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Modeling Various Aspects of Sustainability: The Case of Poland

(theoretical outline)

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1. Introduction

For a couple of decades ecological issues struggled for a full recognition and equality among the socio-economic sciences and for thirty years or so they have constituted its integral part. Initiated by the Club of Rome Report, the process of informing the society about the scale of potential worldwide environmental dangers resulted in a plenty of international initiatives aiming at reducing or even diverting the adverse tendencies in devastation of nature. This is so because an innate feature of ecological processes is their supranational character making them inappropriate to be treated solely as domestic problems of individual countries (see e.g. Budnikowski [1994] or Bańkowski [2004]). Still, it is the individual countries to be responsible for implementing the main principles of sustainable development. What is more, the notion of sustainability itself - perceived in its most popular and, apparently, most elastic definition as "… development that meets the needs of the present without compromising the ability of future generations to meet their own needs" (the Brundtland Report [1987]) - by far exceeds the range of problems connected with ecological issues. The latter seem to be given special societal attention simply because of their susceptibility to man's economic activity. However, to be in line with the above definition one has to account for at least economic, social, demographic, health and ecological aspects of development in their mutual interlinks (see e.g. Aniansson, Svedin [1990] or Sterner (ed.) [1994]). This is a challenging task, all the more so as successful compliance with the rules of sustainability requires not only sound theoretical knowledge of such interlinks – which is still far from being satisfactory – but also appropriate tools of quantifying them.

The vast majority of modern States seem to understand the scale of the problem, a conspicuous sign of which is the fact that some of them even declare the willingness to act in accordance with sustainability principles in their constitutions. Among such countries is Poland. The article 5 of her present constitution reads, "*The Republic of Poland shall safeguard the independence and integrity of her territory and ensure freedoms and rights of persons and citizens, safeguard the national heritage and shall ensure the protection of the natural environment pursuant to the principles of sustainable development.*" Well-intentioned and far-sighted as this declaration might be - not to remain an empty word - it calls for a more operative definition of sustainability and possessing some measures, by means of which one could assess the state of affairs with respect to the issue under consideration. To assume an active attitude towards sustainability one should also be able to predict probable paths of growth of its main components, as well as estimate the possible effects of interventions aimed at reaching specific targets conducive to sustainability. Although theoretical and empirical investigations have been carried out for years now we still lack universal, aggregate measures of sustainability, to say nothing of indisputable analytical tools capable of accurate forecasting and quantifying the effects of a given socio-economic policy in the field of sustainability. Instead, one might try to define the – apparently – main chains of sustainability and decide on an analytical tool that ensures their simultaneous treatment. The simultaneity requirement seems to be of crucial importance here as any attempt to cover only one specific element of sustainability in separation from the others must - by definition - be biased due to the existing mutual interactions between individual factors. In brief, under the outlined circumstances the *ceteris paribus* assumption seems hardly applicable.

From among available analytical tools designed to deal with quantification of multifarious socio-economic relationships and satisfying the afore-mentioned conditions are econometric models. They are quite elastic in their capability of both verifying/falsifying a given hypothesis and introducing various aspects of a given problem into one system of simultaneous equations (see e.g. Klein, Welfe W., Welfe A. [2004]). They can be used both for forecasting and policy making analyses. Besides, they are elastic enough to occasionally benefit from outcomes of other quantitative methods, either directly - e.g. by connecting them into a joint system with an input-output model – or indirectly, e.g. via calibrating appropriate structural parameters on the basis of results obtained elsewhere or taking for granted values of exogenous variables computed by another method/model. This feature ensures adequacy of econometric approach in the area of modeling sustainability even for the purposes of a long-run analysis. An example of a successful implementation of an econometric model of the Polish economy to analyze selected issues of sustainability on a national scale can be found in Florczak [2005].

The present paper outlines methodological issues taken into consideration in an attempt to incorporate a large number of sustainability problems within W8D econometric model of the Polish economy. Although far from being exhaustive in its efforts to model sustainability, and neither supreme nor indisputable in the methodology taken, the presented approach guarantees satisfaction of the crucial requirement of simultaneity: it considers all the partial elements of sustainability – covered by the model - in their contemporaneous linkages.

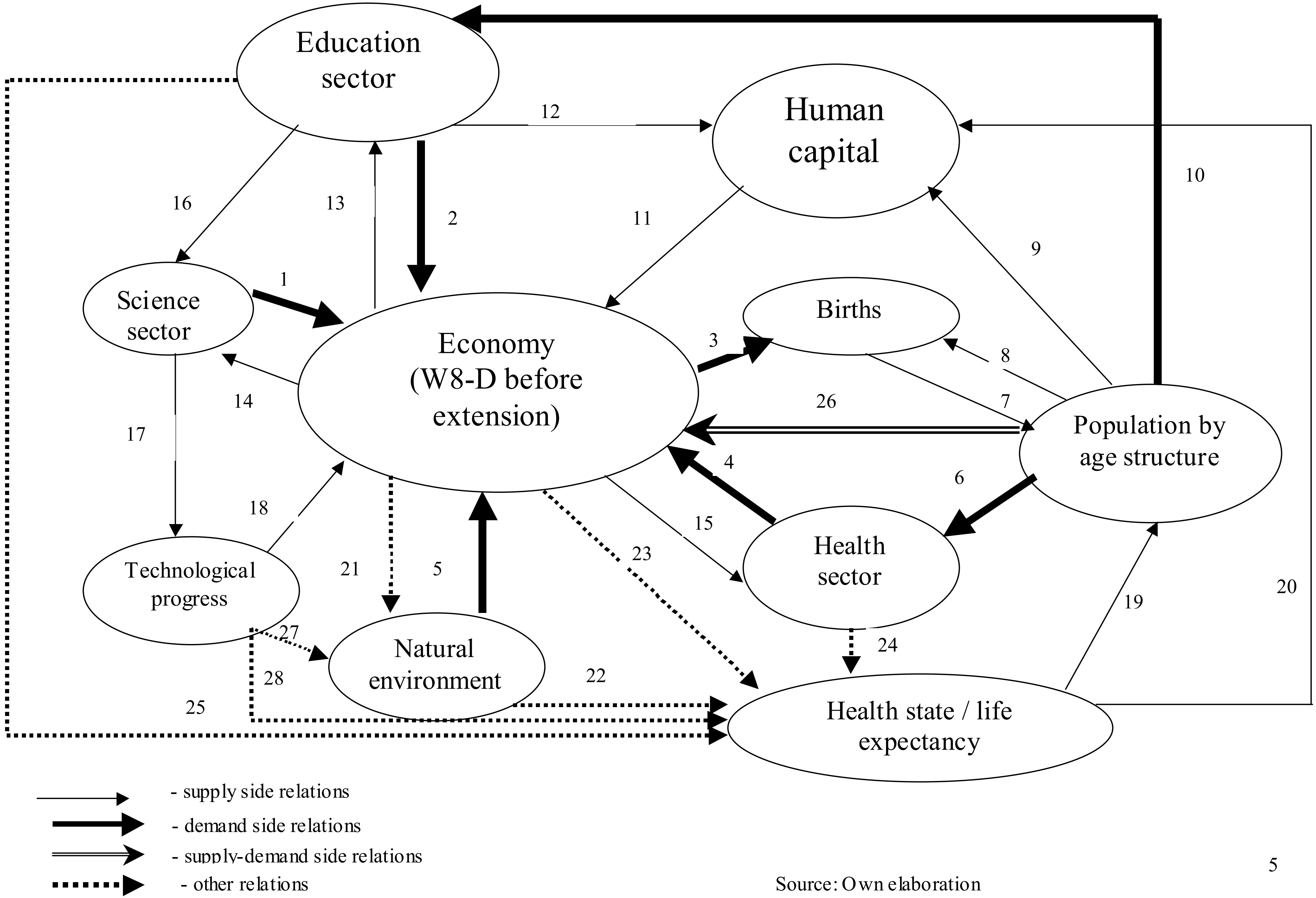
The structure of the presentation is as follows. Section 2 gives a general gist of what it is all about from a "bird's-eye view". Section 3 sketches some main properties of the W8D model in its initial version, designed to deal with economic issues solely. The remaining sections describe the extension of the model aimed at incorporating some significant aspects of sustainability. And so, section 4 presents the crucial equation of the whole system: a production function, being the central equation of the simulation model, responsible for the most important feedbacks existent in the extended version of the W8D. Section 5 deals with formation of human capital. In section 6 demographic issues are presented. Section 7 presents specification of a life expectancy equation. Section 8 describes an aggregate measure of environmental state as well as its determinants. Section 9 depicts education and science sectors as well as foreign R&D activity and their role in technological progress formation. In section 10 some sustainable policy questions are raised to be potentially answered by means of the enlarged W8-D model. Finally, section 11 concludes.

2. Bird's-eye view

The core of the entire system rests on the initial version of the W8D model of the Polish economy, which to much extent affects the way the sustainability issues were treated. The central relation of the whole construction is a generalized production function comprising – apart from traditional production factors: built capital and labour force – human capital and endogenous technological progress. The human capital includes both education, learning by doing and health state of the labour force. To meet the requirements of such defined human capital measure one has to possess quite detailed information about the population by age structure. In the long-run it is also necessary to account for fertility. Life expectancy that stands for health indicator of the whole society influences labour productivity and is itself determined – among others - by economic, social and environmental factors. The standing of natural environment represented by air and water quality as well as by waste accumulation affects – among other things – life expectancy, and thus –indirectly – also labour productivity. Technological progress - associated in the model with total factor productivity - is a function of human capital, imported R&D, and science sector activity measured by a stock of accumulated patents. The individual blocks are in mutual, contemporaneous interlinks against one another, which is depicted in figure 1.

The outlined system of simultaneous relationships touches upon what constitutes the essence of broadly understood sustainability - not limited to ecological questions only – from a macroeconomic perspective with some priority given to economic growth. For obvious

Figure 1. Macro-feedbacks between main blocks of the extended W8-D model



Source: Own elaboration

reasons is not, and cannot be exhaustive. This is both because of the taken (macroeconomic and national) perspective and - more importantly – because of inappropriateness of traditional econometric approach to deal with such vital aspects of sustainability as valuation of biodiversity or intertemporal fairness. Still, it is worth emphasizing that even in this form, the model might prove useful in analyzing various socio-economic policy decisions (see section 10).

3. Initial version of the W8D model

Specifications of individual equations of the W8D rest on the extensive macro-modeling experience described both in the world and in the Polish literature on the subject (see e.g. Bodkin et al [1991], Dreze et al [1990], Whitley [1994], W. Welfe [1992], W. Welfe, A. Welfe [2004]). They allow for particular mechanisms with respect to producers and state institutions existent in the Polish economy in the transition period.

Basic equations of the model (production function, consumer and investment demand functions, formation of human capital, price and wage equations, etc.) are stochastic. Consequently, to get sufficiently long and coherent time series, one had to construct a homogenous data base (see W. Florczak [2003]).

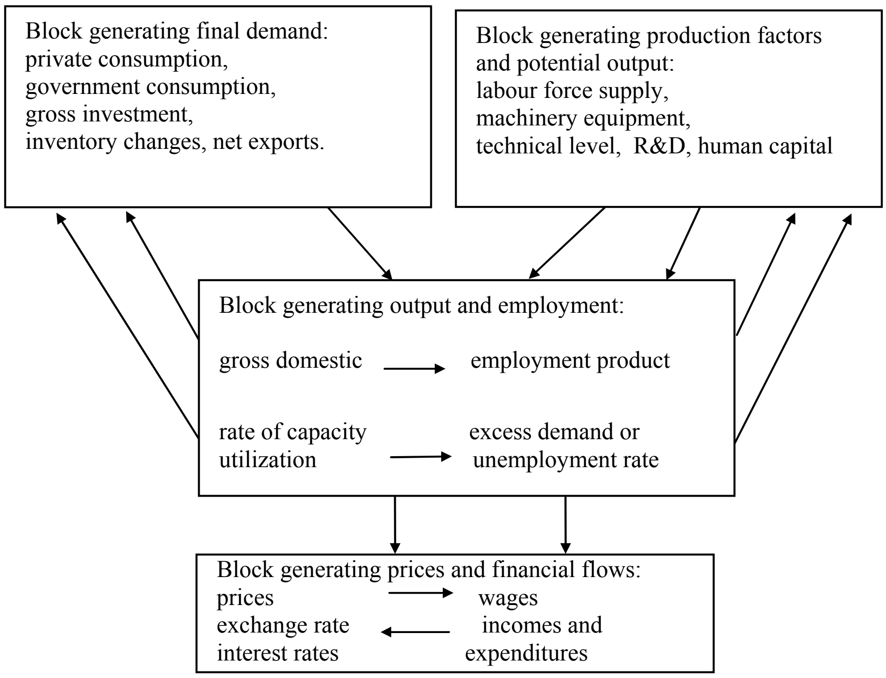
Parameters of individual equations were estimated on the basis of annual frequency data covering, in general, 39 observations (the years 1960-1998). Information on the majority of financial entries have been available only since the early or even mid 90-s. In such a case proper estimates were obtained by means of calibration rather than estimation.

The structure of the simulation model W8D was designed in such a way as to reflect economic mechanisms typical of a centrally planned economy, to a higher or smaller degree characterised by shortages of products and production factors, and of an economy in the transition period towards a market economy. We mean here an economy where demand constraints are becoming typical, and an excess of production factors follows, and where market adjustments (concerning prices and wages) are starting to play an important role, reinforcing the quantitative adjustments. These mechanisms are reflected in the model in numerous feedbacks.

The most important feedbacks that identify relationships in the production sector on the demand side are: a) between consumption, production and employment (the consumption multiplier), and b) between investments and production (the accelerator), c) and then the relationships between the production and financial sectors channelled, amongst others, through the taxation system and the budget (fiscal multiplier), as well as d) the relationships between prices and wages (the inflationary spiral). The relationships between the production sector and the financial sector in transition economies are reflected most of all in the transformation of the quantitative indicators of disequilibria (excess demand, unemployment rates) into price and wage adjustments which, on the other hand, influence the intensity of quantitative adjustments (for example demand).

The schematic relationships between particular blocks can be described as in figure 2.

Figure 2. Structure of model W8D



The economic mechanisms and the relations reflecting them are different in particular economic regimes. They are specific for the regime where the demand for production and production factors is being met, and the regime when supply is realised, which implies imperfection of the price-wage adjustments. In fact, both of the situations may be concurrent. Then the mechanisms characteristic of the demand and supply oriented models will co-exist in different, varying proportions.

In the long term version of the model there are additional relationships introduced in the real sector in the process of generating potential GDP. Those are feedbacks: e) between gross investment outlays (including FDI) and fixed assets, f) between absorption of imported R&D and total factor productivity, g) between domestic outlays (from the budget and from private means) on R&D and total factor productivity, h) between budget expenditures along with households' outlays on tertiary education and formation of human capital. Domestic R&D stock, being dependent on real domestic R&D expenditures and hence domestic GDP affects TFP increase and potential GDP growth. Similarly foreign R&D stock, being dependent on imports of machinery and on additions to foreign R&D, affects domestic TFP and GDP. In turn, the human capital per employee being dependent on investment in human capital due to an increase of real expenditures on education, especially high education which positively changes the structure and educational level of graduates – affects the TFP and GDP.

4. Production function

The central equation of the modified model is the one explaining labour productivity. The production function existent in the initial W8D model did not take into account issues of sustainability, so in order to close the loop linking natural habitat (see section 8), as well as the age structure of the Polish society, with overall productivity, the equation generating the latter had to be extended. After modifying the measure of human capital to directly incorporate into the production function an indicator of population health status – identified with life expectancy – as well as educational commitment of the working force connected with population age structure (see section 5), the loop is closed (see figure 1).

As the estimation of structural parameters of the model is, in general, based on time series data, while specifying the equation one should also account for demand shocks to exclude their influence on parameter estimates from the otherwise supply side relationship that underlies the production function equation. This is relatively easy to accomplish as the demand shock can be identified on *a priori* grounds. Besides, bearing in mind the fact that it is the number of workers – not hours worked – that stands for a measure of labour force, one should also introduce some additional measure of time worked. The same applies to fixed assets. After all, the intensity with which they are utilized must affect the parameter estimates.

The technological progress, associated with total factor productivity, can be derived from the production equation and consists of three components: human capital (including life expectancy component), imported R&D and accumulation of domestic patents (see section 9).

Three approaches are going to be considered with respect to the specification of the production function, whereas which of them to choose will be decided on the basis of empirical evidence. In the first of them a generalized Cobb-Douglas will be used. All production factors are regarded as direct causes of growth, which justifies rejection of constant returns to scale hypothesis. TFP is then meant as that share of production variability that is not explained by “raw” fixed capital and labour variability.

The second approach takes advantage of growth accounts, where the influence of all production factors - except for fixed capital and labour – is determined after deducting the effects of the latter upon output. Thus the following well-know growth accounts identity is employed to arrive at TFP:

$$TFP = \frac{Y}{K^{\alpha} L^{(1-\alpha)}} \tag{1}$$

where: TFP – total factor productivity Y – GDP; K - fixed capital; L – labour; α - elasticity of production with respect to fixed capital, computed as the share of return of fixed capital in GDP.

Afterwards, TFP given by formula (1) is made dependent upon the remaining production factors.

The third approach resembles the second one, the common feature being the two-stage procedure of explaining TFP, whereas the main difference - the way of fixing parameter α. In approach three, it is derived via estimation under the assumption of constant returns to scale.

All in all, the following explanatory variables are expected to enter the equation of production:

$$Y = f(K, L, H, DRO, IR\&D, PATZS, WN, U(\cdot), IU(\cdot), \varepsilon) \tag{2}$$

where:

Y – GDP, K – fixed capital, L – labour (number of working people), H – human capital (see section 5), DRO - dependency ratio (number of people beyond productive age to working population); this variable is introduced to catch the possible negative effects stemming from increasing life expectancy upon GDP (see section 7), $IR\&D$ – imported R&D (see section 9), $PATZS$ – cumulated number of domestically “produced” patents (see section 9), WN – indicator of intensity of primary (fixed capital and labour) production factors utilization, $U(\cdot)$, $I(\cdot)$ - dummies and interaction variables introduced in order to account for demand side shocks and possible shifts in structural parameters.

5. Human capital

Human capital is identified with such man’s personal features as their innate abilities, acquired knowledge, education, job experience and skills, health state, personal culture, socio-economic activity, etc, that either directly or indirectly affect labour productivity and are inseparably related to man as carrier of these values (see also e.g. Shultz [1961], Laroche et al. [1999], OECD [2001]). In a narrow sense human capital is usually associated with man's formal education.

The reason why human capital should not be omitted from any analysis dealing with sustainability is the fact that - beside physical and natural capital - it is a decisive factor of long-term growth (see e.g. Aghion, Howitt [1999], chapter 5). Moreover, human capital to much extent determines formation of technological progress – another key element essential for sustained growth. Of equally much importance is also the fact that human capital is characterized by significant substitubility with respect to the other forms of capital, especially with respect to "raw" labour force, which - under shrinking population growth tendency observed in developed countries - should by no means be undervalued. One can also mention numerous externalities connected with human capital (see e.g. Steeg [2005]), among which is higher consciousness regarding environmental protection and consumption of non-renewable goods (see e.g. Smith [1997]).

Although the human capital notion is well-fixed in the theory of endogenous and sustainable growth, its indisputable, universally accepted measures are still missing. A lot of alternative indicators of human capital have been implemented in empirical research (for a review of human capital measures used in empirical research see e.g. Woessman [2003], and for a review of human capital in empirical models of growth see e.g. de la Fuente, Ciccone [2002])

For the sake of the present investigation we suggest an alternative measure that takes into account - at least *implicitly* - three crucial aspects of human capital: formal education, job experience / *learning by doing*, and health state. The indicator is computed as follows:

$$H = e^{\sum_{lev=\min}^{\max} r_{lev} \cdot s_{lev}} \cdot e^{\sum_{i=18}^{65} \frac{\alpha_5 i + \alpha_6 i^2}{\alpha_5 18 + \alpha_6 18^2}} \cdot le \qquad (3)$$

where: $e^{\sum_{lev=\min}^{\max} r_{lev} \cdot s_{lev}}$ - component describing formal education (derived from the Mincer wage equation); le – life expectancy approximating health state of the society; $e^{\sum_{i=18}^{65} \frac{\alpha_5 i + \alpha_6 i^2}{\alpha_5 18 + \alpha_6 18^2}}$ - component responsible for job experience / *learning by*, approximated by age structure of the labour force; estimates of r_{lev} (average rate of return of a given level of education), s_{lev} (average number of school years of a given level of education), and α_5, α_6 (parameters explaining the effects of job experience) are taken from the augmented Mincer wage equation.

All the components making up the aggregate measure of human capital in formula (3) are stock variables with arbitrarily equal weights. Alternatively, one could consider three separate, above-reported indicators of human capital to be inserted as independent variables in the growth equation (1). After all, each of them grasps some different aspect of human capital and there are no *a priori* reasons to claim that each of them exerts equal impact upon potential production. However, as empirical experience shows (see e.g. de la Fuente, Ciccone [2002]), attempts of that kind are bound to fail due to – most probably – multicollinearity.

Indicator (3) rests upon the Mincer wage equation (see Mincer [1970] and for an extension of this notion see Chiswick [1998]), in which it is *implicitly* assumed that wages of employees with various educational background reflect differences in their marginal productivities. Strong as this assumption might be (for a critique see e.g. Blaug [1970]) it enables reasonable weighting of contribution of school education at various levels (usually elementary, secondary and tertiary types of education are distinguished) into an aggregate measure of human capital.

The standard Mincer wage equation, assuming constant rate of return across all education levels, is as follows:

$$\ln W_i = \alpha_0 + \alpha_1 S_i + \alpha_2 X_i + \alpha_3 X_i^{\,2} + \varepsilon_t \qquad (4)$$

where: W_i - wages of an *i-th* employee, S_i - educational level of the *i-th* employee measured by means of the years spent at school, X_i - professional experienced measured by means of the years spent at work (exclusive of the years spent at school), ε_i - error term.

The assumption of the constant rate of return across all education levels – *implicitly* taken in equation (4) – is rather unrealistic. That is why we are going to base our calculation on an extended version of the Mincer wage equation, allowing for differences in the rate of return across individual educational groups. Thus, the modified Mincer wage equation is now as follows (see e.g. Psacharopoulos, Ng [1994]):

$$\ln W_i = \alpha_0 + \alpha_1 D1_i + \alpha_2 D2_i + \alpha_3 D3_i + \alpha_4 D4_i + \alpha_5 X_i + \alpha_6 X_i^2 + \lambda GD + \varepsilon_t \qquad (5)$$

where:

D1, D2, D3 – dummies measuring educational background of an *i-th* employee (elementary, secondary and tertiary respectively); *GD* – gender dummy: 1 for male, 0 for females; λ - parameter accounting for wage differences between males and females under the otherwise equal qualifications; X_i - professional experienced measured by means of the years spent at work (exclusive of the years spent at school), ε_i - error term.

In order to compute specific rates of return for individual education levels – employed in formula (3) one has to run the following calculations:

$$r_{POD} = \frac{\hat{\alpha}_1}{N_{POD}}$$

$$r_{SR} = \frac{\hat{\alpha}_2 - \hat{\alpha}_1}{N_{SR} - N_{POD}} \tag{6}$$

$$r_{WY} = \frac{\hat{\alpha}_3 - \hat{\alpha}_2}{N_{WY} - N_{SR}}$$

where:

r_{POD}, r_{SR}, r_{WY} - rates of return typical of elementary, secondary, and tertiary levels of education respectively,

N_{POD}, N_{SR}, N_{WY} - school durability at a given level of education.

Implementation of human capital indicator proposed in formula (3) calls for estimation of equation (5) on the basis of numerous enough survey data fulfilling all the principles of the representative method. For the purpose of the present project we are going to take advantage of the research outcomes obtained by Kot, Wojciechowska [2003]. However, one more set of information is still needed to compute indicator (3). This is about quite detailed information of the Polish population structure, both by age and gender. This topic is covered in the next section.

6. Demographic issues

To successfully implement the tasks outlined in section 2, as well as for the purposes of a long-term investigation into sustainability, one has to account for natural movement of the Polish population. There are three components constituting this notion: births, deaths and net migration from abroad. It is these three that determine the number of people in a given population and its age structure.

In the research we are going to simplify matters by assuming null net foreign migration. Unrealistic as it might seem at the first sight, this assumption does make sense. This is so because in historical terms (see e.g. Demographic Yearbook of Poland [2005], pp.420-421) – i.e. in the sample period - net international migrations used to be negligible enough not to significantly influence the population number or its structure. As for the present – apparently not fully recognized - tendency of mass job emigration one can expect it to abate pretty soon, along with rising the standard of living and decreasing unemployment in Poland.

Besides - if need be – Polish authorities can relatively easily neutralize the adverse effects of this socio-economic phenomenon by legalizing – and thus increasing - workers' inflow from non-EU countries (in the first place from the Ukraine and Belarus). Actually, the current number of illegal workers staying in Poland is estimated at 300 thousand people (see Korczyńska, Duszczyk [2005]), which to much extent trades off the outflow of Poles abroad.

With the above-mentioned assumption ready, the demographic issues to be modeled boil down to births and deaths, the resultant of which is the age structure of the society. Let us consider births first.

The methodology taken with respect to births rests on taking advantage of the gamma hypothetical distribution of fertility. Empirical research into hypothetical distributions of fertility in Poland shows supremacy of the gamma distribution over other hypothetical distributions (see Kędelski M. [1988] or Marciniak [1999]) such as Pearson type I distribution, Maxwell distribution or logarithmic-normal distribution. Besides, using the gamma hypothetical distribution of fertility is a very convenient and compact way of dealing with births as its not necessary to explain the variability of partial, age-specific fertility ratios. All one needs to know to implement this method is: (i) total fertility ratio, (ii) mean age of woman in labour (iii) standard deviation of the mean age of woman in labour. All these three data can be arrived at *via* traditional econometric methodology by means of an macroeconomic approach. This way, demographic issues will be made dependent upon macroeconomic circumstances, whereas economic phenomena will also depend upon demographic conditions.

Let us now be a little bit more specific about the outlined methodology (see e.g. Pawlukowicz [1990]). Let u_{rt} be the number of the newly born children delivered by women at the age of *r* in year *t*, whereas k_{rt} - total number of women at the age of *r* in year *t*. Then, a partial fertility ratio is defined as:

$$pfr_{rt} = \frac{u_{rt}}{k_{rt}} \tag{7}$$

The sum of all partial fertility ratios (computed for women within the age range of 15-49, with those younger or older than that classified either to the lower or upper end, respectively) defines total fertility ratio, i.e. the hypothetical average number of children a woman is to give birth to under currently existing circumstances):

$$TFR_t = \sum_{r=15}^{49} pfr_{rt} \tag{8}$$

It follows from (8) that:

$$1 = \frac{pfr_{15t}}{TFR_t} + \frac{pfr_{16t}}{TFR_t} + \ldots + \frac{pfr_{49t}}{TFR_t} \tag{9}$$

Thus, expression:

$$sh_{rt} = \frac{pfr_{rt}}{TFR_t} \tag{10}$$

informs about which share of the average number of children born by a woman from the *t-th* cohort falls into the *r-th* reproductive age. It is term (10) that is subjected to the gamma distribution.

The density function of the gamma distribution is as follows:

$$f(x) = \begin{cases} 0 & \text{for } x \le 0 \\ \frac{b^p}{\Gamma(p)}(x - x_0)^{p-1} e^{-b(x-x_0)} & \text{for } x \ge x_0 > 0 \end{cases} \tag{11}$$

where *b>0* and *p>0* are the distribution parameters, whereas $\Gamma(p)$ is the gamma Euler function, and x_0 is the lower limit of variable *x* (here x_0=15).

It follows from the gamma distribution properties that

$$p = \frac{(E(x) - x_0)^2}{V(x)} \tag{12}$$

$$b = \frac{E(x) - x_0}{V(x)} \tag{13}$$

where: *E(x)* – average age of woman in labour, *V(x)* – standard deviation of *E(x)*.

Let further $E(x) = Y_1$ and $\sqrt{V(x)} = Y_2$,whereas $x_0 = 15$ (minimal age of woman in labour). Then (12) and (13) can be rewritten as:

$$p = \frac{(Y_1 - 15)^2}{Y_2^2} \tag{14}$$

$$b = \frac{Y_1 - 15}{Y_2^2} \tag{15}$$

where:

Y_1 - average age of woman in labour,

Y_2 – standard deviation of Y_1

7. Life expectancy

Life expectancy - used as a proxy for the health standing of the Polish society – plays a considerable role in the model. Firstly, it appears directly in the human capital indicator suggested in the paper. Secondly, it affects another component of the afore-mentioned indicator, namely job experience that can be associated – without risking oversimplification – with age structure of the society. Finally, it also defines dependency ratio. All these factors are explanatory variables in the production function – a central relationship of the entire system.

Most economic research on life expectancy focuses on building forecasting models using mortality trends or constructing parameter life expectancy models with samples of individuals. Neither of these two is appropriate in the context of our macro-economic orientated investigation. That is why we suggest building a causal-effect equation of life expectancy allowing for multifarious factors apparently influencing its variability. Although one might risk a statement that it is virtually everything that affects an individual's life durability we shall take into consideration its macro-determinants. The fact that life expectancy is an aggregate measure, reflecting the average life durability of a hypothetical individual - under existing, typical of a given year, variety of conditions - justifies such an approach. However, even with the determinants limited to macro-characteristics only, the list of potential factors is indigestibly vast. Thus, rather than trying to enumerate all of them – an impossible task to accomplish – one might try to identify groups of macro-factors affecting life expectancy. Then, each of such groups can be represented by one or a set of representative variables. In the latter case – to avoid multi-colinearity in the regression analysis - one may benefit form taxonomic methods (see e.g. Strahl [1978]) to construct some aggregate measure, and thus limit the number of explanatory variables.

Below we present a list of such causal-effect groups with examples of possible variables representative of each group (see e.g. Suchecka [1998]):

a) socio-economic factors: GDP per capita, Gini coefficient, unemployment rate, urbanization ratio, residential conditions (e.g. average square meters of residential surface per capita), level of education per capita;
b) health care system: number of physicians per 1000 inhabitants, number of hospital beds per 1000 people, investment outlays on health care system
c) environmental factors: air pollution, water quality, urbanization ratio, amount of waste

d) life-style patterns: consumption of alcohol and/or cigarettes per capita, per capita expenditures on sports and recreation, consumption of non-refundable medicines
e) progress in medical science: cumulated investment outlays on R&D in the medical business on a world rather than national scale

It is worth noting that life expectancy is a stock variable, whereas among the afore-mentioned potential explanatory variables are both stock and stream variables. Due to frequent difficulty in reliable quantification of stock variables (in the presented context this refers to the state/stock of environment from the point of view of its influence upon human's health) we recommend the functional form of the life expectancy equation to be in first differences or rates of growth rather than in levels. In such a case, one can use e.g. emission of gasses (streams) instead of some fancy average measure of air pollution for the whole territory of Poland. If so, stock variables should be differenced, too.

To end this section let us notice that the final version of the life expectancy equation will emerge from empirical evidence, whereas partial death ratios will be computed by means of either some statistical distribution or some top-down bridge equations (with partial ratios being regressed on the aggregate ratios), so that finally it will be possible to generate quite detailed distribution of the Polish population by age and gender.

8. Natural environment

Natural environment seems to be the central link of the whole notion of sustainability. This should not come as a surprise. After all, it is broadly understood natural environment problems that gave rise to this concept. However, issues related to natural environment are so vast and complex that it is hardly imaginable that one can deal with them only within the framework of classic econometric models of national economies. Thus, we have decided on another strategy consisting in joining the modified W8D model with an input-output eco-economic model of the Polish economy: IMPEC (see Plich [2002]). The latter is much better-suited to cope with ecological problems than model W8D does. After such an operation the two models will be in mutual interactions, with IMPEC focused on ecological issues, whereas the modified W8D responsible for macroeconomic issues and other aspects of sustainability.

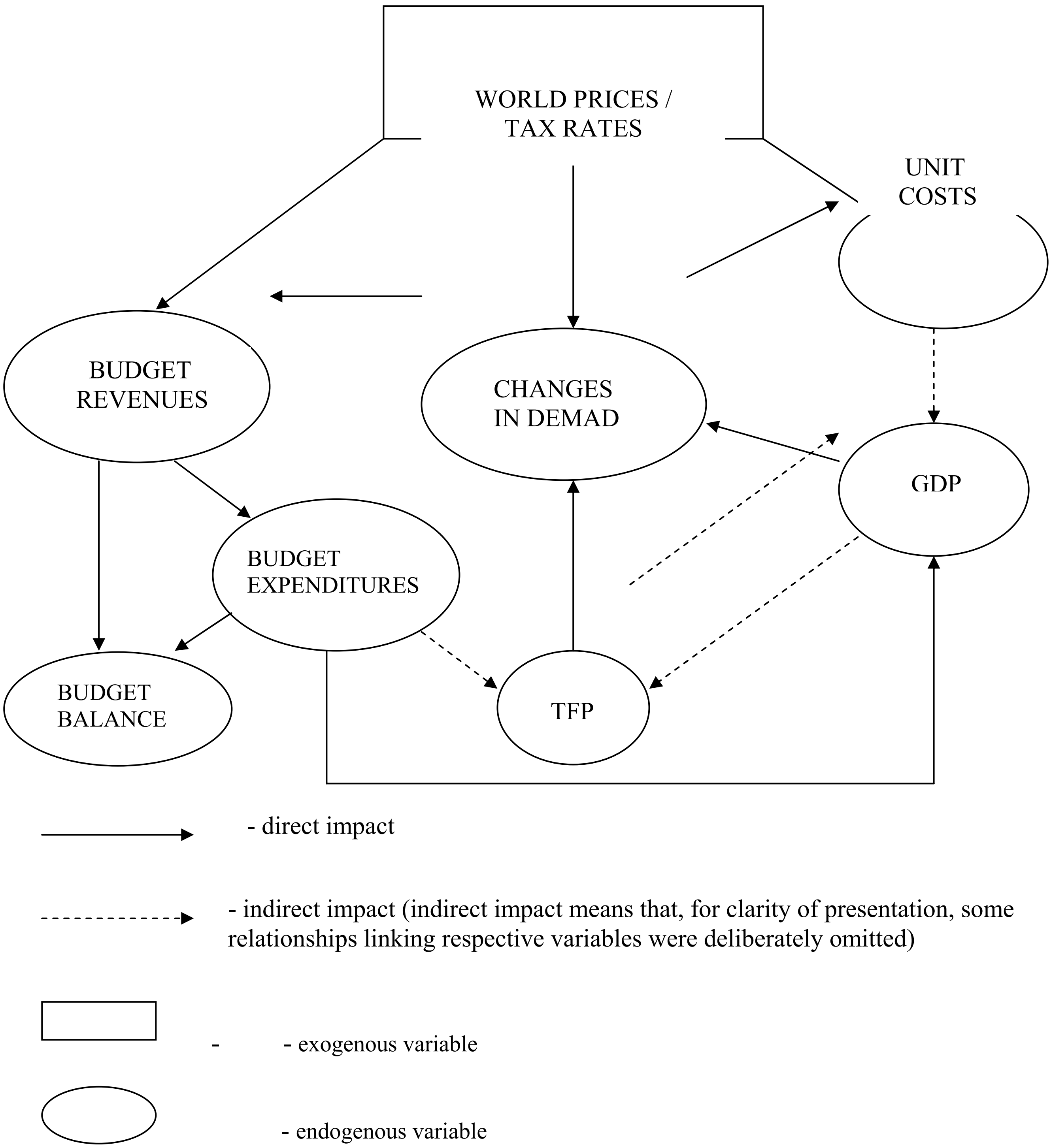
There are, however, some problems of ecological provenance that must be tackled within the framework of the revised W8D. They are related to the long loop connecting the natural environment state – from the point of view of its influence upon human's health - with production *via* life expectancy and human capital (see figure 1). This calls for elaboration of some aggregate measure capable of grasping this aspect of natural environment.

One possible solution is to construct a weighted measure, based on various environmental factors apparently affecting human's health. Although such an approach does not protect us from quite a large dose of arbitrary judgment, in both fixing the factors and the weights, there seems little else one can do when the issue is examined from macroeconomic perspective.

For the sake of the presented target we suggest taking into consideration three environmental components whose influence upon human's health is incontestable, although by no means easy to quantify. Those are: emission of gasses, water quality and the amount of waste, all of which measured as macro-averages per year. It's easy to observe that the three are compound notions consisting of various more or less heterogeneous sub-components (types of gasses, ingredients determining water quality, types of waste).

The following assumptions will be taken to make the concept applicable. Firstly, with respect to the emission of various types of gasses, each unit of emission of a given gas will be

Figure 3. Main feedbacks triggered by world increase in energy carriers or by imposition/increase in environmental taxes



given a weight in line with its toxic ratio established by the Polish authorities. Secondly, as for the water quality – it is going to be approximated by the percentage of fresh waters of first class quality, whereas with respect to wastage – it is going to be only its total volume that will matter. With such simplifying assumptions ready one can employ taxonomic methods (see e.g. Strahl [1978]) to arrive at an aggregate measure of the state of environment in the context of human health.

One further remark is, however, of importance in this context. As recommended in section 7, it is increment in life expectancy rather than its level that should be subject to an analysis. That is why the aggregate measure of environment should comprise stream variables rather than stocks. Consequently, in the aggregate measure gasses and wastee will be given in levels, whereas the indicator of water pollution – in increments.

Another apparently vast application of the modified W8D model in the context of environmental problems consists in analyzing the possible consequences of external shocks in world prices of energy carriers, or imposition/increase in environmental taxes. This can be accomplished via an adjustment of the block of prices existent in the model. The general idea of which links are triggered by changes in prices is depicted in figure 3.

9. Education and science sectors in the formation of technological progress

Model W8D – in its initial version - explained the formation of productive factors determining long-term growth of the Polish economy on the supply side. However, while utilizing the model it turned out that it missed one important feature: the fact that steps taken to stimulate the supply side, such as increasing outlays on R&D or education, should also affect the demand side of the economy. With this important link broken, some artificial crowding out effect used to take place in the simulation system, with a decrease in realized GDP instead of its increase as a reaction to stimulating the to supply side of the economy. In the context of national accounts, an attempt to solve this problem must lead, however, to the introduction of a whole submodel of education and science into the otherwise one-sector model that W8D used to be.

Here is the chain of suggested specifications:

a) value added:

$$VX_{it} = \overset{(?)}{\alpha_0} K_{it}^{\overset{(+)}{\alpha_1}} N_{it}^{\overset{(+)}{\alpha_2}} e^{\overset{(+)}{\alpha_3} T_t} e^{\overset{(?)}{\alpha_i} U_{it}} \varepsilon_{it}, \tag{14}$$

where: VX_{it} - value added in constant prices at period t for sector i (i=1 – education; i=2 – science), K_{it} - fixed capital, N_{it} - employees, T_t - trend, U_{it} - dummies

b) investment outlays:

$$\ln J_{it} = \overset{(?)}{\alpha_0} + \overset{(+)}{\alpha_1} \ln J_{i,t-1} + \overset{(+)}{\alpha_2} \ln X_t + \overset{(?)}{\alpha_i} U_{it} + \varepsilon_t, \tag{15}$$

where: J_{it} - investment outlays in constant prices at period *t* for sector *i* (*i*=1 – education; *i*=2 – science), X_t - GDP

c) fixed capital:

$$DK_{it} = \overset{(?)}{\alpha_0} + \overset{(+)}{\alpha_1} DK_{i,t-1} + \overset{(+)}{\alpha_2} J_{it} + \overset{(?)}{\alpha_i} U_{it} + \varepsilon_t \tag{16}$$

where: DK_{it} - increment in gross fixed capital in constant prices at period *t* for sector *i* (*i*=1 – education; *i*=2 – science)

d) employment:

$$\ln N_{it} = \overset{(?)}{\alpha_0} + \overset{(+)}{\alpha_1} \ln N_{i,t-1} + \overset{(+)}{\alpha_2} \ln STUD_{it} + \overset{(+)}{\alpha_3} \ln G_t + \overset{(?)}{\alpha_i} U_{it} + \varepsilon_t \tag{17}$$

where: N_{it} - number of employees at period *t* for sector *i* (*i*=1 – elementary and secondary education, *i*=2 – tertiary education), $STUD_{it}$ - number of students, G_t - public expenditures.

The above-mentioned specifications, even though very parsimonious, are in line with both basic economic principles (see Welfe W., Welfe A. [2004]) and the general philosophy of the W8D, in the sense that they "mimic" the feedbacks existent in the initial version of the model. However, to complete the loops one needs to supplement the system with some accounting identities. Here they are:

(i) total gross investment outlays:

$$JA \equiv JAI + (JE + JN) \tag{18}$$

where: *JE* – investment outlays on education, *JN* – investment outlays on science

(ii) total employment:

$$N \equiv NI + NE + NSWP + NNSWP \tag{19}$$

where: *NI* – employed beyond education and science sectors, *NE* – employed in elementary and secondary education, *NSWP* – employed in tertiary education, *NNSWP* – employed in science sector, exclusive of tertiary education

(iii) total personal income from wages:

$$FBP \equiv FBPI + FBPNE \tag{20}$$

where: *FBPI* - income from employment beyond education and science sectors, *FBPNE* - income from employment in education and science sectors.

Another novelty suggested in the modified version of the W8D consists in replacing cumulated stock of investment outlays on domestic R&D with cumulated stock of patents in the production function (see section 3). There are two reasons to do so. Firstly, empirical results obtained in the afore-mentioned equation indicate poor significance of the former variable. Secondly, there are theoretical foundations (see e.g. Matthiessen, Schwarz [2000]) strongly supporting the hypothesis of the crucial importance of patents for economic growth.

The possible equations generating formation of the stock of patents might look like this:

$$\text{a) } PATZ_t = \overset{(?)}{\alpha_0}\, NN_t^{\overset{(+)}{\alpha_1}} KN_t^{\overset{(+)}{\alpha_2}} e^{\overset{(?)}{\alpha_i} U_{it}} e^{\varepsilon_t} \qquad (21)$$

where: *PATZ* – number of domestic patents in year *t*, *NN* – employment in science sector, *KN* - fixed capital in science sector

or:

$$\text{b) } PATZ_t = f(\overset{(+)}{NN}_t, B\overset{(+)}{N}TS_t, \varepsilon_t), \qquad (22)$$

where:

$$BNTS_t \equiv (1-\delta)\cdot BNTS_{t-1} + BNT_t \qquad (23)$$

and: *BNT* – number of newly published scientific works in year *t* , *BNTS* – cumulated stock of scientific publications, δ - depreciation ratio to be fixed.

If case b) proves empirically more promising then:

$$BNT_t = f(BNT_{t-1}, NSWP_t + NNSWP_t, KN_t, \varepsilon_t) \qquad (24)$$

with all the symbols explained above.

The last item necessary to close the discussion on the role of the patents is their cumulated volume. It will be derived from the following formula:

$$PATZS_t = (1-\delta)\cdot PATZS_{t-1} + PATZ_t \qquad (25)$$

The estimates of the depreciation ratio, δ, - both in equation (23) and in equation (25) - are going to be fixed on the basis of the perpetual inventory method (see e.g. Coe, Helpman [1995]).

As for the supply side of the education sector as well as the treatment of foreign R&D activity and its influence upon the Polish economy we refer the reader to our previous works (see e.g. Welfe (ed.) [2001]) as we are going to benefit from those solutions without any alterations.

Finally, for the purpose of our investigation we associate technological progress with total factor productivity. The latter is defined in the way described in section 3 and consists of the following components: human capital, imported R&D and cumulated stock of patents. Education sector (its supply side) partakes in formation of human capital whereas science sector determines the stock of patents. Both the sectors will be also reflected on the demand side of the new model.

10. Possible policy scenarios

Although moderate in size and not exhaustive in the problems covered, the model outlined in the previous sections will still be capable of answering a lot of weighty questions from the area of broadly perceived sustainability. Firstly – once its simulation version constructed and a BAU scenario elaborated – the model can be used to run a multiplier analysis, by means of which one is able to assess - in quantitative terms - the impact of a unit change (increase/decrease) of a given exogenous variable upon the other endogenous variables present in the system. It should be emphasized that this kind of information cannot be derived from individual equations' parameters due to the simultaneity of all the relationships. Under such circumstances the *ceteris paribus* interpretation of estimates obtained in individual equations does not hold.

All in all, the scope of a multiplier analysis is limited only by the number of exogenous variables present in the model, although – in a more general case – one may also analyze the effects of a unit change of some selected endogenous variables providing it makes sense. E.g. though interest rate is treated endogenously in the model, one can easily imagine it as an exogenous variable (Central Bank) and – via temporary exogenization – observe the effects of its unit change upon the whole system. As for other endogenous variables (such as exchange rate or investment outlays on education) one may interpret a multiplier exercise in terms of external shocks or shifts in macroeconomic policy.

As far as policy scenarios are concerned the extent of available variants seems to be limited only by the model's user's creativity and reliability of the taken assumptions. After all, this type of analysis is – things simplified slightly - nothing but a sensible mix of multipliers of various magnitude. Thus, one might want to acquire quantitative knowledge of the possible consequences of pursuing definitive macro policies directed towards sustainability (environmental taxes, increased outlays on science and education, promotion of healthy life styles etc. - all of these measures taken contemporaneously as opposed to single steps in this direction (multiplier analysis)). One might also be interested in the possible macro-economic effects of the aging society or increasing the mandatory age of retirement. Moreover, by means of the analytical tool under consideration one is also able to deal with issues not *explicitly* covered by the model. This can be accomplished either by making some additional calculations outside the system and finding an appropriate way to introduce them into it (for technical details see Whitley [1994]) or by further extending the model or finally by linking it with another system.

11. Final comments and further tasks

The theoretical construction proposed in the paper is based on macroeconomic fundamentals, with the W8D model constituting its starting point. This fact has a bearing on the way the model is going to be extended. The quantitative relationships grasped by the modified system are all centered around the long-run growth, with the production function being responsible for the main feedbacks in the system. This was an intentional choice. After all, Poland is still falling far behind the well-developed countries both with respect to *per capita* GDP, and social as well as institutional reliance. Thus, it seems that some vital sustainability problems, such as environmental issues, will be given a full social attention and priority only after the Polish society – as a whole – has enjoyed higher material wealth.

The solutions taken seem to prove a high potential elasticity of the W8D model as a tool of quantitative analysis also in the context of sustainability. For obvious reasons the model – even in its modified version - cannot account for global issues such as the prices of energy carries or global warming. Therefore, to try to deal with problems of that type on a national scale, one has to get some reliable information from external sources (global models designed to address such issues) and – even more importantly – some quantified hints on how the global circumstances are expected to affect the links existent in the model, i.e. one must identify an appropriate entrance to the system. These conditions fulfilled, the model might be successfully applied also in analyses of national consequences of some global changes.

The theoretical outline presented in the paper determines further research tasks. It is about elaborating an extended and updated data base in the first place. Re-estimation of the W8D equations seems necessary as its initial version was spanned on the 1960-1998 sample. Verification of the specifications described in previous sections must follow. Once all the individual equations estimated, the model must be completed with appropriate identities. Then all the stochastic equations as well as identities will have to be united into a simulation system, whereas all possible errors, arisen in the process of coding, must be deleted. A multiplier analysis should precede any attempts to apply the model to policy scenario analyses.

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