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A general equilibrium analysis of international TFP growth rates.

The paper presents a study of the TFP performance among developed countries between 1985 and 1990. The analysis includes three big economies: the US, Japan and Europe.

A general equilibrium model of the three big economies is used to estimate the TFP growth at the sectoral and at the aggregate levels. The model is based on the fundamentals of the economies and employs only data on input-output statistics, factor inputs across sectors, consumption and trade patterns and endowments. Prices are endogenous in the model. They are obtained as shadow prices from the corresponding linear programming and then used for measuring TFP growth and its decomposition to the technical change effect, demand effect and terms-of-trade effect.

Introduction.

The level of well-being of the citizens in a national economy may rise for three reasons. First, and foremost, technical progress allows producing more by less. Second, preference may shift to less resource intensive consumption of goods and services. Third, the terms of trade may improve. The first source of growth, technical progress, is measured by the well-known Solow residual. The other two sources are less well known. True, shifts in final consumption are known to influence the relative importance of sectors in the economy and hence the weights in the aggregate Solow residual. What is discussed less, however, is that such shifts may be economical from the resource saving point of view and, hence, boost the level of well-being. The shift towards the electronics not only adds more weights to that sector in the Solow residual, but also facilitates more efficient use of resource inputs.

Changes in the terms of trade are known to be equivalent to technical progress in theory. In practice, however, few studies ascribe productivity growth to this trade component. Moreover, terms of trade changes ought to be reduced to technology and preference shifts, possibly in a partner economy.

In this paper we measure total factor productivity growth for a system of national economies linked by trade. TFP growth comprises three terms: the Solow residual, the taste effect and the terms-of-trade effect, following Mohnen and ten Raa (1997). In their analysis the terms of trade is exogenous as is fitting for a small open economy. Here, however, TFP growth of the main players in the world, USA, Japan and Europe, is measured and, therefore, terms-of-trade effect is endogenous and explained in terms of technology and preference shifts. Roughly speaking, any such shift favors the TFP growth of the national economy if its imports become cheaper. A clear measurement of technology and preference-shift effects on national TFP growth rates requires competitive, hence, endogenous valuations of all inputs and outputs, for the same reason as exposed by Solow (1956) for a national macro-economy.

This paper presents a general equilibrium model to measure TFP growth and decompose it into national Solow residuals, demand effect and terms of trade effect.

A conventional definition of TFP growth as a weighted sum of changes in technical coefficients corresponds to the Solow residual component. This component measures the growth of the output not attributed to the growth of inputs. It accounts for the growth of quantity produced, rather than the changes in the value assigned to these units. If there is no division on sectors then there is no changes in real value of one unit of output, real price does not change and growth of quantity produced is the same as growth of its value. However, if an economy consists of more than one sector then the growth in terms of the number of units does not coincide with the growth in terms of value assigned to them. Changes in relative prices cause changes in real value of a unit of one commodity relatively to that of others and, therefore, cause changes in the productivity of factors for their production.

Starting with the definition of TFP as the sum of productivities of all factor inputs and taking into account the effect of relative price changes, we can extend the expression for the TFP growth with additional terms, which implement this effect.
For a closed economy changes in relative prices are limited to changes in the fundamentals of the economy. But for an open economy domestic relative prices can also change due to changes in fundamentals of the other economies, which are transferred to international prices.

Traditionally the measurement of the TFP growth is performed basing on observable production levels and prices (or value shares). If the production is efficient and the observable prices are perfectly competitive, this conventional measure reveals the shifts in the production possibility frontier. However in real life these assumptions hardly hold, that is why an alternative way of measurement may be preferable. Such an alternative is to use the optimal production levels and shadow prices, obtained from the solution of the correspondent optimization problem (Mohnen, Ten Raa, 1997). Since, the optimal point lies on the production possibility frontier of the economy and shadow prices of factor inputs reflect the true marginal productivities, such a measure is corrected for both production inefficiency and the distortions, to which the observable prices were subjected.

The present paper applies this methodology to measure TFP growth in a few related economies. The optimal levels of production and consumption together with shadow prices are obtained as a solution of the optimization problem and then used to compute TFP growth.

Further the TFP growth is decomposed into three effects. The first of them corresponds to the conventional measure of TFP growth and reflects the growth due to technological changes. Surprisingly the results of its computation using shadow prices and optimal production levels have been found highly correlated with the results of computation based on the observed prices and output levels. Two other terms in the TFP growth decomposition - demand effect and terms of trade effect - come from changes in relative prices. Since the world relative prices as well as the optimal trade patterns are endogenous in the model, the terms-of-trade effect is completely endogenized.

The paper proceeds as follows. The next two sections introduce the model and a formula for the TFP growth decomposition. The fourth section describes the data used to estimate the model. The fifth section discusses the results. And the last section concludes.

The model.

A free trade model of 'the world economy' is applied to find the optimal production and trade pattern as well as shadow prices of commodities and factors of production. The 'world' in this model consists of a few large economies and 'the rest of the world'. The trade with the rest of the world is pegged at the observable level, so, the model describes interactions among these few large economies only. World prices corresponding to the optimal activity levels in the considered economies are endogenous and determined as a result of international trade.

A model of this type has already been used by Mohnen, Ten Raa (1996) in their paper on the location of comparative advantages between Canada and Europe. The present paper extends empirical applications of the model employing it to find optimal levels of productions and adjacent shadow prices for three big economies: the US, Japan and

Europe (3)[1] (an aggregate of the UK, France and Germany), which together cover a significant share of the world trade.

In the model the level of the world final consumption is maximized subject to commodity and factor inputs constraints.

Tradable goods are assumed to be not differentiated with respect to a country-producer. The technology of each economy j[2] is described by capital and labor input coefficients k_j [n], l_j [n] and the commodity input coefficient matrix A_j [n,n][3], where n is the number of different commodities, which is the same as the number of sectors. Capital and labor are mobile across sectors within each economy, but immobile among the economies. Gross output vector of economy j is denoted by x_j. Thus, the net output of economy j can be expressed as $(I-A_j)x_j$.

It is assumed in this setting that consumers have preferences of Leontief type. It implies that the preferences of consumers in economy j can be described by the vector of domestic final demand of this economy, which is denoted by f_j (j=1,2,3). To maximize utility each economy expands its final demand vector. Correspondent expansion factors are denoted by c_1, c_2, c_3 ($c_1=c$, $c_2=c\gamma_2$, $c_3=c\gamma_3$). Given weights γ_2, γ_3 the corresponding weighted sum of final demands of three economies is $f_1+\gamma_2 f_2+\gamma_3 f_3$. Then c can be interpreted as the expansion factor for the vector of total final demand of three economies.

Each tradable commodity can be consumed as a final good, used in production as an intermediate good or exported. That is $x_j=A_j x_j+c_j f_j+z_j$, j=1,2,3. Here z_j denotes total net export from country j.

The total trade of three countries with the rest of the world is assumed to be fixed at the observable level. It is useful to notice that *the sum of total net exports* of the three economies is equal to the total net export from those countries *to the rest of the world*. Thus, since the trade with the rest of the world is fixed we have equality

$$\sum_{j=1}^{3} z_j = \sum_{j=1}^{3} z_{j0} \ ,$$

where index 0 corresponds to the observable level.

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[1] The data for Europe (3) were constructed by aggregation of the data for three European economies: Germany, France and the UK.

[2] Indexes 1,2,3 are used for the US, Japan, Europe (3) correspondingly.

[3] To define the corresponding technical coefficients the commodity technology model is used. The model assumes that any industry producing a commodity produces it by the same technology, which leads to the expression for the matrix of technical coefficients $A=U(V^t)^{-1}$, where U, V are correspondingly "use" and "make" matrixes. In the traditional one-matrix input output framework V is assumed to be a diagonal matrix with gross outputs of each sector on the diagonal. Then labor and capital coefficients for each industry are expressed as a ratio of the correspondent factor of production employment in the industry to gross output produced by the industry.

The linear program is as follows:

$$\max_{x_j, c} \quad ce^t \sum_{i=1}^{3} \gamma_i f_i \tag{1}$$

for tradables: $$\sum_{j=1}^{3} (I - A_j) x_j \geq \sum_{j=1}^{3} c\gamma_j f_j + \sum_{j=1}^{3} z_{j0} \tag{2}$$

for nontradables: $$(I - A_j) x_j \geq c\gamma_j f_j, \quad j = \overline{1,3} \tag{3}$$

for factor inputs: $$k_j x_j \leq K_j, \qquad l_j x_j \leq L_j, \qquad j = \overline{1,3} \tag{4}$$

non-negativity: $$x_j \geq 0, \qquad j = \overline{1,3} \tag{5}$$

Where K_j is the capital stock in country j, L_j is the labor force in country j.

The corresponding dual problem is:

$$\min_{p_{trad}, p_{nt,i}, r_i, w_i} p_{trad}^t \sum_{i=1}^{3} z_{i0} + \sum_{i=1}^{3} r_i K_i + \sum_{i=1}^{3} w_i L_i \tag{6}$$

$$-p_i (I - A_i) + r_i k_i + w_i l_i - \sigma_i = 0, \qquad i = \overline{1,3} \tag{7}$$

$$\sum_{i=1}^{3} p_i^t \gamma_i f_i = e^t \sum_{i=1}^{3} \gamma_i f_i \tag{8}$$

$$p_i \geq 0, \; i = \overline{1,n}, \qquad w_j \geq 0, \; r_j \geq 0, \; \sigma_j \geq 0, \; j = \overline{1,3} \tag{9}$$

where $p_i = (p_{trad}, p_{nt,i})$ is a vector of prices in country i, which components corresponding to tradable commodities, p_{trad}, are equalized across countries, r_i, w_i are rent and wage rate in country i, σ_i are slacks. The commodity will be produced by a country if and only if the cost of its production does not exceed its price. Therefore, in active sectors the slacks are equal to zero and $\sigma_i x_i = 0$.

Condition (7) implies the well-known macroeconomic identity of the national product and national income

$$p^t (I - A) x = rK + wL \tag{10}$$

It can be seen as follows. Multiplying (7) by x_i, we obtain that for any country i

$$-p_i^t (I - A_i) x_i + r_i k_i x_i + w_i l_i x_i - \sigma_i x_i = 0.$$

The complementary slackness condition gives us $r_i k_i x_i = r_i K_i$, $w_i l_i x_i = w_i L_i$. It has already been shown that $\sigma_i x_i = 0$. Hence, (10) holds.

Condition (8) determines the normalization for shadow prices: the value of the weighted final demand at shadow prices has to be the same as at the observable prices.

The solution of the dual program gives us shadow prices and optimal levels of output in each sector for each economy. The trade surplus (total) of country j at the optimal point can be expressed as $S_j = p_{trad}^t (x_j - A_j x_j - c\gamma_j f_j)$, whilst the observable trade surplus of country j is given by the formula $S_{j0} = \pi^t z_{j0}$, here π is a vector of observable international prices. Notice that in our setting the optimal total surplus on trade with the rest of the world is not necessarily equal to the observable one, i.e.,

$$p^t \sum_{j=1}^{3} z_j \neq \pi^t \sum_{j=1}^{3} z_{j0} .$$

The solution of the linear program depends on the choice of 'optimal' weights
($1, \gamma_2, \gamma_3$). They were chosen to match the observable proportions between surpluses of countries on international trade, which is the same as to assume that the value share of each country in international trade is pegged at the observable level.[4]

$$\frac{S_1}{S_2} = \frac{S_{10}}{S_{20}}, \qquad \frac{S_1}{S_3} = \frac{S_{10}}{S_{30}}, \qquad \frac{S_2}{S_3} = \frac{S_{30}}{S_{30}} \qquad (11)$$

Any two of these equations imply the third one, so they determine exactly two conditions to find weights γ_2 and γ_3, which characterize the optimal welfare distribution among these three economies.

Linear program (1-5) together with condition (11) define an equilibrium level of production and consumption for three economies.

An adjustment process underlying to this equilibrium is a kind of the Nigishi's adjustment process on the weights in the social welfare function (Nigishi, 1960). It can be described

[4] An alternative is, for example, to take ($1, \gamma_2, \gamma_3$) = (1,1,1), i.e., to assume that all countries expand their domestic final demand in the same proportion. Another way is to restrict the bilateral surpluses on trade to be equal to observable ones.

as follows. Let us start at some point (γ_2,γ_3). If surplus of country i (i=2,3) exceeds $\frac{S_{i0}}{S_{10}} S_1$, then this country consumes too little and exports too much. Thus, the country can increase its share in the world consumption: γ_j goes up. And v.v., if surplus of country i is below $\frac{S_{i0}}{S_{10}} S_1$, γ_j should go down.

Definition of TFP growth.

The solution of the above problem provides the optimal allocation of consumption and production for a given year. The computation of TFP growth between two years will be based on the potential optimal output level and correspondent shadow prices. The following *definition for the TFP growth* is used

$$T\hat{F}P = \frac{\dot{r}K + \dot{w}L}{rK + wL} \qquad (12)$$

where a dot denotes derivative w.r.t. time $\frac{d}{dt}$.

The National Identity reads $p^t(I-A)x = rK + wL$, which implies the expression for the change in TFP as follows

$$\begin{aligned}
(dr)K+(dw)L &= d(rK+wL)-rdK-wdL= \\
&= d(p^t(I-A)x)-rdK-wdL= \\
&= p^t d\big((I-A)x\big)-rd(kx)-wd(lx)+(dp^t)(I-A)x= \\
&= -(p^t dA+rdk+wdl)x+p^t(I-A-rk-wl)dx+(dp^t)c\gamma f+(dp^t)z= \\
&= -(p^t dA+rdk+wdl)x+(dp^t)c\gamma f+(dp^t)z
\end{aligned} \qquad (13)$$

The first term describes *the effect of reduction in technical coefficients* for intermediates, capital and labor inputs. In other words it is the Solow residual evaluated at shadow prices and the optimal gross output levels. Prices entering this term as weights show relative importance of technological changes in different sectors. What is not reflected by this term is the effect of changes in the relative prices.

Even if all technical coefficients in the country remain the same, the TFP may still change because of the re-evaluation of prices, which occur due to shifts in domestic final demand or due to shifts in technology or final demand in the other economies. These shifts are captured by the last two terms, which are called the demand effect[5] and the terms-of-trade effect respectively.

The demand effect can be decomposed even further. For each country i we obtain

$$\begin{aligned}(dp_i^t)c\gamma_i f_i &= d(p_i^t c\gamma_i f_i) - p_i^t d(c\gamma_i f_i) = \\ &= d\left(\frac{p_i^t\gamma_i f_i}{\sum_{j=1}^3 p_i^t\gamma_j f_j}\right)\left(c\sum_{j=1}^3 p_i^t\gamma_j f_j\right) + \frac{p_i^t\gamma_i f_i}{\sum_{j=1}^3 p_i^t\gamma_j f_j} d\left(c\sum_{j=1}^3 p_i^t\gamma_j f_j\right) - \\ &\quad - c\gamma_i p_i^t df_i - (dc\gamma_i)p_i^t f_i\end{aligned} \qquad (14)$$

The first term in (14) shows the influence of changes in the share of country's domestic final demand in total final demand of the system. The second term is responsible for changes in the value of total final demand of the system. The third term describes the effect of changes in domestic tastes, and the fourth term shows the impact from change in the expansion coefficient assigned to a country.

The last term in expression (13) characterizes *the terms-of-trade effect*, i.e., the effect of changes in the terms of trade. It can be seen that an increase of price of an exported commodity brings TFP growth, whilst an increase of price of an imported commodity leads to TFP decline. If there were no trade with the rest of the world, then total net export of the system would be zero. Consequently the sum of terms-of-trade effects for three economy would be zero as well. In our case, however, the terms-of-trade effects for three countries do not have to sum up to zero.

A similar decomposition of TFP growth has been done in the paper by Mohnen, Ten Raa (1997). In their paper the observable relative world prices still enter the expression for the TFP growth, because there the case of a small open economy is considered. In the present model the international prices are endogenous, determined from the linear program. They reflect the true marginal cost of production of commodities at the optimal levels of production and consumption. The expression for the TFP growth relies only on changes in fundamentals of the economy: endowments, tastes and technologies.

Data description.

[5] Do not confuse with *the value share effect* (considered in Wolff, (1985, 1994)), which is the effect of relative price changes on change in the Solow residual.

The present analysis is conducted for three economies: the US, Japan and Europe (3), which is an aggregation of France, Germany and the UK, for the years 1985 and 1990. It uses input-output tables and data on labor and capital stock across sectors.

The fact that each country uses not only different classifications of commodity and industry but also different methodologies of constructing data makes data from national statistical offices incomparable. Adjustment for this is a very complicated process requiring additional data at a lower level of aggregation, which often are not available.

The OECD Statistical Office has made efforts to harmonize national Input-Output tables[6] of 10 OECD countries. The present study operates with two OECD data bases: the Input-Output Data Base (IODB) and the Industrial Structure Data Base (ISDB). The IODB presents the Input-Output tables at several time points for 10 countries[7] and uses common industrial classification (36 sectors). The ISDB contains the data on employment and capital stock. The classification applied in ISDB though less broad (27 sectors, if we exclude subtotals) can be bridged with the classification used in I-O tables. It has to be admitted that the OECD data are still not perfectly harmonized and subject to some inconsistencies[8], which are inevitable when constructing an international data set. However, they seem to be the best alternative available, providing the most complete data set for the purpose of this research.

The OECD common industrial classification used in IODB distinguishes 36 sectors. Though it is in the interests of our analysis to have the number of sectors as large as possible, a certain degree of aggregation has been required. After the aggregation the number of sectors has been reduced to 31. (For details see Appendix A).

The conversion of tables to constant prices in 1990 US dollars is done as follows. First, the data for 1985[9] are expressed in constant 1990 prices using the ratio of GDP in constant 1990 prices to GDP in current 1985 prices as deflators. Second, the data in

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[6] There are also a few other studies on harmonization of international data. In particular, Eurostat has done work on harmonization if I-O tables for European countries and created aggregated I-O tables for the whole European Union; Yoshinaga (1996) has recomputed Japanese I-O Tables according to the ESA method and presented a comparison of input-output structure between Japan and EU; MITI (Ministry of International Trade and Industry, Japan) has constructed a few multycountry I-O tables (e.g., Japan-US I-O Tables for 1985 and 1990, Pentilateral I-O Table for Japan-US-Germany-France-UK for 1985, etc.).

[7] The OECD table of 1985 and 1990 for the US is an extrapolation of the benchmark table for 1982 using 1977 weights. Updating these tables with more recent information would improve the results.

[8] See the introduction to OECD Input-Output Data Base description, 1995.

[9] In fact the table for Germany and the UK presented by OECD are not for 1985 but for 1986 and 1984 correspondingly. It was assumed in this study that the input-output structure in Germany (and the UK) did not change between 1985 and 1986 (and between 1984 and 1985 for the UK). Consequently, the table for Europe (3) was constructed as follows. The tables for Germany (1986) and the UK (1984) were first expressed in constant prices and then added up with the data for France (1985) also expressed in constant prices. The input-output coefficients of the aggregate are weighted sums of the input-output coefficients of each country, the weights being the gross output shares.

constant 1990 prices are converted to constant 1990 dollars by 1990 PPP's. The data for GDP across sectors in current and constant prices for this procedure as well as PPPs are taken from the ISDB produced by OECD. The deflators for observed international prices are constructed as weighted averages of deflators for observed domestic prices, with domestic final demands taken as weights.

Data on capital and labor across sectors come from ISDB for all countries except for the data on labor for Japan, which are taken directly from the Japan Statistical Yearbook[10]. Data on labor force for 5 countries are taken from the Labor Force Statistics published by OECD (1995).

Capital and labor coefficients are constructed as ratios of capital (or labor) employed in the industry to the gross output produced by the industry. Employed capital in industry is defined as capital stock of industry corrected for capital utilization. The values for capital utilization rate[11] for 1985 and 1990 are taken from OECD Economic Outlook, 1993 and The statistical abstract of the US, 1995. For a few sectors, where missing values for labor or capital are encountered, input coefficients are assumed to be equal to the average numbers observed for those sectors in the other countries.

Wage shares, which are used for the TFP computation at the observable prices and output levels, are obtained from IO tables for all countries except for the US, whose IO Tables do not provide data on compensation of employees. For the US wage shares are taken from the ISDB. Rent shares are constructed residually as a difference between value added and wage share.

A bridge table, which links the classification used in the IODB to the classification from ISDB is presented in Appendix B. We can see that ISDB data are slightly more aggregated, thus, there are ISDB sectors, which combine a few IODB sectors. In such cases coefficients for each of these IODB sectors are assumed to be equal and computed as a ratio of the capital (or labor) employed in the ISDB sector to the sum of gross outputs produced by the correspondent IODB sectors.

Commodities 23 and 31 are considered as nontradable, since the input-output tables for all countries except for the Germany reported zero values of export and import for these sectors.

Results of the Total Factor Productivity growth estimation.

[10] The labor coefficients for Japan based on ISDB data were inconsistent with labor coefficients for other countries.

[11] We had in our disposal only the data on average capital utilization rates in manufacturing. Data on capacity utilization corresponding to agriculture, mining and services have not been available. Consequently capacity utilization rates for all industries are assumed to be equal to the average observed for manufacturing.

Let us start with the analysis of the technical change effect.
Conventionally the Solow residual at the sectoral level can be presented as follows

$$SR_j = \frac{1}{p_j}\left[-\sum_i p_i \dot{A}_{ij} - w_j \dot{l}_j - r_j \dot{k}_j \right] = -\sum_i \frac{p_i A_{ij}}{p_j} \frac{\dot{A}_{ij}}{A_{ij}} - \frac{w_i l_j}{p_j} \frac{\dot{l}_j}{l_j} - \frac{r_i k_j}{p_j} \frac{\dot{k}_j}{k_j}$$

Then the expression for the aggregate Solow Residual will read

$$SR = \frac{\sum_j p_j x_j SR_j}{p(I - A)x}$$

and shows how much changes in technical coefficients of each sector contribute to the total factor productivity growth.

The results are shown in Table 1. The first three columns present the Solow residuals for three economies computed at the observable level of production and prices on commodities and factor inputs. The consequent three columns correspond to those at optimal production level and shadow prices. The resulting Solow residuals based on observable data on output and prices are found to be highly correlated with those obtained for the optimal level of output and shadow prices. The correlation coefficients are 0.96 for the US, 0.92 for Japan and 0.94 for Europe. The results based on shadow prices and optimal activity levels show a greater variance than that at observable levels. The aggregate Solow residuals in the US and Europe were found to be lower than those in Japan for both methods. According to table 1 manufacturing shows a higher TFP growth than services, which agrees with the common observation on their relative performance.

The presented results are still preliminary and to large extend are explained by the data used to estimate the model, which themselves inherited some distortions from the initial input-output tables. For example, surprisingly low aggregate Solow residual for the US are probably due to the fact that input-output tables for the US used for construction of technical coefficients are not benchmark tables, but just extrapolations (see data description). Incorporation of information from other sources will certainly improve the analysis.

Table 1. Annual Solow residuals (1985-1990).

Industry	SR at observ. prices and levels of prod. (in %)			SR at shad. prices and opt. levels of prod. (in %)		
	US	Japan	Europe	US	Japan	Europe
Agr., hunting, forestry, fishing	0.84	1.24	2.25	0.01	3.95	3.23
Mining and quarrying	3.19	0.33	2.10	4.65	4.04	4.90
Food, beverages, tobacco	-1.03	- 1.65	-0.50	-0.88	-1.55	-0.10
Textiles, wear. apparel, leather	2.32	0.57	0.11	2.02	0.87	0.99
Wood and prod., incl. furniture	3.17	2.34	-0.06	3.19	2.80	0.54
Paper and prod., printing, publ.	-0.65	0.88	-0.08	-0.45	1.49	0.67
Ind. chemic., Drugs, medicines	0.43	-0.16	-0.44	0.59	-0.74	-0.84
Petroleum and coal	-7.31	1.93	-1.92	-7.49	2.28	-3.14
Rubber and plastic products	0.36	-0.54	-0.57	0.51	0.62	-0.85
Non-metallic mineral products	1.93	0.08	0.76	2.52	0.62	1.75
Iron and steel	-1.86	0.24	-0.80	-1.89	0.48	-0.59
Non-ferrous metals	-1.85	0.04	-1.83	-0.74	0.39	-1.93
Metal products	-0.60	4.10	1.51	-0.41	5.52	3.08
Non-electrical machinery	1.82	2.47	-0.24	2.64	3.52	-0.51
Office & computing machinery	5.27	0.90	-2.47	5.80	1.60	-2.69
Electric appar.,Radio, TV ,etc.	3.61	1.97	0.79	4.25	2.79	1.45
Shipbuilding and repairing	0.50	1.09	0.01	0.71	1.55	1.40
Other transport, Motor vehicles	1.28	0.61	0.09	1.66	1.04	0.91
Aircrafts	-0.64	1.17	0.73	-0.41	1.26	2.42
Professional goods	5.62	1.57	3.98	7.56	2.78	7.89
Other manufacturing industries	2.35	-6.16	1.11	4.64	-5.63	1.43
Electricity, gas and water	-1.77	0.78	0.52	-1.37	1.47	1.69
Construction	-1.71	0.23	0.01	-1.92	1.21	0.80
Wholesale and retail trade	3.30	3.88	0.33	5.88	7.69	2.26
Restaurants and hotels	0.23	2.38	-1.41	0.51	4.51	-0.70
Transport and storage	2.89	2.33	3.12	3.61	5.49	5.07
Communication	2.47	1.92	2.06	3.79	3.82	6.95
Financ.institut. and insurance	-1.37	-1.11	-2.71	0.03	-0.68	-0.89
Real estate, business services	-0.83	0.22	0.20	-1.28	0.18	-1.53
Com., soc., personal services	-2.41	-2.80	8.04	-3.11	-2.63	12.50
Non-market services	-5.73	-7.95	-4.13	-3.61	-5.58	-3.16
Aggregate SR	-0.26	0.64	0.51	-1.20	3.24	-0.04
Aggr.SR (sectors 1-30)[12]	0.34	1.74	1.32	-0.74	4.33	1.14
Aggr. SR (manufacturing)	1. 31	2.32	0.05	-0.18	5.22	2.00

[12] Sector 31 (non-market services) is not an 'ordinary industry'. First of all, due to general problems of accounting for this kind of services we observe inconsistency in the data reported on them for different countries. Output in non-market services is often measured by their inputs, which makes it impossible to reveal technological changes there. Second, we reallocated all statistical discrepancy to this sector. Inconsistencies in as well as the presence of statistical discrepancy suggests a necessity of some special treatment , which has not been made in this preliminary analysis.

The results of decomposition of the TFP growth for the three economies are given in the Table 2. Both methods of computations (with observable prices and outputs and with shadow prices and optimal outputs) show that in 1985-1990 Japan was leading in terms of TFP growth.

Table 2. Decomposition of the annual TFP growth.

(shadow prices and optimal output levels)

	SR	**Demand effect**	**Terms-of-trade effect**	**TFP growth**
US	-1.20	1.38	0.33	0.57
Japan	3.24	0.75	-1.39	2.72
Europe (3)	-0.04	-0.16	0.55	0.35

The contribution of the demand effect and terms-of-trade effect is found to be different across countries and sensitive to the method of computation. Negative terms-of-trade effect for Japan implies that introducing a free trade would shift the welfare gain from Japanese innovations towards the other countries.

Conclusion.

The paper introduces a method for estimation of the TFP growth in a system of linked economies basing solely upon changes in fundamentals of the economies. Following the line suggested in Mohnen, ten Raa (1997), we look at TFP growth as a reflection of changes in marginal valuation of factor inputs in the economy. These marginal valuations result from interactions between all counterparts of the system. Incorporating a few linked economies allowed us to endogenize the international prices and consider them as outcome of the underlying system. Any change in tastes, endowments or technology of an economy-participant effects these prices, hence, impacting on the TFP growth as well.

The theory was applied to estimate the TFP growth in the US, Japan and Europe (3) in 1985-1990. We found that Japan was leading in aggregate TFP growth over the observed period. The growth due to technological change was much higher there than either in the US or Europe. However, it is likely that the terms-of-trade effect on the aggregate TFP growth in Japan was unfavorable, shifting the gain from the technological changes toward the other countries.

The lack of sufficient international data available was highlighted by this analysis. Basically all necessary data for the research have been limited to technical coefficients, endowments of labor and capital and proportions of final demands across sectors. The numerous problems with this kind of international data (like, e.g., different treatment of the secondary products by national input-output tables, incomparability in capital utilization rate construction, missing values, an absence of cross sector data on real exchange rate between countries, etc.) suggest that the empirical results of this paper should be interpreted carefully. Improving the underlying data set will contribute to making the results more accurate. The part of the work on incorporation of data from the other sources is still left as a direction for the future research. Another possible extension for this paper is to add more economies to the system, since the assumption that interactions of a few big economies determine the world prices becomes more realistic as the size of 'the rest of the world' gets relatively smaller than that of the considered economies.

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Appendix A.

Details on the aggregation of sectors from the IODB.

Sector 7 (Industrial chemicals) was aggregated with sector 8 (Drugs and medicines) since the data for them were not separately available for Germany.

Sector 17 (Electrical apparatus) was aggregated with sector 18 (Radio, TV and communication equipment) due to lack of separate data for the UK and Germany.

Sector 20 (Other transport) was not separately available for Germany either. The tables for Germany allocated this data among sectors 14 (Metal products), 15 (Non-electrical machinery) and 21(Motor vehicles). In the other countries the output for sector 20 made up less than 0.3% of total gross output and it is low compared to gross output of each of sectors 14, 15 and 21. This suggests that the way of accounting for production in sector 20 would not affect the results much. Not to violate the correspondence with the classification used in the ISDB for labor and capital, in which sectors 19, 20 and 21 constitute one sector as well as sectors 14 and 15, sector 20 was united with sector 21.

There were some cross-country differences in accounting for sectors 35 (Other producers), 36 (Statistical discrepancy). As a result all tables except for those for Japan show either very low or zero gross output reported for these sectors. In the present analysis sectors 35, 36 were aggregated with sector 34 (Producers of government services). In the future we will refer to this sector as Non-market services, since the most of it corresponds to non-market activities.

Appendix B. Bridge table showing the correspondence between IODB and ISDB.

	Title of category **IODB**	ISIC code		ISIC code	Title of category **ISDB**
1	Agriculture, hunting, forestry, fishing	1.	**1**	1.	Agriculture, hunting, forestry, fishing
2	Mining and quarrying	2.	**2**	2.	Mining and quarrying
3	Food, beverages, tobacco	31.	**3**	31.	Food, beverages, tobacco
4	Textiles, wearing apparel and leather industries	32.	**4**	32.	Textiles, wearing apparel and leather industries
5	Wood and wood products, including furniture	33.	**5**	33.	Wood and wood products, including furniture
6	Paper and paper products, printing and publishing	34.	**6**	34.	Paper and paper products, printing and publishing
7 8	Industrial chemicals Drugs and medicines	351.+352.-3522. 3522	**7**	35.	Chemicals and chemical petroleum, coal, rubber and plastic products
9	Petroleum and coal	353.+354.	**8**		
10	Rubber and plastic products	355.+356.	**9**		
11	Non-metallic mineral products	36.	**10**	36.	Non-metallic mineral products
12	Iron and steel	371.	**11**	37.	Basic metal industries
13	Non-ferrous metals	372.	**12**		
14	Metal products	381.	**13**	381.	Fabricated metal products
15	Non-electrical machinery	382.-3825.	**14**	382.	Machinery except electrical
16	Office and computing machinery	3825.	**15**		
17 18	Electric apparatus, n.e.c. Radio, TV and communication equipment	383.-3832. 3832.	**16**	383.	Electrical machinery apparatus, appliances and supplies
19	Shipbuilding and repairing	3841.	**17**	384.	Transport equipment
20 21	Other transport Motor vehicles	(384)2.+4.+9. 3843.	**18**		
22	Aircrafts	3845.	**19**		
23	Professional goods	385.	**20**	385.	Professional, scientific, measuring and controlling equipment n.e.c., photographic and optical goods
24	Other manufacturing industries	39.	**21**	39.	Other manufacturing industries
25	Electricity, gas and water	4.	**22**	4.	Electricity, gas and water
26	Construction	5.	**23**	5.	Construction
27	Wholesale and retail trade	61.+62.	**24**	61.+62.	Wholesale and retail trade
28	Restaurants and hotels	63.	**25**	63.	Restaurants and hotels
29	Transport and storage	71.	**26**	71.	Transport and storage
30	Communication	72.	**27**	72.	Communication
31	Financial institutions, insurance	81.+82.	**28**	81.+82.	Financial institutions, insurance
32	Real estate and business services	83.	**29**	83.	Real estate and business services
33	Community, social and personal services	9.	**30**	9.	Community, social and personal services
34 35 36	Producers of govern. services Other producers Statistical discrepancy		**31**		Producers of government services Other producers