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GROWTH DETERMINANTS OF ECONOMIC POTENTIAL. THE POLISH CASE[1]

New long-term annual W8-D model of the Polish economy was constructed. Its core constitutes of extended Cobb-Douglas production function aimed to generate potential GDP and TFP. TFP growth was related to the increase in domestic and transferred foreign R&D capital and human capital. All these variables were further endogenized.
The paper outlines the underlying theory starting with the extended Solow's production function and allowing for the outcome of the theory of endogenous growth. In the empirical part the paper shows parameter estimates of production function for Poland (sample 1966–1998). Potential GDP was calculated. Further calculations show that the impact of primary production factors was decisive for its growth, TFP growth rates for transition period explain 10–30% of potential GDP increase only. Total impact of R&D amounts at nearly 3/4 of TFP increase, imported technology being decisive, whereas human capital impact stays below 1/4 TFP increase.

Last decades of XX century witnessed the development of empirical research aimed at explaining the differences in growth rates in the world economy. Starting from neoclassical framework – following R.Solow the researches tried to measure the impact of technical progress. Further they attempted to endogenize it, making use of endogenous theory of growth.

Many country studies were developed in order to explain the impact of particular factors of growth in East-Asia, especially to distinguish the impact of primary factors (fixed capital, employment) and total factor productivity (TFP).

Next developments were related to the studies on differences in the growth rates per capita (convergence hypothesis) based on cross-sectional date, where the impact of human capital was distsingnished. Independently studies were developed initialed by E. Helpman on the impact of R&D capital on the TFP growth based on cross sections of countries.

These developments led us to the conclusion, that it would be worth wile to extend production function for a single country allowing simultaneously for the impact of R&D capital and human capital.

The major aim of this paper is to discuss the above issues in some detail and to show the results of such an empirical exercises for Poland, which might be of use to the administrative bodies engaged in elaborating long-term scenarios of economic growth.

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We had to clarify first the major conceptual issues. The analysis of GDP fluctuations in short – and medium term in a market economy rests on an analysis of final foreign and domestic demand, assuming that production potential is not fully utilized. Our aim is, however, to study the development of potential GDP. Hence, the focus should rest on the impact of major factors of growth – fixed capital, labour and technical progress represented by TFP. Hence, we had to estimate first the level and changes in potential GDP for Poland and the rates of its utilization (there is no official data on it). This allowed to answer the question to what extent the effective rates of GDP growth were accompanied by the increase in production potential and by its higher or lower utilization[2].

Next we had to analyze the impact of the growth in the primary production factors (fixed capital and labor) on the one hand and of the absorption of broadly understood technological progress, on the other hand.

The first section provides theoretical premises for empirical growth analyses, building on the endogenous growth theory assumptions.[3] It allowed us to derive the production function for Poland within the long-term model W8-D of the Polish economy. The next section presents estimates of the function's parameters based on the productivity function of the fixed assets. It also shows results of empirical analysis that reveals the impact on GDP growth of changes in the production capacities and their rates of utilization.

Then the results of estimation of the dynamics of the total productivity of production factors (TFP) for Poland will be presented – in the context of international research outcomes. These estimates will be based both on *macro accounting* as well as on parameter estimates of the aforementioned production function.

Following these outcomes the results of an attempt to break down TFP growth will be shown. The decomposition into effects of technological progress embodied in fixed assets, allowing for its relationships with R&D real capital both domestic and foreign and then represented by employees (analyses of changes occurring in human capital) will be outlined.

Our results will be presented mainly for the last decade (1990s) and partly for earlier years, which will enable international comparisons[4].

Theoretical basis for analysing potential economic growth. Empirical analyses of economic development based on growth models use production functions that allow to generate potential output (in macro scale GDP). These are usually generalized two-factor production functions that take into account effects of broadly understood technological progress. Such effects are usually considered to be represented by this part of production growth that cannot be attributed to the increment in the primary production factors: fixed assets and labour, called Solow

[2] This helped to settle the dispute whether or to what extent the transformation-related recession contributed to the elimination of under performing production factors, i.e. machinery equipment, or to the decline in the rate of utilization of production capacities.

[3] A more elaborate discussion can be found in W.Welfe [2000].

[4] The presented results base on results of research conducted under the KBN research project H02BO1914 entitled "Econometric Growth Models and their Implications in the Analysis of Potential Economic Development of Poland". In this research participated in different stages also W.Florczak, L.Sabanty and A.Welfe.

residual (Solow [1975]). They are generally assumed to reflect increments in total factor productivity (TFP) being due to a higher efficiency of machinery equipment, quality (qualifications) of the labour force, i.e. human capital and the general knowledge of science, technology and organization. Initially it was believed that the only way to describe these processes was using time functions and treating them as exogenous. In the last years attempts were taken to make them endogenous.

It was assumed therefore that the major engine of the higher productivity of machinery equipment was innovation and implementation of new domestic and foreign technologies that together could be accounted for by patents and or expenditures on R&D. The latter depend on the GDP and the propensity to invest in research and development.

On the other hand, it was accepted that a higher labour force quality results from a growing share of persons with higher levels of education (secondary, higher), participation in vocational improvement and gaining vocational experience. Development of human capital, being a concise characteristics of the labour force, can be accomplished through outlays on education and vocational training. Such outlays are determined by the GDP and propensity to invest in human abilities.

It should be stressed that the above discussion concerns potential output (GDP) and not effective output which in most cases expresses actual realization of the final demand for domestic output – as it was mentioned above. Indeed the assumption taken in the growth theory that production is realized at a level equal to the potential output is frequently not met. It is one of the severe problems that arise from empirical applications of the growth models.

Production functions used in econometric analyses of growth are usually Cobb-Douglas functions and are built on assumptions taken by R.Solow [1957], and particularly that the production function is characterized by constant returns to scale and a declining marginal productivity of fixed capital and labour, as well as limited substitutability of the above production factors. Hence we have:

$$X_t = A_t K_t^a N_t^{(1-a)} e^{\varepsilon_t}, \tag{1}$$

where: X_t – GDP or value added (constant prices), K_t –fixed assets (constant prices), N_t – number of employees , A_t – total factors productivity (TFP), ε_t – disturbance term.

It can be proved though that this form can be derived from the identity describing GDP distribution while ignoring neoclassical premises, assuming however that shares of labor costs and fixed capital are constant in time (see W.Welfe [2000]).

This function's parameters are frequently calibrated and elasticises of production with respect to fixed capital are taken as equal to the share of real capital outlays represented by the gross surplus.

Parameters of function (1) are estimated assuming constant returns to scale, and hence using the functions of labour productivity or fixed capital productivity derived from that function. The logarithms of variables are taken and possibly refer to their first differences in order to allow for variable non-stationarity. OLS is frequently applied.

Extended production function for Poland. The production function parameters were estimated according to the aforementioned rules within the framework of the long-term model W8-D of Polish economy. The estimation was based on the sample covering years 1966–1998 and reconciled with the previous versions of the W8 model (R.Courbis, W.Welfe, eds. [1999]). The following modifications were introduced to function (1).

To avoid specification errors resulting from omitted disturbance effects produced by sudden demand shocks (e.g. the drop in the period 1991–92) or supply shocks (e.g. foreign exchange restrictions constraining imports in the years 1980–81) various methods were generally used. In the analyses of the Far East countries it was attempted to expand the production function (1) to include foreign demand components (Fagerberg [1987], Gapiński [1996]). However, the construction of mixed demand-supply production functions provokes many reservations regarding the identification of the function's parameters. Hence we deem that it is more correct to expand the production function (1) by allowing for the characteristics of the rate of utilization of production factors, especially that they also reflect the effects of supply shocks (W.Welfe [1992, 1999]). In analyses made for Poland two such proxies were introduced – rate of utilization of shifts (WKZ_t) and of working time (WN_t). This turned out to be insufficient, so for years with such shocks corresponding dummy variables were additionally introduced.

Fixed assets variables usually relate to their totals. In the analyses for Poland two variants were distinguished – machinery and equipment (KM_t) playing an active role in production, and total fixed assets (K_t), with priority given to the first variant.

Data on fixed assets usually describes average levels over a year. Consequently, their changes must not necessarily reflect the changes in the volume of fixed capital services as the rate of utilization of fixed assets may change in time. Hence, it was assumed that their changes are symmetric to the changes in employment, more specifically to the modifications in the shift set-up. So in analyses for Poland average levels of fixed assets were adjusted by including the shift utilization rate (WKZ_t).

In effect, parameters of the labour productivity and productivity of fixed assets function were estimated by two variants – using the capital-labour ratio for machinery equipment only and for all fixed assets. In the next analyses only the fixed asset productivity functions were employed. Notice, that estimates of these functions' parameters do not significantly differ from estimates of the labour productivity function's parameters.

Functions of fixed assets productivity are presented below in such a way so to clearly isolate the TFP effects, i.e. A_t[5]. For the machinery equipment-labour ratio the below results have been obtained:

$$\Delta \ln(X_i / KM_t) = -\underset{(4,7)}{0,501}\Delta \ln(KM_t WKZ_t / N_t) + \underset{(4,8)}{1,075}\Delta \ln WKZ_t +$$

$$+ \underset{(1,6)}{0,558}\Delta \ln WN_t + \Delta \ln A_t - \underset{(6,8)}{0,0900}U7981_t + \underset{(2,7)}{0,0448}U8384_t - \underset{(3,4)}{0,107}U90_t; \quad (2)$$

$$\bar{R}^2 = 0,848; \qquad DW = 2,0; \qquad \bar{R}_L^2 = 0,998; \qquad DW_L = 1,6,$$

[5] In the estimation process A_t decomposition was used that we discuss below. Namely, human capital per employee was combined with the number employees, using in the estimation the human capital variable and not one representing the number of employees.

where $A_t = TFP$ – effects of technological progress whose specification will be given in the next sections, L is characteristics calculated for levels of variables. In brackets can be found absolute values of t-Student statistics.

Dummy variables were introduced to isolate demand and supply shocks whose effects were insufficiently reported by variables expressing changes in the rate of utilization of production factors.

For total fixed assets-labour ratio the following results were obtained:

$$\begin{aligned}\Delta \ln(X_t / K_t) = \underset{(1,4)}{0{,}0133} - \underset{(1,3)}{0{,}381}\,\Delta \ln(K_t WKZ_t / N_t) + \underset{(4,4)}{1{,}226}\,\Delta \ln WKZ_t + \\ + \underset{(2,1)}{0{,}722}\,\Delta \ln WN_t + \Delta \ln AK_t - \underset{(7,4)}{0{,}0999}\,U7981_1 + \\ + \underset{(2,10)}{0{,}0348}\,U8384_t - \underset{(3,1)}{0{,}0934}\,U90_t\end{aligned} \qquad (3)$$

$$\overline{R^2} = 0{,}870; \qquad DW = 2{,}5; \qquad \overline{R_L^2} = 0{,}994; \qquad DW_L = 2{,}2,$$

where AK_t – TFP for the variant with total fixed assets-labour ratio.

So, following estimates of production elasticity with respect to fixed assets (a) were obtained for two variants – with machinery equipment $\alpha = 0{,}50$ and with total fixed assets $\alpha = 0{,}62$. Elasticities obtained for the first variant are closer to those provided by international research.

The above functions were used to determine potential GDP values, taking $WKZ_t = 1$. The dynamics of these values as well as primary production factors for five year periods can be found in Table 1 and in Graph 1.

In the 1980s potential output showed slightly positive average rate of growth with a small average decline in effective GDP, which was accompanied by a regularly falling rate of utilization of production capacities. During the first half of 1990s the production capacities growth was slightly slower than effective production which slightly improved the rate of utilization of the production capacities. However, in the second half of that decade the situation reversed, as high GDP growth was accompanied by faster growing capacities because of a considerable expansion of investments and fixed assets. In effect, the rate of utilization of capacities slowly declined.

Table 1

Average percentage rates of GDP growth and production factors in the years 1981–2000

Macro variables	**1981–1985**	**1986–1990**	**1991–1995**	**1996–2000**
GDP	-0,20	-0,88	2,21	5,38
Potential GDP	1,93	0,30	2,13	5,66
Rate of utilization of production capacities	-2,10	-1,18	0,08	-0,26
Fixed assets	2,56	2,67	1,82	4,93
of which:				
Machinery and equipment	2,82	4,08	3,60	9,65
Employees	-0,22	-1,35	-1,97	1,02

Sources: Statistical Yearbooks; for the year 2000. LIFEA forecast [2000] and author's calculations based on the productivity function of machinery and equipment.

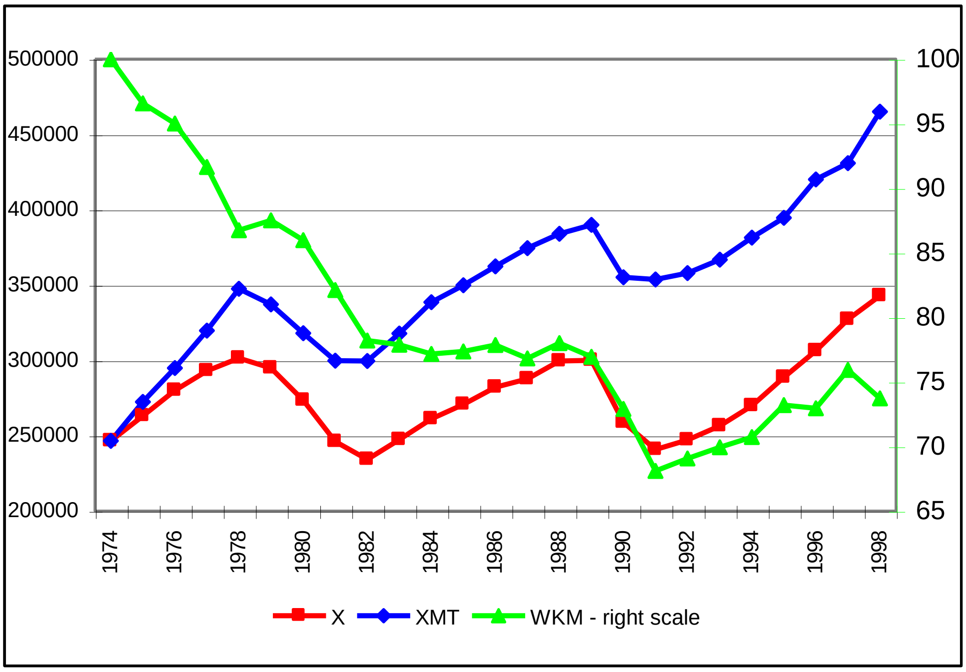

Figure 1. Dynamics of effective GDP (X) and potential GDP (XMT) for productivity of machinery and equipment (mln zł 1995) and the rate of utilisation of potential GDP (WKM) in %

Such comparisons can be misleading because of the transformation-related recession present from the outset of 1990s and growth deceleration from 1998. Periodicity taking into account these disturbances would be more adequate. It gives a slightly different picture. Namely, more detailed estimates show that as a result of the transformation-related recession the 20% GDP drop in the years 1990–1991 was accompanied – despite the continuously expanding fixed capital – by a reduction in the effective production capacity reaching almost 9%. This evidenced that the utilization of a corresponding portion of machinery equipment was permanently given up. The rate of utilization of the production capacities dropped significantly from 77% in 1989 to 68% in 1991 (see also P.Glikman [2000]).

In the first period of recovery the potential GDP grew at a similar rate as the effective GDP, likewise in the years 1994–1997, with the exception that the rates were high then (GDP at 6,3% and capacity at 6,4%). Hence, the rate of capacity utilization remained basically unchanged. This situation reversed in the period 1998–2000 when capacity – as a result of the 1995–1997 investments – continued to grow at a high rate (6,5%), whereas the rate of GDP's effective growth went down to above 4%, which brought about a decline in the rate of utilization of production capacity again (to 72%).

The increment in production capacities was mainly due to the expansion of real capital (growing investments in fixed assets) combined with the realization of technological progress flowing in mainly from abroad, but also to growing human capital that accompanied changes in the number of employces. This will be discussed below.

Estimates of total factor productivity growth. In the 1990s numerous studies were undertaken to isolate total effects of technological progress in the Far East countries, OECD and then the developing countries. Initially, the studies meant to identify how much the effects contributed to the considerable rise in the growth rates in the Far East countries and to what extent the phenomenon resulted from the accumulation of real capital and related growth in employment.[6] The estimate of the dynamics of total factor productivity was obtained using either macro economic accounting of growth or by applying results of the estimation of the production function parameters (1).

At its core, the macro economic accounting of growth was about calibration of elasticities of production with respect to fixed assets (α), usually at a level close to the share of gross surplus in value added. These values generally ranged from 0,3 to 0,4 [7]. Then values of TFP indices (i.e. of variable A_t) were estimated. They were obtained by dividing growth rates of the observed production by growth rates of the potential output derived from function (1), using the primary production factors only, so

$$\left(\hat{A}_t / A_{t-1}\right) = \left(X_t / X_{t-1}\right) / \left(K_t / K_{t-1}\right)^{\alpha} \left(N_t / N_{t-1}\right)^{(1-\alpha)}, \qquad (4)$$

or in logarithms:

$$\Delta \ln \hat{A}_t = \Delta \ln X_t - [\alpha \Delta \ln K_t + (1-\alpha) \Delta \ln N_t]. \qquad (4')$$

It is easy to observe that estimation of TFP increments includes estimation errors (also non-random), for instance effects of the demand shocks, that are reflected in observed GDP but not in fixed capital changes.

In the second case the production function parameters (1) were estimated directly, assuming that A_t is a (usually exponential) function of time[8]. We should nevertheless note that in both cases rather unrealistic assumption was taken that the potential output generated by the production function catches up with the actually observed production. As we mentioned above, few studies (Fagerberg [1987], Gapiński [1996]) attempted to introduce adjustments by allowing for the foreign demand as a variable making the output vary.

Results of empirical research whose extensive discussion can be found in Fagerberg [1994], Felipe [1997], reveal generally the presence of significant effects of technological progress, that is increments in total productivity of production factors in the Far East countries, especially in the 1980s and in the first half of the 1990s. The results are highly diversified, however. According to Young [1995] in the years 1966–1990 the TFP rate of growth in Singapore was on average somewhat above 0% which indicated that the growth was triggered by the accumulation of real capital. On the other hand, in South Korea and Taiwan in the

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[6] In few studies human capital was added (usually that per worker) as an additional variable. It is equivalent to excluding this effect from the technological progress effects represented by TFP as shown above.

[7] Interestingly, that average production elasticities with respect to real capital estimated for 22 OECD countries were much higher α = 0,458 (Coe, Helpman [1995] Table B2), quite close to estimates that we obtained for Poland.

[8] Notice, that Kim and Lau [1994] applied a translogarithmic production function, breaking down productivity trends into production factors.

1980s TFP rates of growth were 5% and 3,3 %, respectively, which translated into over 25% and over 40% contributions to the generation of GDP growth in South Korea and Taiwan, respectively (Young [1995]). Average values for the years 1965–1990 are over 50% lower (Kim and Lau [1994]), which indicates a growing in time significance of technological progress measured by TFP[9].

In mid 1990s a comprehensive study was published that discussed TFP rates of growth and the role of R&D expenditures in explaining them, which study initially analyzed OECD countries in the years 1971–1990 (Coe, Helpman [1995], and then the developing countries (Coe, Helpman, Hoffmaister [1997]). Rates of TFP growth were estimated using the macro economic accounting of growth, taking advantage of (4). In the next study the world economy model MULTIMOD was applied (Bayoumi, Coe, Helpman [1999]).

We are presenting rates of growth for countries being Poland's major trading partners and for countries that emphasized technological progress in economic growth in the last decades (Table 2). Compared with the Far East countries results for these countries show lower TFP rates of growth combined with lower rates of economic growth.

Table 2

Average growth rates of the total actual productivity of the production factors (%) in selected OECD countries, years 1971–1990

Countries	**Average rates of growth (%) in years**					**Av. TFP share in GDP rates of growth**
	1971–1975	**1976–1980**	**1981–1985**	**1986–1990**	**1971–1990**	**1971–1990**
Finland	2,31	1,49	1,57	2,53	1,96	62
France	1,43	1,96	1,22	2,07	1,68	59
Greece	1,96	2,11	-0,78	0,75	0,95	36
Spain	1,17	0,15	1,05	1,19	0,88	30
The Netherlands	1,78	1,09	1,10	0,61	1,11	51
Ireland	2,18	1,02	0,67	1,92	1,53	-
Japan	2,18	2,50	2,27	3,45	2,72	58
West Germany	0,76	1,72	0,40	2,07	1,02	45
Portugal	-0,28	3,50	-0,86	2,71	1,33	43
USA	0,05	0,35	0,63	0,44	0,39	14
UK	0,87	2,61	0,63	1,08	1,32	58
Italy	1,46	3,47	0,63	1,61	1,80	71
Poland *)	3,71 a)	-2,69	-1,36	-1,52	-0,50 b)	-
**)	3,00 a)	1,41	-0,45	0,36	0,73 b)	26

* actual productivity.
** potential productivity of total fixed capital.
a) years 1974–1975.
b) years 1974–1990.
Source: Coe, Helpman [1995], Table. 4.1 and author's calculations for Poland.

However, in the years 1971–1990 the contribution of technological progress to economic growth was much higher in the OECD than in the For East countries. It reached ca 60% in the most developed Western European countries. In other

[9] Their more extensive discussion can be found in the article by W. Florczak, W. Welfe [2000].

countries its share ranged from 30–40%. The low share of TFP (14%) in the USA seems temporary.

It is worth noting that in periods of recession (oil shocks) TFP rates of growth in the largest countries were lower than in other periods, which is a "statistical" effect resulting from using the observed GDP in calculations instead of the potential GDP.

In this context results obtained for Poland by means of the same methodology are surprising. Apart from the first part of 1970s negative TFP growth rates were obtained. The main reason for this was the deep decline in output and thus in total actual productivity in the years 1980–1981 and 1990. Elimination of these effects by relating potential TFP to the potential GDP essentially changes the picture and indicates that ca 1/4 of the growth of production capacities growth was owned to technological progress, with the effects appearing mainly in the 1970s.

The results of TFP examination for Poland mentioned above were based on production functions whose parameters were either calibrated or estimated using the fixed capital productivity functions (2) and (3).

When calibrating the elasticity of production with respect to fixed assets or machinery equipment it was assumed that it corresponded to the share of gross operational surplus in total valued added. For the first half of the 1990s it was α = 0,5. On the other hand, when the fixed capital productivity function was taken as the basis, formula (4) was used allowing additionally for the rate of changes in the utilization of production factors and effects of the supply and demand shocks. Their impact was thus eliminated from the estimated value of GDP $\left(\hat{X}_t\right)$. For the variant with the machinery equipment-labour ratio, because of (2), we have

$$\begin{aligned}\Delta \ln \hat{A}_t &= \Delta \ln \hat{X}_t - (0{,}499\Delta \ln\left(KM_t WKZ_t\right) + 0{,}501\Delta \ln N_t + \\ &+ 0{,}075\Delta \ln WKZ_t + 0{,}558\Delta \ln WN_t - 0{,}090U7981_t + \\ &+ 0{,}0448U8384_t - 0{,}107U090_t).\end{aligned} \tag{5}$$

$(\hat{A}K_t)$ was calculated in a similar way for the variant with total fixed assets-labour ratio**.**

The TFP rates of growth were calculated for the sample period and additionally estimated for the years 1999–2000. In Table 3 we are presenting their average values, both for five year periods as well as excluding years when either supply or demand shocks appear (see also Graphs 2 and 3).

Interestingly, results concerning actual productivity and provided by the calibration of elasticity α are misleading in many instances. For the 1990s they considerably overestimate the effects of TFP growth, which is particularly clear in the years 1995–1998, when a high GDP growth occurred, unaccompanied by a corresponding increase in TFP. In fact, in the years 1992–1994 TFP contribution to GDP growth exceeded 60% in the case of productivity of machinery and approached 30% in the case of total fixed assets productivity, which may be attributed to the general efficiency increase related to the privatisation process (the rates of growth of investment were low in this period). In the years 1996–2000 TFP contribution to GDP growth dropped to 14%

Table 3

Average rates of growth of total factor productivity (*a*) and their percentage share in GDP growth (*b*)

Elasticity of output with respect to fixed assets	**1982–1985**	**1986–1990**	**1991**	**1992–1994**	**1995–1998**	**1999–2000**	**1991–1995**	**1996–2000**
Machinery equipment								
Calibrated $\alpha = 0,5$								
a	1,04	-2,18	-5,26	3,02	1,39	-5,70	1,42	-1,94
b	43	-	75	78	23	-	64	-
calibrated $\alpha = 0,5$ allowing for WKZ								
a	1,80	-1,46	-2,90	3,13	-0,92	-1,48	1,88	-1,48
b	75	-	42	81	15	-	85	
estimated								
a	-0,92	0,51	-1,28	1,6	0,86	0,67	0,88	0,78
b	-23	173	-	63	17	10	41	14
Total fixed assets								
calibrated $\alpha = 0,5$								
a	1,41	-1,52	-4,70	3,72	3,29	-9,35	2,31	-2,35
b	59	-	67	96	53	-	104	-
calibrated $\alpha = 0,5$ allowing for								
a	2,18	-0,80	-2,22	3,84	2,82	1,14	2,73	1,14
b	91	91	32	96	46	25	12	2,1
estimated								
a	-0,62	0,36	-1,25	0,78	0,37	0,37	0,27	0,38
b	-0,1	27	-	28	9	8	12	8

N o t i c e : the percentage shares in GDP rates of growth were calculated for the variants with calibrated elasticities with respect to actual rates of growth of GDP and for variants with estimated elasticities with respect to the rates of growth of potential GDP.

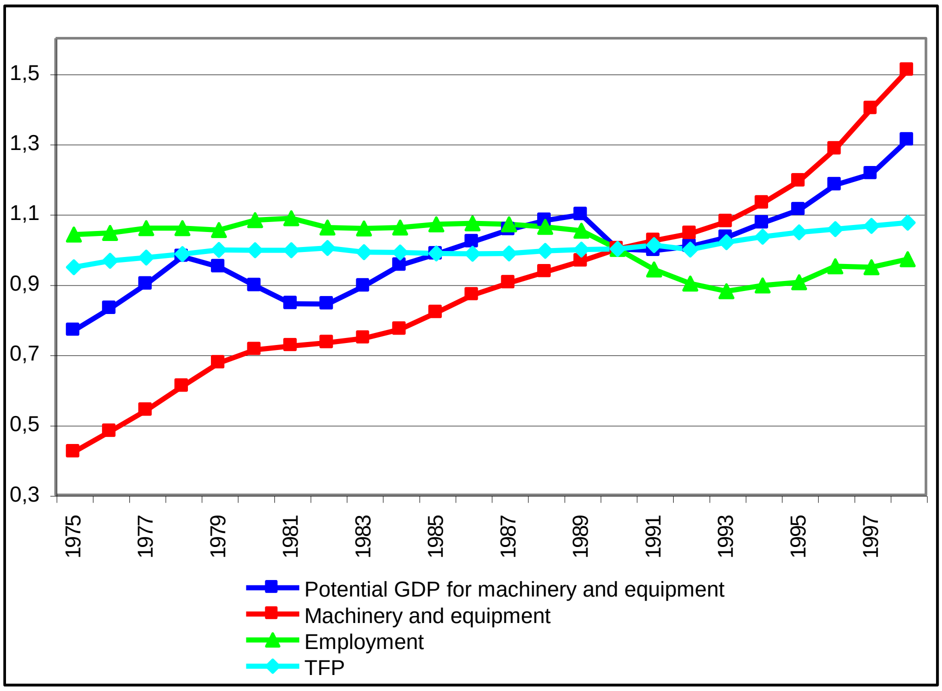

Figure 2. Indices (in %) of potential GDP (for productivity of machinery and equipment), of machinery and equipment, employment and TFP (1990=1)

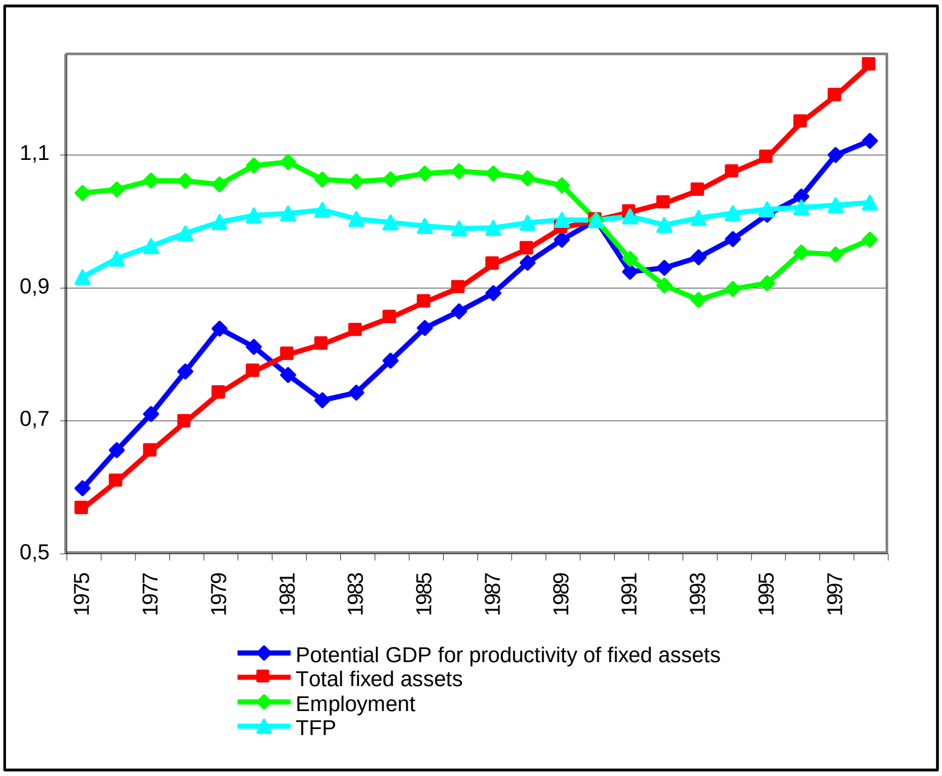

Figure 3. Indices (in %) of potential GDP (for productivity of fixed assets), of total fixed assets, employment and TFP (1990=1)

(productivity of machinery) and to 8% (total fixed assets). In both these cases the TFP contribution clearly declined. This shows that in the second period of transition the main growth engine was the accumulation of fixed assets resulting from modernization activities and new investments in the enterprise sector, especially in the years when the investments grew fast.

Total factor productivity decomposition. In the early discussions the changes in the total productivity of production factors A_t representing the impact of the technical progress were treated as a function of time, i.e. no attention was played to the sources (channels) that transmit its effects. The TFP growth can be broken down into factors related to the increase of quality of machinery equipment, labour and the general level of technological knowledge impacting the level of management. In the last case we take into consideration broadly understood innovative processes occurring in economy, unrelated to a particular machinery or educational level of individuals (elements of infrastructure, computer networks, etc.). To take them into account variable A_t^W was introduced. Assuming that the quality of fixed assets (fixed capital augmented technical progress) and of labour (labour augmented technical progress) can be separated we introduced two other variables – namely A_t^K that represents the productivity of capital and A_t^N – reflecting productivity of labour which are related to particular production factors. By assuming that these are time functions (Kim and Lau [1994]) the technological progress is approached as exogenous. On the other hand, relating these characteristics to variables explaining their level (for instance to human capital) leads to making them endogenous.

Taking into account the above decomposition, the Cobb– Douglas function can be presented as follows:

$$X_t = A_t^W \left(A_t^K K_t\right)^{\alpha} \left(A_t^N N_t\right)^{(1-\alpha)}, \tag{6}$$

or equivalently

$$X_t = A_t^W \tilde{K}_t^{\alpha} \tilde{N}_t^{(1-\alpha)}, \tag{6'}$$

where $\tilde{K}_t = A_t^K K_t$ – fixed assets given in efficiency units**,** taking into account the technical progress embodied in these assets, $\tilde{N}_t = A^N{}_t N_t$ – the number of employees in efficiency units that take into account workers' education and work experience that comprise human capital.

The above form is most convenient as it allows, after specific quality characteristics of fixed assets and labour in (6) are moved to the front of the bracket, to return to the original form of the production function (1), with the total productivity of production factors represented by[10]:

[10] Total productivity of production factors (TFP) is sometimes interpreted in a different and narrower way. If fixed assets and labor are defined in the efficiency units, then TFP will be reduced to effects of absorption of technological knowledge A^W. This shows the necessity to stay cautious when interpreting results of empirical research.

$$A_t = A_t^W \left(A_t^K\right)^{\alpha} \left(A_t^N\right)^{(1-\alpha)}. \quad (7)$$

The above form is so general that it enables to present alternative concepts of endogenous growth using appropriate modifications.

First studies leading to the extention of the productivity function in order to include effects of the technological progress, that referred to changes in human capital, aimed to introduce characteristics, representing this variable as a per worker value in efficiency units (that is A_t^N), as an additional explanatory variable. At the same time it was recognized that the progress in science and technical knowledge operates mainly through its application by the employed.

An illustration to this concept is the Mankiw, Romer, Weil model [1992]:

$$X_t = K_t^{\alpha} \left(\tilde{A}_t^N\right)^{\beta} \left(A_t^W N_t\right)^{(1-\alpha)}, \quad (8)$$

where $\tilde{A}_t^N = H_t / A_t^W N_t$ and H_t – human capital whose growth was approximated by including persons aged 15–19 years that attended secondary schools.

More frequently, this formula is written down by isolating human capital H_t as an explanatory variable:

$$X_t = K_t^{\alpha} H_t^{\beta} \left(A_t^W N_t\right)^{(1-\alpha-\beta)}. \quad (8')$$

In this model the interpretation of effects resulting from changes in technological knowledge may be discretionally broad (and include A^W as well as A^K), since the authors treat them as time functions.

On the other hand, the Romer model (1990) assumes that the effects of technological knowledge application are connected with the expansion of fixed capital, and not employment. Hence we have

$$X = \left(A_t^W K_t\right)^{\alpha} \left(A_t^N\right)^{\beta} N_t^{(1-\alpha)}, \quad (9)$$

or alternatively:

$$X_t = \left(A_t^W K_t\right)^{\alpha} H_t^{\beta} N_t^{(1-\alpha-\beta)}, \quad (9')$$

where $H_t = A_t^N N_t$, A_t^W – proxy for scientific and technological knowledge depending on human capital in the R+D sphere $\left(H_t^A\right)$:

$$\Delta A^W = \sigma H_t^A A_t^W, \quad (10)$$

where σ – efficiency of the R+D expenditures.

The common feature of the above models (appealing to the endogenous growth theory) is that they allow to isolate the impact of human capital H_t as a separate explanatory variable, mainly to capture the external effects of its growth. On the other hand, they are different in terms of the scope and methodology of capturing other specific effects of higher quality of fixed capital, employment and the level of the scientific and technological knowledge, thus diverging from earlier attempts to specify them.

We will continue to use the general decomposition formula of the total factor productivity (6), showing separately effects of technological progress embodied in fixed assets and growth effects of human capital.

Technological progress embodied in fixed assets. The technological level of fixed assets is thought to depend on the fixed capital-labour ratio: on its up-to-dateness and, in effect, on the technological thought embodied in machinery and equipment. Alternative methods to measure it have been presented in numerous studies whose summarized review can be find in works by W.Welfe [1992, 2000].

The common feature of the earlier studies was that they treated the technological level of machinery and equipment as a time function: $A_t^K = f(t)$. Contemporarily, it has been attempted to make growth rates of fixed assets' productivity endogenous. At their core, such attempts tend to relate these rates to the stream of innovations in the manufacturing sector (Eaton et al. [1998], Jones [1995]). In practice, two measures are important: R&D expenditures and the number of patents. For the macro scale we will give Fagerberg's calculation results [1987] based on a time cross-section sample covering 26 countries and years 1960–1983. His research presented the GDP rate of growth as a function of the growth rate characterizing the number of patents that were applied outside the country of registration. The result was significant, positive parameter estimates for this variable. (R&D expenditures were skipped owing to the lack of complete information). The only reservation arises from the use of the current period patents, whereas the impacts of the technological progress are rather expressed by the cumulated size of patenting activities.

This direction was followed by Tokarski's research [1995], where the production function (1) was supplemented by an independently introduced variable expressing R&D expenditures (converted into fixed prices) with an appropriate time lag (usually 5 years)[11]. The research results for 6 most developed countries (1971–1989 sample) provided elasticities with respect to R&D real expenditures of 0,12–0,29. This secured a considerable contribution of these effects to the GDP growth.

Methodologically, the most advanced research is that by Coe and Helpman [1995], which treats total productivity of production factors A_t as a function of cumulated (and not current) R&D real expenditures. The authors took into account not only expenditures in the country of origin, but– to take into account the transfer of innovations – also those incurred abroad (weighted by imports from countries where these expenditures were incurred). Moreover, the size of the last effect was related to the imports of manufactures (their share in GDP). So we have:

$$\ln A_t = a_d \ln S_t^d + a_f m_t \ln S_t^f , \qquad (11)$$

where: S_t^d – cumulated domestic R&D expenditures, i.e. R&D capital stock, in fixed prices, S_t^f – cumulated foreign R&D expenditures, i.e. foreign R&D capital stocks, weighted by imports from the countries where the outlays were spent (fixed prices), m_t – imports' of manufactures share in GDP.

Cumulated R&D expenditures (S_t as at the beginning of the period) were found using the identity: $S_t = (1-\delta)S_{t-1} + R_{t-1}$, where: R_t – current R&D real

[11] The author estimated also CES function parameters, but without a significant success.

expenditures in year t, and δ – depreciation rate of knowledge; its alternative values were assumed as 0,05 and 0,15.

The research for 22 countries (440 observations) was built on a time cross-section sample from the years 1971–1990. Application of relevant tests allowed to conclude that the analysed variables were co-integrated.

TFP elasticities with respect to domestic R&D real expenditures range from 0,06 to 0,10, which was already provided by studies on particular countries. The average calculated for the 22 countries was 0,078, and 0,156 for G7 countries. On the other hand, elasticities with respect to foreign R&D real expenditures are variable and depend on the absorption of imports. On average in the variant allowing for the absorption of imports they amount to 0,294 [12].

The above results seemed promising enough to use the above research strategy in the expansion of the production function in model W8 D of Polish economy. It was however, considered desirable to add effects of human capital, apart from the R&D capital stock that might explain the other part of TFP's variability. This approach enables also to make the embodied technological progress fully endogenous – by relating R&D expenditures to the sources of their funding.

As a result in the expanded production function (6) it was assumed that

$$\ln A_t^K = \lambda_1 \ln BIRKS_t + \lambda_2 \left(M7_t / JV_t\right) \ln BIRMS_t, \qquad (12)$$

where: $BIRKS_t$ – cumulated domestic R+D expenditures , fixed prices, $BIRMS_t$ – cumulated foreign R&D expenditures, that is expenditures in countries being Poland's major trading partners (France, The Netherlands, Germany, USA, UK, Italy) weighted by imports from these countries, fixed prices, $M7_t$ – investment imports, fixed prices, JV_t – investment outlays on machinery and equipment, fixed prices[13].

Parameters of labour productivity and productivity of fixed assets' equations (2), (3) were estimated, after extending them to include (12) and human capital per worker. The parameter estimates obtained were products $\alpha\lambda_1$ and $\alpha\lambda_2$, comparable with Coe, Helpman [1995] estimates.

Based on the fixed assets' productivity functions (2) and (3) for capital-labour ratio defined for

- machinery and equipment we obtained		- total fixed assets	
$\alpha\lambda_1 = 0,076;$	$\alpha\lambda_2 = 0,084;$	$\alpha\lambda_1 = 0,267;$	$\alpha\lambda_2 = 0,057$
(0,5)	(1,4)	(1,9)	(0,9),

respectively.

Unfortunately, the significance of these estimates is a lot below what should be desired. However, in the first variant the TFP elasticity with respect to domestic cumulated R&D is close to that obtained for the OECD countries, especially for small industrial countries and in the second variant to that of G7 countries. This

[12] In the last study (Bayomi et. al. [1999]) the TFP elasticities were obtained separately for three groups of countries. Elasticities with respect to domestic R&D capital were for G7 countries 0,24, for small industrial countries 0.08 and non-oil developing countries close to zero. The TFP elasticities with respect to foreign R&D capital were equal 0,26 for all industralized countries and 0,43 for non-oil developing countries.

[13] Detailed rules for estimating cumulated R+D expenditures can be found in W. Florczak et al. [2000a].

contradicts the frequently expressed opinion that the efficienty of domestic R&D expenditures is low in Poland.

On the other hand the obtained elasticities are considerably lower in terms of the absorption effects of foreign R&D capital stock. This implies that the import of machinery to Poland following also from the FDI did not include state-of-the-art items.

Efficiency of human capital. In the 1990s important became studies on the efficiency of human capital. Let us recall that human capital can be found in all the above models that postulate endogenous growth. Human capital is usually meant as the pool of knowledge acquired by studying at various levels of the school system, improving education and gaining experience[14]. Usually, summary measures representing all forms of acquiring knowledge are not available. Most frequently they are characteristics of education provided by the school system. And so, the number of employed persons with elementary and secondary education is distinguished, including sometimes persons with higher education or their shares in the number of working age population, occasionally distinguishing the gender and relevant age groups. It is not recommended to separately introduce these variables to the production function because of their co-linearity[15].

Therefore, their summarized measure is sought. It is usually obtained by weighting relevant numbers of persons with particular levels of education. Their sum identifies the level of human capital (H_t):

$$H_t = \sum_i \frac{w_i}{w_o} N_{it} \ , \tag{13}$$

where $i -$ level of education, $i = 0$ – elementary education.

The average level of human capital per person can be obtained from the formula:

$$A_t^N = H_t / N_t = \sum_i \frac{w_i}{w_o} \frac{N_{it}}{N_t} . \tag{14}$$

Two types of weights are usually taken. The first weight, when it is possible to identify the number of school years for particular levels of education, is the ratio of the number of school years to the number of elementary education years $w_i = h_{ii}$ where h_t – total number of school years at level i. So in the considered case it is assumed that the productivity of labour is proportional to the number of school years.

In theoretical terms more justified seems to be the rule, according to which higher quality of labour in market economy is expressed by the level of average wages z_t. Hence in formula (13) the weight is the relation of average wages earned by persons with i-th level of education to average wages in the group of persons with the lowest education in predetermined period $w_i / w_o = z_i / z_o$.

To identify changes in the level of human capital, i.e. human investments, it is necessary to define the "depreciation" of human capital and to know the number of persons flowing in and out from the original pool of persons in the given

[14] A broad discussion of generation and accumulation of human capital can be found in R.Domański [1999].

[15] Let us note however successful attempts to distinguish only two categories of education in research by Barro [1991].

category. Detailed discussions of making human investment endogenous can be found in a separate study (W.Florczak et al. [2000b]).

Empirical results of research based on time cross-section samples and provided by various versions of introducing human capital to the production function, for instance those showed in Mankiw, Romer and Weil models [1992], Lucas [1988] or Romer [1990] models, offered highly diversified results. Production elasticities with respect to human capital defined using the number of school years took values ranging from 0,02 to 0,24, (all statistically significant), depending on the specification methodology used (either structural or reduced form) and available data, especially this on human capital. When external effects were taken into account then the elasticities grew to 0,4–0,69 (Hers [1998]).

Let us note, however, that the above results were obtained for models that ignored the effects of technological progress embodied in real capital as explanatory variables, that were discussed in the previous section. Consequently, the above estimates can be biased[16].

Model W8-D of Polish economy assumed that the effects of growing levels of worker education would be taken into account by introducing the number of employed persons expressed in effective units (as an explanatory variable) into the production function. Namely, for elementary, secondary and higher levels of education weights were taken, corresponding to the initial wage relations. These are 1996 average gross wages relations being 1 : 1,2 : 1,75, respectively. Technically, this means that in the labour productivity function and fixed asset productivity functions labour productivity and, correspondingly, capital-labour ratio are obtained by using human capital, that is $H_t = A_t^N N_t$, as the divisor and not the number of employees N_t. This was equivalent to assuming that the production elasticity with respect to human capital per worker $\left(A_t^N\right)$ is $(1-\alpha)$, that is ca 0,5 for the variant with machinery-labour ratio, and 0,4 for the variant with total fixed capital-labour ratio.

An analysis of the impact of changes in the level of human capital will be combined with the analysis of effects of increased R+D real expenditures, below.

Decomposition effects of total factor productivity for Poland. We will present now summarized analytical results of the consequences of changes in R+D real expenditures and growing per worker human capital, while examining their contribution to the total productivity of production factors. Let us recall that the TFP growth was modest, around 0,9% a year in the 1990 s, as measured for the productivity of machinery equipment.

Increments in human capital per employee were stable in time and at a level exceeding 0,3% in the 1980s and 0,5–0,6% in the 1990s. In the last years this has accounted for 1/4 to a half of the TFP growth. (See Table 4 and Graph 4.).

The capital of knowledge cumulated in domestic R+D real expenditures has been characterized by a downward trend in the last decade, 1–1,5% a year, because of the slow increase in current R+D expenditures, not compensating for the loss of knowledge. As a result, the share of this factor in TFP growth was negative.

[16] They are not directly comparable with elasticities expressing growth effects due to the changes in the number of patents or R+D expenditions, as these were designated for total productivity of production factors and not output.

Table 4

Percentage rates of growth of human capital and R&D capital stock (*a*) and their (weighted) percentage shares in the rates of growth of TFP for the variants with productivity of machinery equipment (*b*) and total fixed capital (*c*)

Production factors	**1974–1975**	**1976–1980**	**1981–1985**	**1986–1990**	**1991–1995**	**1996–1998**	**1991**	**1992–1994**	**1995–1998**
Human capital (H/N) per employee									
a	0,44	0,46	0,34	0,33	0,58	0,47	0,45	0,55	0,44
b	12	37	-	33	33	27	-	17	25
c	6	12	-	35	81	45	-	27	49
Domestic R&D stock $(BIRKS)$									
a	8,38	4,56	-1,50	0,02	-1,61	-0,14	-0,05	-1,53	-1,07
b	35	55	55	0,4	-14	-8	12	-7	-9
c	73	85	89	1,8	-160	-63	42	-53	-77
Foreign R&D stock $(BIRMS)$									
a	11,03	3,40	3,64	5,71	12,39	7,28	-1,57	13,22	8,15
b	53	8	126	67	81	81	123	90	84
c	21	2	40	63	179	119	85	126	133
Total factor productivity (TFP) (percentage rates of growth %)								1,61	0,86
b	1,78	0,62	-0,21	0,51	0,88	0,86	-1,28		
c	2,99	1,41	-0,45	0,36	0,27	0,39	-1,35	0,78	0,37

Source: Own compatutions based on the W8-D model of the Polish economy.

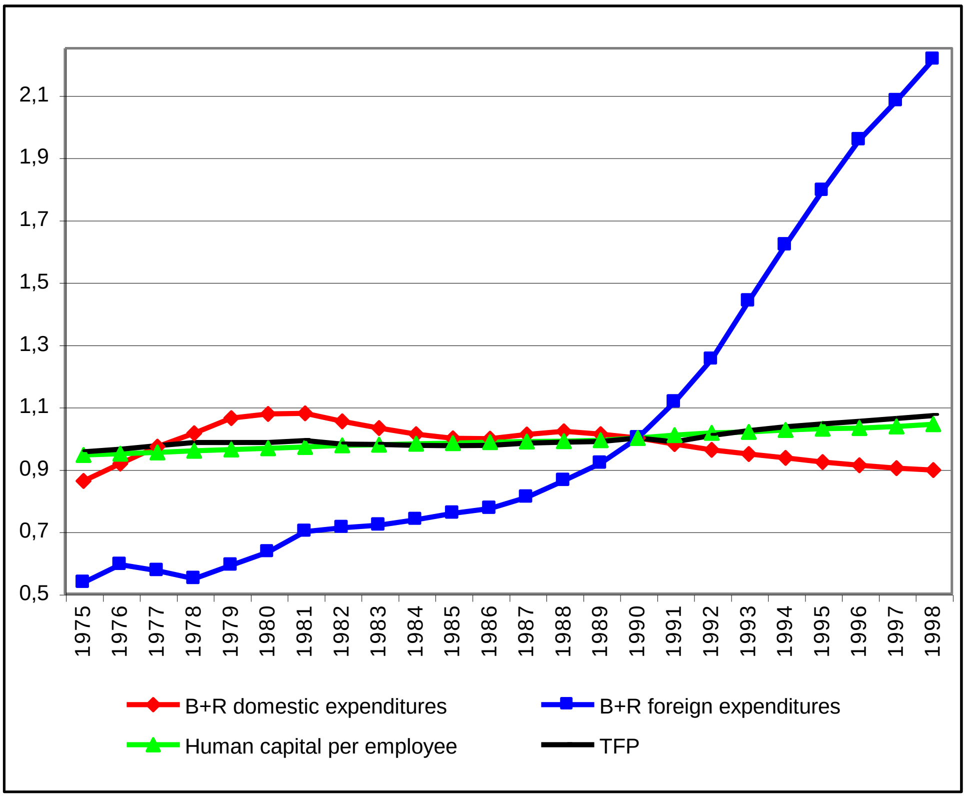

Figure 4. Indices of TFP, human capital per employee, real B+R cumulative expenditures - domestic and foreign (1995=1)

These effects were compensated for by a considerable growth in the absorption of technological knowledge generated abroad. Increases in foreign R+D real expenditures ranged in the last decade from 7 to 13%, whereas in the 1980s it was 4,6 %. This accounted for almost 80 % of the TFP growth. Taking into account the aforementioned decline in domestic R+D expenditures, the total effect of technological progress embodied in fixed assents would account for a half to 3/4 of the TFP growth.

The above picture of the effects produced by technological progress in the past years does not fill with excessive optimism. Polish economy has been through two deep recessions that brought about a drop in economic activity, including especially investments, which then restricted the growth of economic potential in the country. In periods of recovery and growth the basic growth factor of production capacities was building up accumulation, resulting in a growth of fixed assets and higher numbers of jobs. In the first half of the 1990s this factor produced half of the potential GDP's growth, and in the second half it accounted for ca 80–90% of the growth.

Effects of technological progress (TFP) were therefore limited, and apart from a regular growth in human capital, a significant role was played by the absorption of foreign achievements in science and technology, with a diminishing role of domestic technical thought, which was not surprising considering the declining cumulated R+D real expenditures, i.e. shrinking capital of domestic technical knowledge.

Growth prospects. For the next decade the growth prospects of production capacities are not very optimistic. The growth in fixed assets will stabilize – after a period of temporarily slower investment activity – with the share of gross investment in GDP excecling 25%. Considering the slow increase and then drop in the number of employees this can ensure a 3–3,5% growth in the potential GDP.

For the potential growth to be 6–7% it takes that the total share of technological progress (TFP) in the GDP growth must account for at least 50% if not 60%. With human capital expanding at 0,5% a year (growing shares of persons with higher education), this would mean the necessity to increase 4–5 times the intensity of absorption of foreign technological knowledge to the level of less industrialized countries. Parallel to that, stronger effects should be expected produced by growing domestic R+D real expenditures. A 10% rate of growth of cumulated domestic R+D real expenditures could ensure additional 0,8% of GDP growth. In the long term it would be necessary to have a 10% increment in current R+D real expenditures, that is more than twice as high as the desired 5% rate of GDP growth. All this is combined with the need to strongly support the use of information technologies that pave the way – like in the developed countries – to the so called new economy.

More detailed analyses of the prospects and development alternatives of the above growth factors and their effects will be a subject of a separate study.

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