products-based PPF, the productivity shift $\Pi = \tilde{z}^t(L, K, Q_M, 1) / \tilde{z}^{t-1}(L, K, Q_M, 1)$ is exactly represented by the difference between a translog index of

[21] See Diewert and Nakamura (2007) for a more formal demonstration of this technique in the context of a cost function and as a way to deal with decreasing returns to scale.

the rate of change of final products and a translog index of the volume of labour, capital, imported inputs and one fixed input.

$$\ln \Pi = \Delta \ln Q_{FD} - \bar{v}_L \Delta \ln L - \bar{v}_K \Delta \ln K - \bar{v}_M \Delta \ln Q_M \text{ where} \tag{27}$$

$\Delta \ln Q_{FD} = \sum_{j=1}^{N_I} \bar{s}_{FDi} \Delta \ln Q_{FDi}$: share-weighted growth of final products

with

$\bar{s}_{FDi} \equiv 0.5\left(s_{FDi}^t + s_{FDi}^{t-1}\right),\ s_{FDi}^t \equiv \dfrac{P_{FDi}^t Q_{FDi}^t}{FD^t}$ for i=1,2,...N_I products

$\bar{v}_L \equiv 0.5\left(v_L^t + v_L^{t-1}\right),\ w_L^t \equiv \dfrac{P_L^t L^t}{FD^t}$, $P_L L = \sum_{i=1}^{N_L} P_{Li} L_i$, $P_{Lij} = P_{Li}$ for j=1,2,...N_I industries

$\bar{v}_K \equiv 0.5\left(v_K^t + v_K^{t-1}\right),\ v_K^t \equiv \dfrac{P_K^t K^t}{FD^t}$ $P_K K = \sum_{i=1}^{N_K} P_{Ki} K_i$ $P_{Kij} = P_{Ki}$ for j=1,2,...N_I industries

$\bar{v}_M \equiv 0.5\left(v_M^t + v_M^{t-1}\right),\ v_M^t \equiv \dfrac{\tilde{P}_M^t Q_M^t}{FD^t}$ $P_M Q_M = \sum_{i=1}^{N_I} P_{Mi} Q_{Mi}$

As a final step, we shall now link the economy-wide productivity growth rate Π based on a final demand concept to the economy-wide productivity growth rate ρ based on value added and via ρ to the rates of industry-level productivity growth ρ_j (j=1,2,...N_j). This is achieved by using the expression for value added based productivity growth (21), inserting it into (27) and collecting terms:

$$\ln \Pi = \bar{v}_{VA} \ln \rho + VAL + INDEX \text{ where} \tag{28}$$

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

and

$$\bar{v}_{VA} = 0.5\left(v_{VA}^t + v_{VA}^{t-1}\right);\ v_{VA}^t = \frac{VA^t}{FD^t}$$

$$VAL \equiv \bar{s}_{FD} \Delta \ln Q_{FD} - \bar{s}_M \Delta \ln Q_M - \sum_{j=1}^{N_J} \bar{w}_{VAj} \bar{v}_{VA} \Delta \ln V_j$$

$$INDEX \equiv \sum_{i=1}^{N_L} \left(\bar{w}_{Li} \bar{v}_{VA} - \bar{v}_L\right) \Delta \ln L_i + \sum_{i=1}^{N_K} \left(\bar{w}_{Ki} \bar{v}_{VA} - \bar{v}_K\right) \Delta \ln K_i$$

Equation (28) shows that economy-wide productivity growth $\ln \Pi$ is the sum of the following components:

- a share-weighted average of industry-level productivity growth $\ln \pi_j$. The composite share $\bar{v}_{VA} \bar{w}_{VAj} / \bar{v}_{VAj}$ for each industry is best interpreted by looking at the ratio of the same shares when not averaged over two periods: $v_{VA}^t w_{VAj}^t / v_{VAj}^t = \dfrac{VA^t}{FD^t} \dfrac{VA_j^t}{VA^t} / \dfrac{VA_j^t}{P_j^t Q_j^t} = \dfrac{P_j^t Q_j^t}{FD^t}$.

  Thus, each industry's rate of productivity growth enters the economy-wide productivity change with a weight that reflects the industry's gross output in relation to economy-wide final demand. This is a different version of a system of Domar weights, scaled up from the Domar weights that provided the link between the set of $\{\pi_j\}$ and the value-added based productivity measure in (22);

- two reallocation terms $REALL_L$ and $REALL_K$ described earlier;

- a valuation effect VAL: this valuation effect arises from the presence of taxes on products and transportation margins that drives a wedge between the growth rate of GDP at purchasers prices, measured from the expenditure side of the accounts ($\bar{s}_{FD}\Delta \ln Q_{FD} - \bar{s}_M \Delta \ln Q_M$) and the growth rate of economy-wide value-added at basic prices ($\sum_{j=1}^{N_J} \bar{w}_{VAj} \bar{v}_{VA} \Delta \ln V_j$);

- an index number effect INDEX that is a simple consequence of the fact that ratios of arithmetic averages are not equal to arithmetic averages of ratios. Indeed, had Fisher ideal indices been employed for the derivations above, this term would be identically zero. Because Fisher and translog indices approximate each other, this effect is likely to be small in practice.

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 1960-2007. 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.[22] 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 eight major industry groups to economic growth during the period 1960-2007. Table 2 presents the underlying growth rates and shares in nominal GDP for all eight groups. The contributions of six of these groups increased during the IT investment boom of 1995-2000, relative to the period 1960-1995, while the contributions of seven 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 labour inputs as sources of U.S. economic growth for the period 1960-2007. Productivity growth accounts for just under eleven percent of U.S. economic growth, considerably less than the fifteen percent of growth for 1945-1965 estimated by Jorgenson and Griliches (1967). The contribution of capital input accounts for 53 percent of growth during the period 1960-2007, while labour input accounts for 36 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

[22] 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, Ho, and Samuels (2010). This is essential for analyzing the economic impact of information technology.

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 (22) also depends on the reallocations of capital and labour inputs among industries.

Table 3 gives the decomposition of the rate of growth of productivity presented in Table 1 above. The Domar-weighted sum of industry productivity growth rates for the period 1960-2007 is 0.34 percent, the same as the aggregate productivity growth rate in Table 1. The positive reallocation of capital input of precisely offsets the negative reallocation of labor input. 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, Gollop, and Fraumeni (1987), Chapter 9. For the relatively short sub-periods of 1995-2000 and 2000-2007, the reallocations are quantitatively 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. Table 5 gives contributions of these industries to aggregate growth of IT- and Non-IT capital input and College and Non-College workers.

Conclusions

By recognizing capital services as an integral element the *2008 SNA* has cleared the way to 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 official industry-level and total-economy estimates of productivity within the framework of the national accounts. Standardization rests 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, Ho, and Samuels (2010), the EU (European Union) KLEMS (capital, labor, energy, materials, and services) project described by O'Mahony and Timmer (2009), and the studies presented in Jorgenson (2009a), *The Economics of Productivity,* have presented industry-level data on productivity within the framework of national accounts. The EU KLEMS study was completed on June 30, 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.[23] 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.[24]

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

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

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Table 1: Growth in Aggregate Value-Added and the Sources of Growth

	1960-2007	1960-1995	1995-2000	2000-2007	1995-2000 less 1960-1995	2000-2007 less 1960-1995
	Contributions					
Value-Added	3.18	3.24	4.02	2.26	0.78	-0.98
Agriculture, Forestry, Fishing, Hunting, and Mining	0.04	0.04	0.07	0.03	0.03	-0.01
Transportation, Warehousing, Utilities	0.16	0.17	0.16	0.11	0.00	-0.06
Construction	0.04	0.06	0.12	-0.14	0.06	-0.20
Manufacturing	0.66	0.72	0.83	0.22	0.11	-0.50
Trade	0.56	0.56	0.75	0.39	0.19	-0.17
Information	0.22	0.20	0.32	0.24	0.12	0.04
Finance, Insurance, Real Estate, Rental and leasing	0.64	0.63	0.83	0.59	0.20	-0.04
Other Services	0.62	0.59	0.78	0.70	0.19	0.11
Government	0.24	0.27	0.16	0.13	-0.12	-0.15
Capital Input	1.70	1.82	1.84	1.03	0.02	-0.79
IT Capital	0.51	0.45	1.00	0.47	0.55	0.02
Non-IT Capital	1.20	1.37	0.85	0.56	-0.53	-0.81
Labor Input	1.13	1.21	1.51	0.47	0.31	-0.74
College Labor	0.71	0.72	0.88	0.51	0.16	-0.21
Non-college Labor	0.43	0.49	0.63	-0.05	0.14	-0.54
Aggregate TFP	0.34	0.21	0.66	0.76	0.45	0.54
	Quality and Stock Contributions					
Contribution of Capital Quality	0.43	0.44	0.68	0.20	0.24	-0.24
Contribution of Capital Stock	1.28	1.38	1.16	0.84	-0.22	-0.55
Contribution of Labor Quality	0.27	0.27	0.24	0.26	-0.03	-0.01
Contribution of Labor Hours	0.86	0.93	1.28	0.20	0.34	-0.73

Notes: All figures are average annual percentages. The contribution of an output or input is the growth rate multiplied by the average value share. IT capital input includes computer hardware, computer software, and telecommunications equipment services. College labor includes labor services of workers with a B.A. degree or above.

Table 2: Growth and Shares of Aggregate Variables

	1960-2007	1960-1995	1995-2000	2000-2007	1995-2000 less 1960-1995
	Growth Rates				
Value-Added	3.18	3.24	4.02	2.26	0.78
Agriculture, Forestry, Fishing, Hunting, and Mining	1.17	1.01	2.80	0.82	1.79
Transportation, Warehousing, Utilities	2.70	2.75	3.11	2.15	0.36
Construction	0.89	1.35	2.92	-2.89	1.57
Manufacturing	3.32	3.33	5.27	1.83	1.94
Trade	4.77	4.69	6.81	3.77	2.13
Information	5.98	5.87	7.39	5.53	1.53
Finance, Insurance, Real Estate, Rental and leasing	3.82	3.95	4.22	2.86	0.27
Other Services	3.33	3.48	3.23	2.67	-0.25
Government	1.68	1.89	1.18	0.95	-0.71
Capital Input	4.90	5.26	5.24	2.91	-0.02
IT Capital	17.43	18.90	19.59	8.56	0.69
Non-IT Capital	3.74	4.24	2.81	1.87	-1.43
Labor Input	1.73	1.84	2.34	0.74	0.49
College Labor	3.62	4.08	3.19	1.67	-0.89
Non-college Labor	0.95	1.05	1.71	-0.10	0.65
	Shares				
Value-Added	100.0	100.0	100.0	100.0	0.0
Agriculture, Forestry, Fishing, Hunting, and Mining	4.0	4.5	2.4	2.7	-2.1
Transportation, Warehousing, Utilities	5.7	6.0	5.1	4.9	-0.8
Construction	4.6	4.6	4.4	4.8	-0.2
Manufacturing	19.1	20.8	15.6	12.7	-5.2
Trade	11.6	12.0	10.9	10.4	-1.0
Information	3.7	3.5	4.4	4.4	0.8
Finance, Insurance, Real Estate, Rental and leasing	17.4	16.4	19.7	20.7	3.4
Other Services	19.5	17.5	24.3	26.0	6.8
Government	14.4	14.7	13.2	13.3	-1.6
Capital Input	34.8	34.6	35.2	35.5	0.6
IT Capital	3.2	2.5	5.1	5.5	2.6
Non-IT Capital	31.6	32.1	30.1	30.0	-2.0
Labor Input	65.2	65.4	64.8	64.5	-0.6
College Labor	21.1	18.3	27.7	30.5	9.4
Non-college Labor	44.1	47.1	37.1	34.0	-10.0

Notes: Growth rates are average annual percentages. Shares are the mean two-period average for each period in percentages.

Table 3: Decomposition of Aggregate Productivity Growth

	1960-2007	1960-1995	1995-2000	2000-2007	1995-2000 less 1960-1995	2000-2007 less 1960-1995
Aggregate TFP	0.34	0.21	0.66	0.76	0.45	0.54
Domar-Weighted Productivity	0.34	0.19	0.80	0.78	0.61	0.59
Agriculture, Forestry, Fishing, Hunting, and Mining	-0.01	-0.02	0.07	-0.04	0.09	-0.03
Transportation, Warehousing, Utilities	0.03	0.02	0.04	0.05	0.02	0.03
Construction	-0.08	-0.04	-0.09	-0.25	-0.05	-0.20
Manufacturing	0.33	0.30	0.47	0.41	0.17	0.11
Trade	0.26	0.24	0.41	0.26	0.17	0.02
Information	0.07	0.05	0.02	0.23	-0.03	0.19
Finance, Insurance, Real Estate, Rental and leasing	-0.11	-0.19	0.14	0.13	0.33	0.32
Other Services	-0.13	-0.14	-0.29	0.04	-0.15	0.18
Government	-0.03	-0.03	0.03	-0.05	0.05	-0.02
Reallocation of Capital Input	0.01	0.02	-0.12	0.00	-0.14	-0.02
Reallocation of Labor Input	-0.01	0.00	-0.02	-0.03	-0.02	-0.03

Notes: Notes: All figures are average annual percentages. The contribution of an output or input is the growth rate multiplied by the average value share. The Domar weight is the ratio of gross industry output to aggregate value-added.

Table 4: Industry Contributions to Aggregate Value-Added and TFP Growth, 1960-2007

	Value-Added			Productivity		
	V-A Weight	V-A Growth	Contribution to Aggregate V-A	Domar Weight	TFP Growth	Contribution to Aggregate TFP
Farms	0.020	2.60	0.039	0.046	1.30	0.048
Forestry fishing and related activities	0.003	1.80	0.006	0.007	-0.84	-0.006
Oil and gas extraction	0.010	-1.44	-0.018	0.018	-2.09	-0.051
Mining except oil and gas	0.005	1.87	0.008	0.010	0.39	0.001
Support activities for mining	0.002	1.40	0.005	0.004	-0.72	-0.004
Utilities	0.022	1.49	0.033	0.041	-0.54	-0.028
Construction	0.046	0.89	0.037	0.101	-0.78	-0.078
Wood products	0.005	1.25	0.006	0.012	0.05	-0.001
Nonmetallic mineral products	0.006	1.52	0.010	0.014	0.20	0.002
Primary metals	0.012	-0.19	-0.001	0.036	0.06	-0.006
Fabricated metal products	0.016	1.82	0.031	0.037	0.33	0.010
Machinery	0.017	3.13	0.065	0.040	0.37	0.014
Computer and electronic products	0.016	15.77	0.255	0.042	5.15	0.220
Electrical equipment appliances and compo	0.008	2.24	0.021	0.018	0.34	0.003
Motor vehicles bodies and trailers and parts	0.015	2.48	0.042	0.056	0.38	0.018
Other transportation equipment	0.011	0.78	0.012	0.026	-0.02	0.000
Furniture and related products	0.004	2.23	0.009	0.009	0.45	0.004
Miscellaneous manufacturing	0.006	3.58	0.022	0.014	0.92	0.012
Food and beverage and tobacco products	0.019	1.42	0.031	0.086	0.07	0.008
Textile mills and textile product mills	0.006	2.03	0.017	0.017	0.97	0.018
Apparel and leather and allied products	0.008	-0.59	0.006	0.019	0.24	0.001
Paper products	0.008	1.37	0.014	0.022	0.09	0.002
Printing and related support activities	0.006	1.73	0.012	0.012	0.00	0.000
Petroleum and coal products	0.004	3.92	0.013	0.032	0.21	0.008
Chemical products	0.019	3.16	0.062	0.056	0.19	0.008
Plastics and rubber products	0.007	3.93	0.029	0.018	0.51	0.009
Wholesale Trade	0.052	6.04	0.315	0.083	1.70	0.144
Retail Trade	0.065	3.83	0.245	0.090	1.34	0.121
Air transportation	0.005	8.16	0.037	0.011	1.42	0.016
Rail transportation	0.007	0.42	0.003	0.011	1.48	0.016
Water transportation	0.001	4.21	0.005	0.004	0.48	0.002
Truck transportation	0.010	3.51	0.036	0.021	0.58	0.011
Transit and ground passenger transportation	0.002	0.38	0.000	0.004	-1.06	-0.005
Pipeline transportation	0.001	3.64	0.005	0.004	0.38	0.001
Other transportation and support activities	0.007	4.01	0.027	0.010	1.16	0.010
Warehousing and storage	0.002	4.87	0.011	0.003	1.62	0.005
Publishing industries (includes software)	0.009	4.61	0.043	0.018	0.56	0.013
Motion picture and sound recording industr	0.003	3.30	0.009	0.006	0.08	0.000
Broadcasting and telecommunications	0.023	6.83	0.153	0.041	1.34	0.054
Information and data processing services	0.002	5.85	0.017	0.004	-0.46	0.004
Federal Reserve banks credit intermediation	0.028	3.83	0.100	0.040	-1.59	-0.060
Securities commodity contracts and invest	0.008	8.29	0.093	0.013	1.31	0.050
Insurance carriers and related activities	0.019	2.83	0.050	0.040	-0.55	-0.022
Funds trusts and other financial vehicles	0.001	-2.42	-0.003	0.007	-1.55	-0.011
Real estate	0.109	3.37	0.363	0.147	-0.23	-0.029
Rental and leasing services and lessors of ir	0.009	5.16	0.042	0.014	-1.97	-0.035
Legal services	0.011	2.36	0.021	0.016	-1.62	-0.025
Computer systems design and related servic	0.005	7.55	0.042	0.007	-1.58	-0.005
Miscellaneous professional scientific and te	0.030	5.05	0.147	0.047	0.08	0.007
Management of companies and enterprises	0.017	2.73	0.045	0.028	-0.38	-0.012
Administrative and support services	0.017	5.03	0.077	0.026	-0.20	-0.004
Waste management and remediation service	0.002	3.96	0.008	0.005	0.54	0.003
Educational services	0.007	2.76	0.019	0.013	-0.59	-0.008
Ambulatory health care services	0.026	3.29	0.084	0.035	-1.02	-0.031
Hospitals Nursing and residential care facili	0.020	2.80	0.040	0.038	-0.93	-0.040
Social assistance	0.004	5.36	0.019	0.007	0.39	0.003
Performing arts spectator sports museums a	0.003	3.48	0.010	0.005	0.19	0.001
Amusements gambling and recreation indus	0.004	3.93	0.015	0.006	-0.01	-0.001
Accommodation	0.007	3.84	0.027	0.011	0.69	0.007
Food services and drinking places	0.015	2.10	0.033	0.035	0.00	0.000
Other services except government	0.025	1.46	0.038	0.046	-0.45	-0.024
Federal General government	0.050	0.35	0.021	0.080	0.06	0.005
Federal Government enterprises	0.007	1.11	0.008	0.010	0.24	0.002
S&L General Government	0.079	2.62	0.196	0.113	-0.20	-0.023
S&L Government enterprises	0.007	1.99	0.015	0.016	-0.69	-0.010
Sum	1.000		3.176	1.910		0.344

Notes: All figures are annual averages. Value-added weights are industry value-added as a share of aggregate value-added. Domar weights are industry output as a share of aggregate value-added. A contribution is a share-weighted growth rate.

Table 5: Industry Contributions to Aggregate Capital and Labor Input Growth, 1960-2007

	Capital			Labor		
	Total	IT	Non-IT	Total	College	Non-College
Farms	0.011	0.000	0.011	-0.020	0.002	-0.023
Forestry fishing and related activities	0.007	0.001	0.006	0.005	0.001	0.004
Oil and gas extraction	0.030	0.003	0.028	0.003	0.003	0.001
Mining except oil and gas	0.009	0.001	0.008	-0.002	0.001	-0.002
Support activities for mining	0.006	0.001	0.005	0.003	0.001	0.002
Utilities	0.058	0.008	0.050	0.003	0.003	0.000
Construction	0.019	0.007	0.012	0.096	0.021	0.075
Wood products	0.005	0.001	0.004	0.002	0.001	0.001
Nonmetallic mineral products	0.009	0.004	0.005	0.000	0.001	-0.001
Primary metals	0.012	0.005	0.007	-0.008	0.001	-0.009
Fabricated metal products	0.015	0.006	0.009	0.006	0.002	0.004
Machinery	0.048	0.019	0.030	0.003	0.003	-0.001
Computer and electronic products	0.022	0.013	0.010	0.012	0.014	-0.002
Electrical equipment appliances and comp	0.016	0.003	0.013	0.002	0.003	0.000
Motor vehicles bodies and trailers and part	0.014	0.007	0.008	0.011	0.006	0.004
Other transportation equipment	0.010	0.004	0.006	0.002	0.006	-0.004
Furniture and related products	0.003	0.001	0.002	0.002	0.001	0.001
Miscellaneous manufacturing	0.005	0.002	0.003	0.004	0.003	0.000
Food and beverage and tobacco products	0.025	0.006	0.019	-0.002	0.005	-0.007
Textile mills and textile product mills	0.003	0.001	0.002	-0.004	0.001	-0.005
Apparel and leather and allied products	0.013	0.001	0.011	-0.008	0.001	-0.009
Paper products	0.011	0.002	0.009	0.002	0.002	0.000
Printing and related support activities	0.007	0.002	0.006	0.005	0.003	0.002
Petroleum and coal products	0.008	0.004	0.004	-0.002	0.000	-0.003
Chemical products	0.047	0.013	0.034	0.007	0.008	-0.001
Plastics and rubber products	0.011	0.001	0.010	0.009	0.002	0.007
Wholesale Trade	0.106	0.032	0.074	0.065	0.036	0.029
Retail Trade	0.067	0.020	0.047	0.057	0.029	0.028
Air transportation	0.012	0.008	0.004	0.010	0.005	0.005
Rail transportation	0.002	0.001	0.001	-0.016	0.000	-0.016
Water transportation	0.003	0.001	0.002	0.000	0.001	0.000
Truck transportation	0.009	0.002	0.008	0.015	0.003	0.013
Transit and ground passenger transportatio	0.005	0.003	0.002	0.001	0.001	0.000
Pipeline transportation	0.004	0.002	0.002	0.000	0.000	0.000
Other transportation and support activities	0.005	0.002	0.003	0.011	0.004	0.007
Warehousing and storage	0.001	0.001	0.001	0.004	0.001	0.003
Publishing industries (includes software)	0.010	0.006	0.004	0.020	0.016	0.005
Motion picture and sound recording indust	0.006	0.001	0.004	0.003	0.003	0.000
Broadcasting and telecommunications	0.075	0.049	0.026	0.023	0.013	0.011
Information and data processing services	0.007	0.005	0.001	0.006	0.005	0.002
Federal Reserve banks credit intermediatio	0.127	0.056	0.071	0.033	0.021	0.011
Securities commodity contracts and inves	0.015	0.013	0.001	0.028	0.024	0.004
Insurance carriers and related activities	0.049	0.024	0.025	0.023	0.018	0.005
Funds trusts and other financial vehicles	0.006	0.004	0.002	0.002	0.002	0.000
Real estate	0.373	0.008	0.391	0.019	0.012	0.008
Rental and leasing services and lessors of i	0.070	0.036	0.034	0.007	0.003	0.004
Legal services	0.025	0.011	0.014	0.021	0.017	0.005
Computer systems design and related servi	0.011	0.010	0.001	0.036	0.026	0.010
Miscellaneous professional scientific and t	0.061	0.041	0.020	0.078	0.057	0.021
Management of companies and enterprises	0.021	0.016	0.005	0.036	0.029	0.007
Administrative and support services	0.020	0.011	0.009	0.061	0.020	0.041
Waste management and remediation servic	0.003	0.001	0.002	0.003	0.001	0.002
Educational services	0.006	0.003	0.002	0.021	0.017	0.005
Ambulatory health care services	0.037	0.007	0.030	0.078	0.049	0.029
Hospitals Nursing and residential care facil	0.022	0.006	0.015	0.058	0.028	0.030
Social assistance	0.002	0.001	0.002	0.013	0.005	0.008
Performing arts spectator sports museums	0.002	0.001	0.001	0.008	0.006	0.003
Amusements gambling and recreation indu	0.007	0.001	0.006	0.009	0.003	0.006
Accommodation	0.010	0.001	0.009	0.010	0.004	0.006
Food services and drinking places	0.008	0.002	0.006	0.025	0.008	0.017
Other services except government	0.045	0.005	0.040	0.016	0.008	0.007
Federal General government	0.016	0.004	0.012	0.000	0.014	-0.014
Federal Government enterprises	0.004	0.001	0.004	0.002	0.002	0.000
S&L General Government	0.028	0.004	0.023	0.191	0.141	0.050
S&L Government enterprises	0.007	0.001	0.006	0.018	0.003	0.015
Sum	1.710	0.515	1.221	1.122	0.724	0.398

Notes: All figures are annual averages. Value-added weights are industry value-added as a share of aggregate value-added. Domar weights are industry output as a share of aggregate value-added. A contribution is a share-weighted growth rate.