ARGUMENTA OECONOMICA
No 1-2 (19) 2007
PL ISSN 1233-5835

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KNOWLEDGE CAPITAL AND TOTAL FACTOR PRODUCTIVITY

Development of "new economies" leading to economies mostly based on knowledge implies the construction of new long-term macroeconometric models. They should incorporate the impacts of new technologies being endogenized, as well as human capital. The paper discusses several issues related to the extension of the notion of production function. They cover first of all the measurement and explanation of knowledge capital and of total factor productivity (TFP), the role of domestic and foreign R&D expenditures, as well as educational expenditures. The discussion is extended to include the empirical results obtained in the world literature.

Keywords: Knowledge economy, technical progress, production functions, total factor productivity, R&D expenditures, human capital

1. INTRODUCTION

Over the last decades, market economies have expanded and their functioning has undergone deep changes. This has led many scholars to develop the concept of a "new economy". One of the major challenges was recognition of the leading role of knowledge capital in economic development. Knowledge capital has boosted the efficiency of economies' functioning through the automation of the manufacturing process, fast transmission of management information recently via the Internet, etc. It also affected economic growth, especially due to the increasing role of technical progress, development of research and educational sectors and of Information, Innovation and Technologies (ICT) industries and services. This course of events resulted in the recognition that contemporary economies tend to become knowledge based economies (Smith 2002, Welfe 2006).

The concept of knowledge capital can be broadly understood as any organized accumulation of knowledge, regardless of its forms. In

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analyzing knowledge capital impact on economic growth it is, however, suitable to distinguish between its sources and the mechanisms of its absorption.

Knowledge capital is usually split into the following components:

- generally available knowledge capital (patents, licenses, research papers, etc.) that can be freely distributed and transformed,
- knowledge capital embodied in fixed capital and represented by accumulated R&D expenditures, both of a domestic and foreign origin (technology transfers), as well as in intermediate commodities (new technologies, etc.),
- knowledge capital embodied in labour force (employment) represented by human capital per capita.

Empirical research aimed at quantifying the level and dynamics of particular components of knowledge capital involves numerous measurement problems that will be discussed below, in the next sections.

The knowledge capital impact on economic growth is typically measured using the concept of the total factor productivity (TFP) as an empirical description of the effects of technical progress.

However, the TFP dynamics is not directly observable. Therefore, various notions and procedures of its measurement implying the use of the production function concept will be discussed in the next section.

Once the empirical TFP estimates have been obtained, using either time series or cross-section (international) data, the question can be raised, how to analyze the impact of particular knowledge capital components on the TFP dynamics. A specification of the regression equations explaining the disembodied as well as embodied knowledge capital will be analyzed below. Especially, the role of cumulated R&D expenditure, both domestic and transferred from abroad, will be discussed. Various approaches to specifying the impact of human capital will be analyzed in the last section. Conclusions will follow at the end of the paper.

2. THE MEASUREMENT ISSUES OF THE KNOWLEDGE CAPITAL

The general notion of the disembodied knowledge capital covers a broad spectrum of its forms. Problems with the identification and quantification of knowledge capital led early researchers to assume that its growth was stable in time and slow, hence, it could be represented by a trend (exponential). More recently, it has been recognized that it can be depicted by several indicators such as the volume of research papers and their citations, numbers of patents and licenses (Eaton, Kortum 1996) and their citations, numbers of titles in libraries, etc. There is some hesitation about the use of the data, as it is not fully available and comparable, and not necessarily representative (i.e., patents for innovative activity). Construction of aggregate measures able to summarize these different forms of knowledge capital is not an easy task. Hence, they are used rather exceptionally.

The only commonly accepted aggregate measure of knowledge capital is cumulative real expenditures on R&D, i.e., R&D capital. They represent the knowledge potential that the research sector has developed through its activities. Such knowledge capital is augmented by additions of current real expenditures on R&D, but depreciation reduces it at a rate estimated at 15-20% annually.

It is composed of the domestic knowledge capital, represented by domestic cumulative expenditures on R&D, S_{it}^{k}, and foreign knowledge capital transferred from abroad, S_{it}^{m}, mostly from the highly industrialized countries.

Issues in measuring the impact of foreign R&D capital were broadly discussed in the last decade, but outcomes of the debates are not convincing. Let us review them in some more detail.

The cumulative real expenditures of foreign country j will be denoted by S_{it}^{k}. The impact of these expenditures on country i is defined as a weighted sum of expenditures of j countries ($j \neq i$), being the source of the transferred technology:

$$S_{it}^{m} = m_{it} \sum_{j} w_{ijt} S_{jt}^{k}, \tag{2.1}$$

where

m_{it} - ratio of country i imports to GDP of country i,

w_{ijt} - appropriate weights.

The major discussions in the last few years have concentrated around the question of how to define the relative importance of knowledge spillovers from particular countries.

Quite recently, the most important role has been attributed to channels through which foreign R&D capital spills over directly (Xu, Wang 1999, Lee

2005, Mae Garvie 2005), as opposed to the previously dominating view that the capital spills over indirectly via the trade channels (Coe, Helpman 1995).

Identification of factors supporting direct diffusion of the R&D capital across particular countries is not straightforward; it is commonly based on several indicators. They characterize the access to foreign technologies via information contained in patent citations and show the possibilities of increased speed of transmission of research information via the telecommunication channels. They also indicate which conditions facilitate the absorption of foreign R&D capital – the most frequently used are the indicators of technical proximity (Jaffe 1986).

The role of patent citations can be established by using the share of citations from the patents of country j found in the patents applied by country i in the total patent citations of country i

$$p_{ijt} = \frac{P_{ijt}}{\sum_k P_{ikt}}, \tag{2.2}$$

where

P_{ijt} - number of citations of the patents of country j found in the patents applied by country i.

More efficient and wider telecommunication infrastructure certainly helps increase the intensity of R&D capital spillovers between country i and country j, offering its R&D capital. There are several indicators that can be used, including the density of the Internet. Lee [2005] used as a proxy the number of telephone lines per capita denoted d_{jt}. The weight w_{ijt} is defined as equal

$$w_{ijt}^{d} = d_{it} \cdot d_{jt} \tag{2.3}$$

if this factor is treated in isolation.

The technological proximity that makes easier the absorption of foreign R&D capital has been defined after Jaffe (1986) in the following manner. An economy is split into k technology homogenous sectors, and shares of patents applied in country i are determined as shown in vector R_{it} below

$$R_{it} = \left(\frac{P_{i1,t}}{\sum_k P_{ik,t}} \cdots \frac{P_{ik,t}}{\sum_k P_{ik,t}} \right) \tag{2.4}$$

The measure of proximity between countries i and j is obtained as follows:

$$pr_{ijt} = \frac{R_{it}R'_{jt}}{\left[\left(R_{it}R'_{jt}\right)\left(R_{jt}R'_{jt}\right)\right]^{2}} \tag{2.5}$$

To develop a composite measure of the direct spillovers of foreign R&D stock many approaches can be used, the most natural being to take an average of the three indicators mentioned above. As the weights that could be attached to them seem arbitrary, a simple mean is advocated. Lee uses an approximation of geometric mean that defines weights attached to R&D capital of particular j countries in the following way:

$$w_{ijt} = pr_{ijt} \cdot p_{ijt} \cdot \left(d_{it} \cdot d_{jt}\right). \tag{2.6}$$

The indirect spillovers of foreign R&D capital accentuate the role of trade channels, i.e., imports to country i from k countries. It is believed that the foreign R&D capital flows are embodied in the imports of commodities. The first empirical research is owed to Coe and Helpman (1995) who advocated the view that the weights should be proportional to the shares of imports of intermediate commodities (in fact, in their empirical study they used shares of total imports, because of the lack of data on the imports of intermediate commodities). Thus, we have

$$w_{ijt} = MQ_{ijt} / \sum_j MQ_{ijt}, \tag{2.7}$$

where

MQ_{ijt} - imports of intermediate commodities by country i from country j

However, Lichtenberg and van Pottelsberghe (1998) showed that this specification might lead to aggregation biases. They proposed an alternative concept, where imports of intermediate commodities from country j were related to the value added of this country, i.e. to use the share of exports to country i from country j in its total value added:

$$w_{ijt}^{i} = MQ_{ijt} / X_{jt}, \tag{2.8}$$

where

X_{jt} - is total value added of country j.

The above formulation was criticized as insufficient, because the intermediate imports represent new technologies only. It is ignoring the fact that foreign R&D capital is mostly embodied in the imported investment goods, i.e., machinery and equipment. Xu and Wang (1999) investigated the impact of those alternative weight formulations. Their results confirmed the intuitive hypothesis that it is imports of investment goods that significantly explains the impact of foreign R&D capital spillovers on economic growth. Therefore, weights for the case of indirect R&D capital spillovers should be defined in the following manner:

$$w_{ijt}^{i} = MJ_{ijt} / X_{jt}, \tag{2.9}$$

where

MJ_{ijt} - imports of investment goods by country i from country j.

Knowledge capital embodied in labour (employment) is represented by human capital per employee. The notion of human capital is understood broadly as the summary description of individuals' properties connected with their efficiency. A whole range of measures is used to represent human capital, the choice of them being rather arbitrary. Nevertheless, all of them treat the education level of employees as crucial. The most commonly used definition of human capital H_t takes advantage of employee classification by education level i. We have:

$$H_t = \sum_i \mu_i N_{it}, \qquad (2.10)$$

where
N_{it} – number of employees belonging to the i -th educational class.
The human capital per capita h_t level is obtained from:

$$h_t = H_t / N_t = \sum_i \mu_i N_{it} / \sum_i N_{it} \qquad (2.11)$$

being the weighted sum of employment shares.

This formula can be extended by splitting employment into further groups with reference to gender, age, position, industry, etc. (Jorgenson et al 2000). The availability of the necessary demographic data in the developed countries in the last decade has made the approach feasible.

The crucial question is, however, how to find weights μ_i corresponding to particular levels of education. In early investigations this issue was ignored, as only one or two education levels were distinguished (illiterate and literate persons, say. The most frequently used approach related μ_i to the length of school education periods measured in schooling years for particular, distinguished levels, i.e., primary, secondary, and tertiary. Initially, it was estimated using the enrolment ratios that relate the number of pupils at a given age to their potential number. More recently, empirical data on the length of schooling has become available, which has considerably improved the quality of human capital estimates (Fuente 2004).

The above approach has been criticized recently, because weights established in the above manner do not reflect the market value of different education levels. It is consequently claimed that weights μ_i should reflect differences in average wages either per employee or per working hour; therefore, after normalizing with respect to the lowest wage, we have:

$$\mu_i = WP_i / WP_o, \qquad (2.12)$$

where
WP_i - average nominal wage of employees at i - th education level.

This specification has its roots in the Mincer wage equation that relates average wages to the education levels.

It has also been proposed to relate the weights to schooling costs. This approach is only exceptionally used for the lack of data, but it is interesting, because it links human capital directly to the expenditure on education. It is also compatible with the evaluation of the quality of labour input in the analyses of growth.

3. ISSUES IN MEASURING THE TOTAL FACTOR PRODUCTIVITY AND ITS GROWTH

The impact of knowledge capital on the rates of growth, i.e., on GDP growth, is frequently studied by splitting that rate of growth into effects of the primary growth factors – fixed capital and employment, on one hand, and the impact of broadly understood technical progress, represented by changes in the quality of these factors, i.e., in total factor productivity (TFP), on the other.

The TFP changes are not directly observable. They are established indirectly, most frequently using the concept of Solow residual (Solow 1957). The concept was broadly applied in international analyses. However, we shall demonstrate below that this measurement concept is not free from doubts. Let us mention issues in covering the technical progress, in empirical identification of the production factors, and the calibration problems related to the estimation of production function parameters (Welfe, ed. 2001, 2004).

It is natural to begin with a specification of production function. For the sake of simplicity, we shall use the Cobb-Douglas production function with constant returns to scale:

$$X_t^p = BA_t K_t^{\alpha} N_t^{(1-\alpha)} e_t^{\varepsilon_t} , \qquad (3.1)$$

where

X_t^p - potential output (fixed prices)

A_t - total factor productivity

K_t - fixed capital (fixed prices)

N_t - employment

ε_t - disturbance term.

The Solow residual will be determined, if we calculate the potential value of GDP, X_t^*, ignoring the impact of the technical progress, i.e, of TFP.

We then have:

$$X_t^* = BK_t^{\alpha} N_t^{1-\alpha} e^{\varepsilon_t} \tag{3.2}$$

where

X_t^* potential output obtained, if the TFP impact is ignored, i.e. $A_t \equiv 1$.

The rate of TFP growth will be obtained, if we solve (3.1) for A_t allowing for (3.2). After switching to logarithms, we have:

$$\Delta \ln A_t = \Delta \ln X_t^P - [\alpha \ln K_t + (1-\alpha)\Delta \ln N_t] \tag{3.3}$$

or in terms of the rates of growth (o):

$$\overset{\circ}{A}_t = \overset{\circ}{X}{}_t^P - [\alpha \overset{\circ}{K}_t + (1-\alpha)\overset{\circ}{N}_t], \tag{3.3'}$$

where A_t stands for TFP obtained as a residual.

The empirical application of the above concept of the TFP is not unique and it is important to notice that several authors use this concept in a narrower context.

Initially, the starting point was the concept of production function, where the primary growth factors were associated with variables representing their quality. The production function was then specified as follows:

$$X_t^P = BA_t^W (A_t^K K_t)^{\alpha} (A^N N_t)^{(1-\alpha)} e^{\varepsilon_t}, \tag{3.4}$$

where:

A_t^W - general technical progress except that embodied in fixed capital and labour,

A_t^K - technical progress embodied in fixed capital and representing its quality,

A_t^N - technical progress embodied in employment and representing its quality, i.e. human capital per employee.

When this concept of production function is used, the TFP notion is reduced to A_t^W which stands for the impact of narrowly defined disembodied technical progress. At first, this concept was broadly applied. More recently, Jorgenson et al. (2003) used it in his study of growth determinants in the USA.

In early studies, the quality of fixed capital was represented by a weighted sum of fixed capital generations assuming their declining efficiency (Solow 1962), then also more simply by splitting fixed capital into new and old fixed capital. More recently, a tendency has emerged to split up the fixed capital into high-tech and the remaining branches, with higher elasticities expected for the first group. For the less developed countries the same role is played by distinguishing between domestic fixed capital and imported fixed capital (or their additions), lately substituted by relating the imported machines to FDI inputs. However, the most important seems to be the distinction within fixed capital between ICT and non-ICT items. The first include computers, computer programs and teleinformation infrastructure and are treated either separately or jointly (Jorgenson et al, 2000, Richards 2000, Collechia and Schreyer 2002, van Leeuwen and van der Wiel 2003). In that case, the impact of computerization on the industrial process will be shown separately, and the TFP scope correspondingly constrained.

When specific quality characteristics of the labour input are introduced simultaneously, as in the production possibility frontier models by Jorgenson (2000), then the TFP will be understood as equal to A_t^W in (3.4).

Let us notice that many scholars treat human capital as a separate, additional factor in the production function (Benhabib and Spiegel 1994). In such a case, the production function can be written as follows:

$$X_t^P = BA_t^W (A_t^K K_t)^\alpha N_t^\beta H_t^{(1-\alpha-\beta)} e^{\varepsilon_t}, \tag{3.5}$$

where:

H_t - human capital per capita.

If the quality of fixed capital is separable, then the TFP will be defined as

$$A_t^1 = A_t^W (A_t^K)^\alpha \tag{3.6}$$

which means that in this case the TFP will reflect the impact of autonomous technical progress and progress embodied in fixed capital only.

The above distinctions are necessary in order to avoid misunderstandings in interpreting the empirical results of estimation of the TFP growth rates.

Nevertheless, let us return to the original broad meaning of the TFP given in (3.3). Assuming that the quality indicators are separable, then using (3.4), we can write:

$$A_t = A_t^W (A_t^K)^\alpha (A_t^N)^{1-\alpha} . \tag{3.7}$$

This TFP decomposition will be further used in specifying regressions explaining the TFP dynamics.

In order to calculate empirically values of the TFP increase using (3.3) or (3.3'), we need information approximating the rate of growth of potential output X_t^P, which is not directly observable. This is frequently approximated by means of the rate of growth of observed, effective GDP (or value added) in real terms being the realization of final demand for domestic output. We then have an estimate of the rate of growth of the residual obtained by subtracting rates of growth of the potential output that ignores the TFP impact from the rate of growth of effective GDP X_t:

$$\overset{\circ}{RES}_t = \overset{\circ}{X}_t - [\alpha \overset{\circ}{K}_t + (1-\alpha) \overset{\circ}{N}_t], \tag{3.8}$$

or in logarithms:

$$\Delta \ln RES_t = \Delta \ln X_t - \alpha \Delta \ln K_t - (1-\alpha) \Delta \ln N_t \tag{3.8'}$$

This calculation may lead to a biased estimate of the TFP growth, as it reflects not only the impacts of technical progress, but also shocks affecting the final demand that induce changes in the rate of utilization of capacity output.

Let us define the rate of utilization of capacity output WX_t as

$$WX_t = X_t / X_t^P \tag{3.9}$$

From the definition it follows that effective output X_t is expressed by

$X_t = WX_t X_t^P$, and hence

$$\overset{\circ}{X}_t = W\overset{\circ}{X}_t + \overset{\circ}{X}{}_t^P . \tag{3.10}$$

If we now substitute for $\overset{\circ}{X}_t$ in equation (3.8), we obtain

$$R\overset{\circ}{E}S_t = W\overset{\circ}{X}_t + [\overset{\circ}{X}{}_t^P - \alpha \overset{\circ}{K}_t - (1-\alpha)\overset{\circ}{N}_t] = W\overset{\circ}{X}_t + \overset{\circ}{A}_t . \tag{3.11}$$

This explicitly shows that only if the capacity utilization rate does not change, i.e., $W\overset{\circ}{X}_t = 0$, the dynamics of the RESIDUAL will represent the dynamics of technical progress.

This condition is frequently not met, especially when the TFP growth is analyzed for countries where the capacity utilization rate shows substantial variations. It may reflect fluctuations in the business cycle, thus over- or underestimating the rate of GDP growth.

To deal with this obstacle, studies (mainly international) operating long time series use five or ten year averages or operating short time series use hours worked instead of numbers of employees. Otherwise, attempts are made to define relevant measures of the capacity utilization rates. The applied methods differ in respect of accuracy and rely on data availability. Let us mention first the direct measurement procedures that take advantage of business survey data, broadly applied in the EU (cf. Grzęda-Latocha 2005).

Next, methods are used that analyze deviations from the output trend and look for estimates of output gaps; they are popular at central banks' research units. They may serve as indicators of market tensions and changes in the expected rates of inflation, but they are questionable as measures of the rates of utilization of capacity output: in fact, the utilization rates exceed 100%, i.e., yield positive deviations only exceptionally. This criticism does not apply to methods, where the trend links the peaks, i.e., maximum values of output or the capital productivity in the business cycle.

Methods based on observations of the utilization rates of discernible production factors are used less frequently. In principle, we can decompose the rate of capacity utilization into the rates of utilization of production factors, i.e. fixed capital and employment. As for the fixed capital, it has been proposed to replace total fixed capital with its working component, i.e., machinery and equipment.

The lack of suitable information at macro-level allows of no determination of the rate of utilization in terms of hours or shifts worked, i.e., flows of fixed capital services. Having in mind that they are correlated with employees' working time (or at least with the number of shifts worked) these indicators can be used as proxies in estimating the rate of utilization of fixed capital. Introduction of hours worked by employees to the production function instead of employee numbers helps fulfill the requirement that the rate of labour utilization should be taken into account. This is so because the number of hours worked can be split into the number of employees and their average working time. This requirement, however, could not be met for Poland because of the unavailability of relevant data (Welfe 1992).

Several issues are related to the construction and estimation of parameters of the production function (3.1), (Welfe 2002).

Firstly, the choice of an output measure is an issue. Regarding the macro scale, a typical assumption is that production should be represented by value added (GDP in terms of the entire economy), which is equivalent to introducing only the primary production factors, i.e., fixed capital and employment, to the production function. For the micro scale and frequently also the mezzo scale (sectors, branches), the gross (or sold) output is used quite often, where it is more easily available and calculated more precisely. This approach, however, involves the modification of the production function (3.1) by adding the use of intermediate inputs (energy and materials) as explanatory variables, i.e., by applying the KLEM production function. The last requirement cannot be easily met because of the shortage of information about intermediate inputs.

Secondly, by using formula (3.3) or (3.11) it is assumed that parameter α is known, i.e., the elasticity of output with respect to fixed capital. There are two ways of obtaining the parameter's estimate: either by estimating parameters of production function (3.1) or via calibration. In the first case, the equation explaining the TFP (i.e., A_t) needs a more detailed specification, which is discussed below. The other approach, quite common, takes advantage of the neoclassical theory of production. According to its results, parameter α can be approximated using the share of surplus in value added, that is by deducting the share of labour costs in value added from one. Although broadly applied in the empirical research, it also gives rise to doubts, since share α is evolving in the long term, and additionally labour costs definitions are not applied in a uniform manner. For instance, various investigations took α values for Poland ranging from 0.25 to 0.5. The differences resulted in considerable variations in the estimates of TFP dynamics, because slowly expanding volumes of fixed capital were accompanied by fluctuations in employment and especially in several years by its decline (Welfe 2002).

To illustrate the likely discrepancies in TFP growth caused by differences in the calibrated values of α let us show the calculated values of the average rates of TFP growth using data for Poland for a period covering years 1998-2000. In that period, average rates of GDP growth were 4.3%, 3.4% for total fixed capital, and 0.9% for employment. For these values, the following average rates of TFP growth were obtained using different elasticities α :

Elasticity α	0.25	0.30	0.35	0.40	0.50	0.60	0.70
Average percentage rate of TFP growth	5.0	4.6	4.3	3.9	3.3	2.6	2.0

(Source: Welfe, 2002)

Let us notice that α values of 0.35 and less yield higher rates of growth for the TFP than GDP, which is quite unreasonable. Only for $0.6<\alpha<0.7$ the rates of TFP growth approached ca 50% of the GDP growth rates, which for Poland still seems very high.

The above analysis leads to a conclusion that the calibration of elasticity α may easily result in hardly acceptable estimates of the TFP rates of growth. Elasticities of α should rather be estimated from the data using the production functions. This, however, would imply that the TFP rates of growth need to be endogenized, related to the growth rates of particular components of knowledge capital discussed in the previous paragraph.

4. EQUATIONS EXPLAINING TOTAL FACTOR PRODUCTIVITY GROWTH. THE ROLE OF KNOWLEDGE CAPITAL

Explanation of the TFP growth most frequently requires TFP decomposition into homogenous components. As it was mentioned above, the most suitable decomposition relies on differences between forms of knowledge capital. We shall distinguish the impacts of generally available disembodied knowledge capital (A_t^W), then the effects of knowledge capital embodied in fixed capital (A_t^K), and labour force (human capital per capita A_t^W). This decomposition for the Cobb-Douglas production function was shown in (3.7).

The effects of growth of generally available knowledge capital (A_t^W) are either treated as exogenous (most frequently represented by an exponential trend) or associated with employment.

The explanation of the TFP growth due to the growth of knowledge capital embodied in fixed capital (A_t^K) is quite complex and calls for an extensive, further discussion. The major explanatory variable is cumulated R&D real expenditures, both domestic (S_t^k) and transferred from abroad (S_t^m). Its changes represent the potential impact of technological and organizational knowledge (Coe and Helpman 1995).

It is usually assumed that this relationship is multiplicative. Hence, we have

$$\ln A_t^K = \beta_1 \ln S_t^k + \beta_2 m \ln S_t^m. \tag{4.1}$$

An estimation of the equation's parameters requires that either all components of the TFP, i.e., A_t given by (3.7), will be taken into account as in Welfe, ed. (2001), or the human capital will be neglected as in the early studies by Coe and Helpman (1995). In both cases, parameters β_1 and β_2 can be interpreted as TFP elasticities with respect to the domestic and foreign real R&D capital stock, respectively.

At the macro level, the international time series cross-section data were used most frequently. Studies by Coe and Helpman (1995) were based on a 1971-1990 time series cross-section international sample for 22 countries. They provided the following results. The TFP elasticities with respect to the domestic R&D stock ranged from 0.06 to 0.10, likewise results obtained for particular countries. The average for 22 countries was 0.078, but 0.156 for the G7 countries. Results obtained in a further study (Bayoumi et al 1999) yielded somewhat different results. For the G7 countries, the elasticity went up to 0.24, but for the small industrial countries it was 0.08 and almost zero for the non-oil developing countries.

However, the estimates were biased, as the omitted human capital per capita variable was not uncorrelated with the R&D stock. The investigation by Engelbrecht (1997) showed that for the sample of 21 OECD countries based on 1971-1985 data the estimate of β_1 was 0.08, when human capital was neglected, but after lagged human capital per capita was introduced it went down to 0.055, still being high. Using imports of capital goods as weights in foreign R&D stock spillovers, Xu and Wang (2000) received average elasticity of 0.068 and for G7 0.138. A recent study by Lee (2005), where the human capital was neglected, but direct spillovers of foreign R&D capital introduced, showed similar significant results for the major estimation procedures as biased adjusted OLS.

The studies for particular countries using time series were recently less frequent. Let us mention the results obtained for the US economy by Richards (2000) who analyzed the impact of domestic R&D only. He distinguished, however, several components of fixed capital, including computers. His results have shown increasing elasticities with respect to R&D, which in turn was related to rising computer quality.

The results for Poland based on time series covering the sample 1970-1998 were not far from the above estimates for the OECD countries. They were obtained in the variant constraining fixed capital to machines and equipment with human capital per employee as explanatory variable (Welfe ed. 2001).

The treatment of the impacts of foreign R&D capital transfers was the subject of extensive discussions. Initially, the indirect international R&D spillovers via foreign trade channels were distinguished. More recently, direct R&D spillovers were analyzed. A few authors (Xu and Wang 1999, Lee 2005) stressed the importance of direct spillovers. This approach is reflected in the construction of the foreign R&D capital mentioned in section 2. The foreign R&D capital is typically defined as a weighted sum of selected countries R&D capital:

$$S_{it}^{m} = m_{it} \sum_{j} w_{ijt} S_{jt}^{k} , \tag{4.2}$$

where
$j \neq i$

w_{ijt} - fraction of j-th country's R&D stock that spills over to country i,

$\sum_j w_{ijt} = 1$,

m_{it} - total imports to GDP ratio in country i.

For the direct spillovers, weights w_{ijt} represent particular countries' shares in determining the total impact of transfers of foreign R&D capital obtained using either particular determinants, e.g., the telephone line penetration, or their composite measure (geometric average) including, for instance, also the number of patent citations and measures of technical proximity.

Empirical results obtained by Lee (2005) who used a 1971-2000 sample with 510 observations yielded positive and significant elasticities of the TFP with respect to the composite variable showing the impact of direct spillovers. After several estimation procedures, these elasticities concentrated around two values – 0.02 and 0.04. In the regression equations, the impact of both domestic and indirectly transferred R&D stock was controlled.

Investigations in the effects of indirect R&D stock spillovers via foreign trade channels have a much longer tradition and have been more controversial. Initially, Coe and Helpman (1995) suggested that weights w_{ijt} should represent the shares of imports of intermediate commodities from particular exporting countries, i.e.,

$$w_{ijt} = MQ_{ijt} / MQ_{it} \tag{4.3}$$

where

MQ_{ijt} - imports of intermediate commodities from country j,

$MQ_{it} = \sum_j MQ_{ijt}$.

Because of data scarcity, they used total imports in their study instead.

This approach was criticized by Lichtenberg and van Pottelsberghe (1998) who suggested that in order to avoid potential aggregation bias, the weights should represent ratios of imports from country j to that country's total value added, i.e., shares of exports to country i from country j in the total value added of that country.

However, it has been pointed out that imports of the intermediate commodities represent only the impact of technological innovations, whereas most of the embodied R&D stock spillovers are transferred via the imports of investment goods (machinery and equipment). Coe et al (1997) found that trade in capital goods is a better measure of indirect spillovers than total imports. More recently, Xu & Wang (1999) have shown using the 1983-1990 data for OECD that the use of imports of capital goods is superior to alternative solutions (non-capital goods or total imports). The elasticities they obtained were close to 0.24, when regressions ignored the impact of total and non-capital goods imports.

In the next study (2000), they used the Coe-Heplman 1971-1990 sample and obtained slightly lower elasticity estimates – 0.19. However, for regressions controlling human capital and direct spillovers measured in a controversial way by means of the unweighted sum of foreign R&D capital they obtained elasticities of only 0.08-0.10.

The indirect foreign technology transfer most frequently takes an organized form and accompanies foreign direct investment (FDI). Multinational corporations either build new factories or reconstruct old ones, mostly in less developed countries. Hence, inward and outward FDI was proposed as an additional channel of foreign R&D stock spillovers (Saggi et al, 2000; van Pottelsberghe and Lichtenberg 2001). It has been argued that the FDI flows stimulate domestic technical progress rather than affect TFP growth via the imports of investment goods, which partly justifies the separate treatment of the FDI flows.

In this case, we have to define an additional variable representing the foreign R&D stock transferred via the FDI channel:

$$FD_{it} = \sum_{j} \mu_{ijt} S_{jt}^{k}, \tag{4.4}$$

where

$\mu_{ijt} = FDI_{ijt} / Q_{jt}$

FDI_{ijt} - foreign direct investment flowing from country j to country i (constant prices)

Q_{jt} - either GDP of country j (X_{jt}) after Wang (2000), or gross fixed capital formation of country j (I_{jt}), after Pottelsberghe and Lichtenberg (2001).

FDI inflow from j countries should primarily represent the knowledge potential of these countries. Hence, its cumulated or average value over a certain period should be represented, rather than its value in a particular year t. Therefore, Pottelsberghe and Lichtenberg (2001) used a 4 year moving average in their empirical study. According to them, the elasticity of TFP with respect to outward FDI was equal to 0.053, and statistically significant. The authors controlled for domestic and foreign R&D spillovers. Taking first differences, they obtained a slightly lower, but also significant, result 0.04.

Many authors emphasized that the absorption of FDI requires the receiving country to have a minimum level of domestic R&D activities and skilled personnel. Consequently, further extensions of the TFP function were proposed towards introducing the interactive variables, mainly $FD_{it}S_{it}^{k}$ and $FD_{it}H_{it}$, where H_{it} denotes domestic human capital (Borensztein et al, 1998). In the latter case, it has been shown that unless a certain level of human capital per capita is achieved, the impact of FDI can be meaningless (Crispoli and Mazconi 2005). Their result is higher than those shown previously – 0.098, but after the term with H_{it} was introduced, it fell to 0.06. When the elasticity with respect to the composite variable was introduced, it went down to 0.009.

The above discussion leads to the following specification of the extended equation explaining the TFP:

$$\begin{aligned} \ln A_{it} &= \beta_o + \beta_1 \ln S_{it}^{k} + \beta_2 m_i \ln S_{it}^{m} + \beta_3 \ln FD_{it} + \\ &+ \beta_4 m_i \ln S_{it}^{m} FD_{it} + \beta_5 \ln H_{it} + \beta_o \ln H_{it} FD_{it} + \xi_{it} \end{aligned} \tag{4.5}$$

This does not put an end to the discussion about the role of foreign R&D capital spillovers. It has been emphasized that institutional differences and/or changes should be taken into account (Prescott 1998), as well as the technical proximity, the distance between countries, etc.

For a long time, the impact of human capital growth was a highly controversial and long-disputed subject. Let us recall that human capital is – following Lucas – frequently viewed as an independent production factor and excluded from the TFP notion. In our opinion, this approach is not legitimate as human capital per employee represents the quality of labour input and should be treated jointly with R&D capital. It is positively linked to the absorption of foreign capital (accumulated R&D), according to the Nelson and Phelps approach, as we mentioned above.

Notwithstanding, it has to be stated that the issue and explanation of the human capital impact requires an extended scope of research. Many researchers still operate primitive approaches and only use data on the share of employees with higher education among the economically active, or even on graduates/school-leavers or students in secondary schools or higher learning institutions, even though global measures of human capital per worker have been developed.

Very broadly, human capital can be presented as a weighted sum of the number of the economically active persons by level of education (N_{it}):

$$H_t = \sum_i \mu_{\hat{i}t} N_{\hat{i}t}, \qquad ¢(4.6)$$

where i - education level (for instance, primary, secondary, tertiary)

μ_{it} - weight attached to education level I

Human capital per worker h_t is obtained by dividing total human capital by the total number of employees (N_t):

$$h_t = H_t / N_t = \sum_i \mu_{it} N_{it} / N_t \,. \qquad (4.7)$$

The weights may represent: a) a standardized number of school years, hence the right-hand side stands for total school years of the economically active population; b) the average wages earned by persons with different education levels; c) average costs of education, as has been mentioned in section 2.

The first approach, frequently used in regressions based on cross-section international databases, did not bring convincing results for many years (Benhabib and Spiegel 1994, and followers). The main reason was deficiencies of the international databases. The most recent results of research based on improved data samples show that the impact of human capital measured thereby (mainly treated as a separate regressor) provide statistically reliable, convincing results (Fuente 2004).

Let us reproduce the results shown in Fuente's paper against the previous estimates of the output elasticities with respect to human capital (per employee). They were based on a Cobb-Douglas production function with constant returns to scale obtained using different specifications and schooling years for the OECD countries for the period 1960-1990 (Fuente 2004, table 4, 103).

The results were obtained using both levels and first differences in logs. The most important are (t-statistics in brackets):

Table 1

Elasticities of output with respect to human capital

	Levels	First difference
Nehru et *al*. (1995)	0.078 (2.02)	0.079 (0.70)
Barro and Lee (1996)	0.165 (4.82)	0.083 (1.47)
Cohen and Soto (2001)	0.397 (7.98)	0.525 (2.57)
Fuente and Domenech (2000)	0.407 (7.76)	0.520 (2.17)

Source: Fuente 2004, table 4, 103

All the estimates using levels were statistically significant. However, earlier studies indicated a much lower impact, whereas estimates based on first differences were significant only for the latest studies and showed a much stronger impact not essentially exceeding that obtained for levels.

All the studies do not explicitly control the impact of R&D spillovers. Engelbrecht (2002) accounts for the indirect R&D spillovers using machinery and equipment imports as weights in his study on the impact of human capital on developing countries. All specifications use, as we mentioned above, average numbers of schooling years as a proxy for the stock of human capital.

The second approach that we described has a more profound theoretical basis. Of course, wage relations between employees with different education levels stand for the differences in schooling years, as Mincer suggested (Krueger and Lindahl 2001, 1003-1007). However, they primarily represent the market efficiency of different levels of education.

The choice of the above variables is not an academic issue. The empirical results of comparisons of human capital dynamics for Poland are substantially diversified. For the period 1991-1998, the average annual rate of human capital growth per employee was 0.54% when wage ratios were applied, and 0.78% for schooling years (Welfe, ed. 2001, Welfe et al 2002).

Let us remind ourselves that the composition of employees can be extended even further. In the industrial studies, employees can be broken down by gender, age, position, etc. (for the USA, see Jorgenson et al 2000). Its broader application depends on the availability of detailed and updated databases on changes in employment structures that the highly developed countries have only started to build.

The third approach accentuating differences in education costs is rarely used, mainly because of the scarcity of more detailed data. This approach has an obvious advantage – it allows a direct link between the investments in human capital and total educational expenditures (Welfe 2005).

A particularly difficult task is trying to relate investments in human capital to expenditures on education (BDE_t). A relevant submodel of educational sector has yet to be constructed (Welfe et al 2002). The above indicated measures are not perfect, because they disregard post-graduate education, effects of learning by doing, consequences of the rising level of culture (e.g. the scale of readership), population's health condition, as well as effects of economic migration and many others (see Benabou 2002). The issues should be given possibly full treatment on a macro scale, so that new methodological solutions could be developed, taking into account the aforementioned broad aspects of expanding human capital.

5. FINAL COMMENTS

The problems that we have raised will be the subject of many research projects mainly utilizing international databases with time-series cross-section data. Research projects aimed to study the impacts of knowledge capital in particular countries will be continued. The Polish economy will also be the subject of further studies by the University of Łódź Centre. The research will take advantage of new macroeconometric W8D models of the Polish economy programmed to study the knowledge-based economy. Preliminary outcomes of the research are promising and will be reported on in separate papers.

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Received: February 2007