The Dynamics of the World Agricultural Production: An Inquiry using the Index Decomposition Analysis

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Abstract

The purpose of this paper is to analyze the dynamics of the world agriculture production and consumption using the index decomposition analysis (IDA). Therefore the changes in both variables were split to shifts in chosen types of level, intensity and structural indicators. Namely world agricultural production can be explained by changes in total agricultural land (scale effect) and its regional composition (structural effect), productivity of labor, land, and capital (intensity effects). In addition, evolution of world food consumption can be described by changes of total population (scale effect) and its composition over the world (structural effect), changes in GDP per capita and structure of consumption (intensity effects). All the effects explain the changes reasonably. However, structural effects are relatively negligible in comparison with intensity effects. Moreover scale effects are in the case of agricultural consumption more significant than in the case of agricultural production.

Key words: Decomposition analysis, Index numbers, World Agricultural Production and Consumption;
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1 Introduction

The dynamics of the agricultural production and food consumption interests researchers, policy-makers, or planners around the world for a variety of reasons. The main reason is the assessment of the world's ability to feed itself (Islam, 1995), but other reasons like impacts of agricultural production on composition of land or regional relationships between agricultural supply and demand are important too. The goal of this paper is to contribute to this research agenda by analysis of regional and intensity shifts in agricultural production and consumption around the world.

To achieve the goal of the paper, the index decomposition analysis (hereafter, IDA) is used. The IDA is a commonly adopted tool for determination of the impact of indicators such as population, economic activity and its structure, technology and possibly other factors on a chosen indicator (Ang [2]). Nevertheless, alternative approaches, such as econometric decomposition analysis (Stern [9]) or structural decomposition analysis (Hoekstra & van der Bergh [6]) have been proposed too. Each approach has different data requirements and provides different pieces of information but there can also been found several common features [1] This paper uses the IDA to isolate the impacts of changes in labor productivity, capital formation, technology and constitution of land on world food production and impacts of shifts in GDP, its structure and population on world agricultural consumption. Namely, logarithmic mean Divisia index method II (hereafter LMDI II) proposed by Ang and Choi [1] or Ang [4] is chosen as appropriate tool for the analysis.

The rest of the paper is organized as follows: Section 2 describes the main stylized facts for the food production and consumption in past years. Section 3 describes the methodology behind the IDA and section 4 shows the results of agricultural production and consumption decomposition analysis. Section 5 concludes.

[1] For example, structural decomposition analysis is often cited together with IDA (eg. Hoekstra & van der Bergh [6]). In both methods, Laspeyeres (weighting by base year), Paasche (weihgting by target year) and Marshall-Edgeworth (weighting by the mean of base and target year) indices can be applied. However, only in IDA approach, different types of Divisia indices can further be employed.

2 Data and stylized facts

The data for the analysis come mainly from the World Bank website.[2] The world has been divided among eight aggregated regions: the Czech Republic, the rest of the EU-27 (i.e. the EU 26), the OPEC countries, the rest of the OECD, rest of the former USSR, the rest of Asia, the rest of Africa, and the rest of Latin America[3]. Grouping of the region respect preferentially economic structures of particular states and their location.

2.1 Changes in world agricultural production

For the purpose of the analysis, we use value added in agricultural sector measured in 2000 USD as variable expressing regional agricultural production.[**?**,**?**] The evolution of total value added in agriculture in selected regions can be seen in figure **??**. In general, the real agricultural value added increased about 42 % between the year 1990 and 2007. The growth can be split into two periods: the years (1990 - 1995) witnessed moderate increase oscillating around 1 % per year. Moreover a very negligible drops in real value added were recorded in the years 1991 and 1995. Since the year 1996 the total real value added in agriculture has permanently been increasing with annual growths oscillating around 2 % and ranging from 1,6 % to 4,8 %.

Namely, the highest growth in real value added in agriculture during the whole period is indicated in the Asian countries followed by Middle East and Latin American countries. The Asian agricultural production increased totally about 76 % which is on average 3,4 % a year. It can also be seen from the figure 2 that the share of agricultural production in Asian countries in total agricultural production gradually increased from 31 % to almost 38 % in the year 2007. More than 2 % of average annual growth in real agricultural value added was further observed in Middle East (2.8 %), Latin America (2.7 %), and African countries (2.2 %). The share of agricultural value added of Latin America increased in analyzed period from 9.9 % to 10.9 %. European countries and non European developed countries recorded only slight increase around 1 % from the year 1990 to 2007, which in the case of European countries led to lost in the total agricultural production share from 19.4 % to 15 %. The former USSR was only region with a drop in real agricultural value added in period 1990-2007. Decreasing agricultural production was observed in this region in the years 1990-1996 and in the year 1998. As a result, the former USSR countries lost approx. 1.4 % share in total agricultural production.

[2] World Development Indicators & Global Development Finance downloadable at: *http://databank.worldbank.org*.
[3] For more detailed specification of world regions see Annex 5

2.2 Changes in world food consumption

Because of lack of the data, the food consumption in selected regions was approximated by the indicator calculated as real value added in agriculture plus real value of agricultural merchandise exports from which real value of agricultural merchandise imports has been subtracted.[4] Total indicator of food consumption in selected regions grew annually about 2 % on average. With exception of the period 1994-1996 permanent drop in nominal consumption was observed up to the year 2001.

Real agricultural consumption increased the most in Asian, African and Middle East countries (around 3 % a year on average). A relatively high annual growth in real consumption was also indicated in the case of non European developed countries (1.47 %). Looking at regional composition of overall food consumption, Asian countries increased their share from 30 % to 37 % in the analyzed period while African countries raised their share from 2.7 % to 3.1 %. The share of European countries on overall food consumption declined by approx. 4 % from 20.6 % to 16.4 %.

3 The index decomposition analysis

3.1 General theory

The goal of the IDA is to understand historical changes in a social, economic, environmental, or agricultural indicator, and to gauge the driving forces or determinants that underlie these changes. The application of the IDA to agricultural indicators has been used especially in assessing the influence of the population size, the amount of arable land, sectoral shifts, capital formation, or technology changes.

Let us consider the indicator Φ, which is given as:

$$\Phi_t = \Upsilon_t \sum_i \phi_{1it} \dots \phi_{Mit}, \tag{1}$$

where Υ_t is the scale measure[5], and the summation runs over countries,

[4] Initially, the variables were available in nominal terms. The nominal values in aggregated regions have therefore been adjusted by agricultural deflator calculated as the ratio of value added in agriculture in constant and current prices.

[5] Such as the total population if the aggregate food consumption is investigated,

commodities, or another interesting dimension. The goal is to decompose the change in the indicator into a number of determinants.

If observations were available in continuous time, the decomposition would be straightforward: the percentage change in the indicator $\dot{\Phi}_t/\Phi_t$ could be written as follows:

$$\frac{\dot{\Phi}_t}{\Phi_t} = \frac{\dot{\Upsilon}_t}{\Upsilon_t} + \frac{\sum_i \frac{\dot{\phi}_{1it}}{\phi_{1it}} \phi_{1it} \ldots \phi_{Mit}}{\sum_i \phi_{1it} \ldots \phi_{Mit}} + \ldots + \frac{\sum_i \frac{\dot{\phi}_{Mit}}{\phi_{Mit}} \phi_{1it} \ldots \phi_{Mit}}{\sum_i \phi_{1it} \ldots \phi_{Mit}} \tag{2}$$

where $\frac{\dot{\Upsilon}_t}{\Upsilon_t}$ is the growth in the scale measure, and the expression $\frac{\sum_i \frac{\dot{\phi}_{mit}}{\phi_{mit}} \phi_{1it} \ldots \phi_{Mit}}{\sum_i \phi_{1it} \ldots \phi_{Mit}}$ could be interpreted as the weighted percentage change in the factors ϕ_{mit}. The problem is that observations are not available in continuous time, and therefore discrete-time approximations should be used.

A discrete-time decomposition approximation can adopt an additive or a multiplicative mathematical form. The additive form decomposes the difference in the indicator Φ between times t_1 and t_2 into the sum of determinants D_i and a residual term $\tilde{R}$:

$$\Phi_{t_2} - \Phi_{t_1} = D_1 + D_2 + \ldots + D_N + \tilde{R}. \tag{3}$$

The multiplicative form decomposes the relative growth of the indicator into the product of determinant effects:

$$\frac{\Phi_{t_2}}{\Phi_{t_1}} = D_1 \times D_2 \times \ldots \times D_N \times \tilde{R} \tag{4}$$

A number of mathematical forms for the additive as well as multiplicative decomposition forms has been proposed. Ang[2], [4] provide useful overviews of mathematical forms and their useful properties. The following four properties are particularly relevant to the index decomposition analysis:

Exactness: an exact decomposition has no residual; in the additive case this means that the residual equals 0, while it equals 1 in the multiplicative case.

Time reversal: the decomposition satisfies this property whenever the decomposition yields the reciprocal results after the reversal of the time periods.

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or the total agricultural land if the production is investigated, but it may represent also the real GDP if the relation between wealth and food production/consumption is investigated

Factor reversal: concerns the invariance with respect to the permutation of determinants.

Robustness: a decomposition is robust if it does not fail when it comes across zero (or even negative) values in the dataset.

3.2 LMDI II

This paper applies the LMDI II suggested by Ang and Choi [1] or Ang [4] as the preferred method under a wide range of circumstances: the LMDI II satisfies the four requirements mentioned above and has no residual (i.e. $\tilde{R} = 0$ in the additive case and $\tilde{R} = 1$ in the multiplicative case. [6]) While LMDI II has both a multiplicative and an additive form the multiplicative form will be applied for subsequent analysis.

The multiplicative LMDI II is defined as follows:

$$D_j^{t_2,t_1} \equiv \exp\left(\sum_i \frac{\mathcal{L}(\Phi_{it_2}, \Phi_{it_1})}{\mathcal{L}(\Phi_{t_2}, \Phi_{t_1})} \log\left(\frac{\phi_{jit_2}}{\phi_{jit_1}}\right)\right), \tag{5}$$

where $\Phi_{it} \equiv \prod_{j=1}^{m} \phi_{jit}$ and $\mathcal{L}$ is so-called logarithmic average:

$$\mathcal{L}(x_1, x_2) \equiv \begin{cases} \frac{x_1 - x_2}{\log x_1 - \log x_2} & \text{if } x_1 \neq x_2 \\ x_1 & \text{otherwise.} \end{cases}$$

The residual term satisfies $R = 1$, since the *LMDI II* is an exact approach.

The *intensity effect* is than given as:

$$D_a^{t_2,t_1} = \exp\left(\sum_i \frac{\mathcal{L}(a_{it_2} s_{it_2}, a_{it_1} s_{it_1})}{\mathcal{L}(\sum_j a_{jt_2} s_{jt_2}, \sum_j a_{jt_1} s_{jt_1})} \log\left(\frac{a_{it_2}}{a_{it_1}}\right)\right),$$

and the *structure* effect is given as follows:

$$D_s^{t_2,t_1} = \exp\left(\sum_i \frac{\mathcal{L}(a_{it_2} s_{it_2}, a_{it_1} s_{it_1})}{\mathcal{L}(\sum_j a_{jt_2} s_{jt_2}, \sum_j a_{jt_1} s_{jt_1})} \log\left(\frac{s_{it_2}}{s_{it_1}}\right)\right).$$

[6] This is advantage since decomposition based on Laspeyres indices could suffer from large unexplained residuals in some cases.

4 Empirical Results

The decomposition is provided both for agricultural production and agricultural consumption for seventeen year period 1991-2007. The explanations of changes in both indicators are, however, different.

4.1 Real Agricultural Value Added

In the case of agricultural production, the *scale effect* explains the changes in real production in agriculture as a result of changes in total agricultural land $\mathcal{L}$. The assumption is that growing agricultural land results in growing agricultural production. Further, the *structural effect* D_s is the result of changes in composition of agricultural land according to selected regions over the world.The *structural effect* is assumed to be rather negative since agricultural production often moves to less productive world regions. The *intensity effect* is in the case of agricultural production consequently decomposed into four sub-effects:

Intensity effect of land D_a: is measured by changes in ratio of real value added in agriculture per square kilometer of agricultural land and positive effect is assumed as the result of the positive technological change in agricultural sector,

Intensity effect of employment D_b: reflects changes in number of employees per value added in agriculture, the assumption is that growing productivity in agricultural sector will lead rather to decline in this indicator because there is pressure on reduction of employees in agricultural sector and simultaneous increase in value added in agriculture,

Intensity effect of capital equipment of labor D_c depicts changes in capital equipment of labor force approximated by number of tractors per employee and the effect is expected to be rather positive, substitution of labor by capital results in higher agricultural production,

Intensity effect of capital utilization D_d: are changes in value added per one tractor, the effect is expected to be ambiguous since both value added as well as capital intensity are assumed to increase in agriculture during analyzed period.

Equations (1), (4), and from the common known approximation $\log(\frac{X_2}{X_1}) \cong \frac{X_2}{X_1} - 1)$ imply:

$$\frac{A^s_{t2} - A^s_{t1}}{A^s_{t1}} = \frac{\mathcal{A}_{t2} - \mathcal{A}_{t1}}{\mathcal{A}_{t1}} + \log D_a + \log D_b + \log D_c + \log D_d + \log D_s, \quad (6)$$

where A^s stands for real agricultural value added, $\mathcal{A}$ is total area of agricultural land and whole fraction addresses scale effect, logarithms of D_a, D_b, D_c, D_d are particular intensity effects, and the logarithm of D_s shows structure effect.

Figure (4) shows the decomposition of changes in real value added. It can be seen that increases in value added are mainly driven by intensity effect of land and capital equipment of labor. In the first case, the positive values are ranging from 0.1 % to 4.9 %, with only exception in the year 1991 with negative influence of this effect. In the case of capital equipment of labor, the positive values are ranging from 1.5 % to 5.4 %. On the other hand, as expected, employment intensity effect adversely affects changes in value added during the whole analyzed period. The intensity effect of capital utilization and structural effect have ambiguous impacts. The structural effect rather shows that the agricultural production is indeed moved to poorer countries. The structural effect is weakened by the fact, that the value added in agriculture naturally increases also in developed countries as a result of production of "more luxurious" agricultural products. The residual term, included for verification, takes a very small values (less than 0.25 percentage points) which is caused mainly by approximation errors.

Deeper analysis of the regions shows that value added per square kilometer of agricultural land favorably developed mainly in Asian countries which supported growths in total agricultural value added. Growing productivity was also possible to see in the European region up to the year 2003, than after a relatively high improvement in the year 2004, continuous drops were observed in the years 2005, 2006 and 2007. In the Europe, the main driver for the highest agricultural production increase in observed period was a relatively large improvement in value added per agricultural land and a large decrease in employees.

4.2 Real Agricultural Consumption

In the case of agricultural consumption, the *scale effect* explains the changes in real consumption of agricultural goods as a result of changes in total population L with an expectation of positive relationship since more people are assumed to consume more food. Furthermore, the *structural effect* reflects changes in composition people in the world. The idea of this effect is that negative effect shows growing number of people in poorer regions with smaller demand on food. The *intensity effect* is in the case of real agricultural consumption split into two sub-effects:

Intensity effect of GDP D_a: is measured by changes in ratio of GDP per capita, it is assumed a positive impact on consumption since higher income usually lead to higher consumption,

Intensity effect of agricultural consumption share D_b: reflects changes in share of consumption of food in GDP, the effect should be rather adverse since food is basic commodity and the share of expenditure on food in total income declines.

Again, using the same approximation we get following formula:

$$\frac{A^d_{t2} - A^d_{t1}}{A^d_{t1}} = \frac{L_{t2} - L_{t1}}{L_{t1}} + \log D_a + \log D_b + \log D_s, \tag{7}$$

where A^d stands for agricultural demand/consumption, L expresses population, D_a intensity effect of GDP, D_b intensity effect of agricultural consumption share and D_s structural effect.

Figure (5) shows the decomposition of changes in real agricultural consumption. It can be seen that annual changes in world agricultural consumption range from approximately - 2 % to 4 %. The growths are mainly driven by intensity effect of GDP. In addition, the growing population also significantly contributed to increases in agricultural demand. On the contrary, the share of consumption in GDP mainly hampered the growth (the only exception is the year 1998). The structural effect is relatively small but its negative direction occurred as expected. The residual term, again included for verification, takes a very small values (less than 0.25 percentage points).

Inspecting the data more deeply, it can be seen that the share of people with lesser food demand (i.e. in the rest of Africa and Latin America) was gradually increasing causing the structural effect to be negative. Intensity effect of GDP was mainly driven by Asian, non European developed and European countries.

5 Conclusion

This paper attempts at explaining the changes in world agricultural demand and supply by changes of other relevant socioeconomic and agricultural indicators. For the analysis, IDA was chosen as appropriate tool with LMDI II as flagship to this approach. While the world agricultural supply was expressed by real value added in agricultural sector real agricultural consumption was calculated as nominal value added plus nominal agricultural merchandise exports minus nominal agricultural merchandise imports deflated by agricultural deflator. Generally, we witnessed moderate increase in both, world agricultural consumption and world agricultural production (the only exception is the former USSR where the level of value added is in the year 2007 approximately the same as in the year 1990). The changes in both variables were described by changes of different types of level, intensity and structural effects. Namely world agricultural production is explained by changes in total agricultural land (scale effect) and its regional composition (structural effect), productivity of labor, land, and capital (intensity effects). In addition, evolution of world food consumption can be described by changes of total population (scale effect) and its composition over the world (structural effect), changes in GDP per capita and structure of consumption (intensity effects). All the effects explain the changes reasonably. However, structural effects are relatively negligible compared to intensity effects. Moreover scale effects are in the case of agricultural consumption more significant than in the case of agricultural production. Therefore in the case of value added intensity effect of land mainly drives the changes where the positive values range from 0.1 % to 4.9 %. Changes in capital equipment of labor also favorably affect the overall changes in value added. On the other hand, as expected, employment intensity effect adversely affects changes in value added during the whole analyzed period. The intensity effect of capital utilization has ambiguous impacts. Furthermore, annual changes in world agricultural consumption range from approximately - 2 % to 4 %. The growths are mainly driven by intensity effect of GDP and the growing population. On the contrary, the share of consumption in GDP mainly hampered the growth (the only exception is the year 1998). The structural effect is relatively small but its negative direction occurred as expected.

References

[1] Ang, B.W., Choi, K.H. (1997). Decomposition of aggregate energy and gas emission intensities for industry: a refined Divisia index method. *The Energy Journal 18(3)*, pp. 59-73.

[2] Ang, B.W. (1999). Decomposition methodology in energy demand and environmental analysis. In van den Bergh J.C.J.M. (Ed.) *Handbook of environmental and resource economics*, pp. 1165-1179, Edward Elgar.

[3] Ang, B.W., Liu F. L. (2001). A new energy decomposition method: perfect in decomposition and consistent in aggregation *Energy 26 (6)*, pp. 537-548.

[4] Ang, B.W. (2004). Decomposition analysis for policymaking in energy: which is the preferred method? *Energy Policy 32*, pp. 1131-1139.

[5] Ang, B.W., Liu F.L., Chung, H.S. (2004). A generalized Fisher index approach to energy decomposition analysis. *Energy Economics 26*, pp. 757– 763.

[6] Hoekstra, R., van der Bergh, J.C.J.M. (2003). Comparing structural and index decompostion analysis. *Energy Economics 25*, pp. 39-64.

[7] Islam, N. (1995). Population and Food in the Early Twenty-First Century: Meeting Future Food Demand of an Increasing Population. International Food Policy Research Institute, Washington DC.

[8] Seigel, I.H. (1945). The 'ideal' index-number formula. *Journal of the American Statistical Association 40*, pp. 520–523.

[9] Stern, D. (2002). Explaining Changes in Global Sulfur Emissions: An Econometric Decomposition Approach. *Ecological Economics 42*, pp. 201-220.

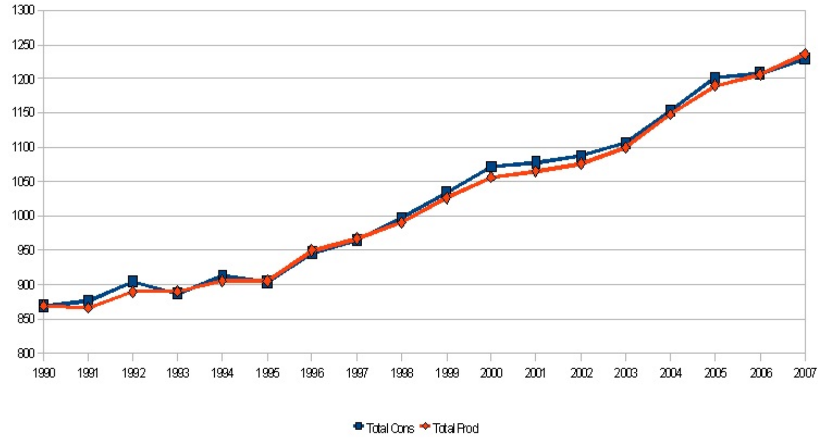

Fig. 1. Total real agricultural value added and proxy consumption

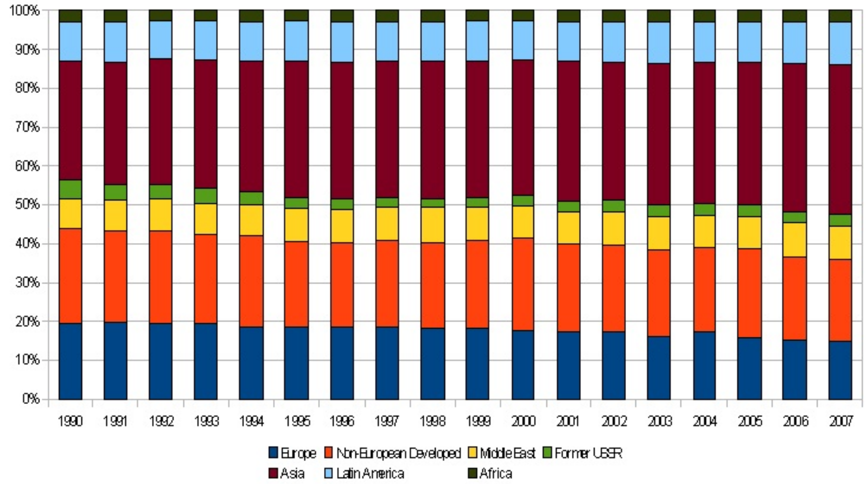

Fig. 2. Shares of particular regions in total real value added in agriculture

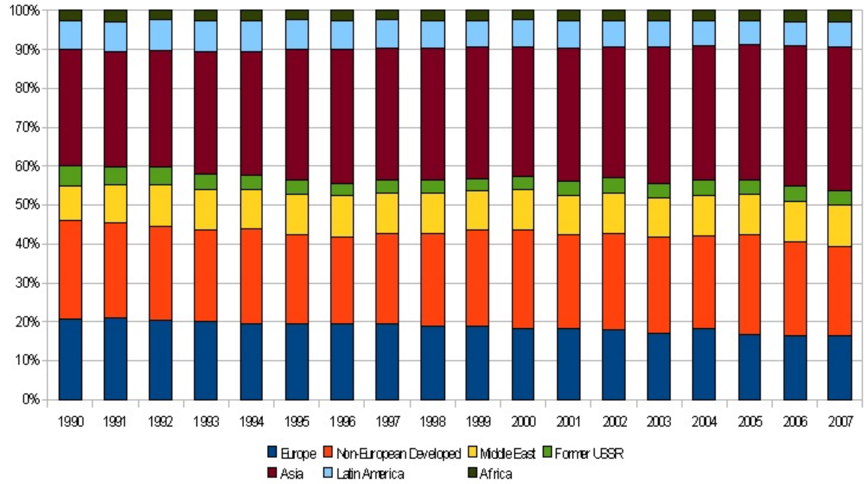

Fig. 3. Shares of particular regions in total agricultural consumption

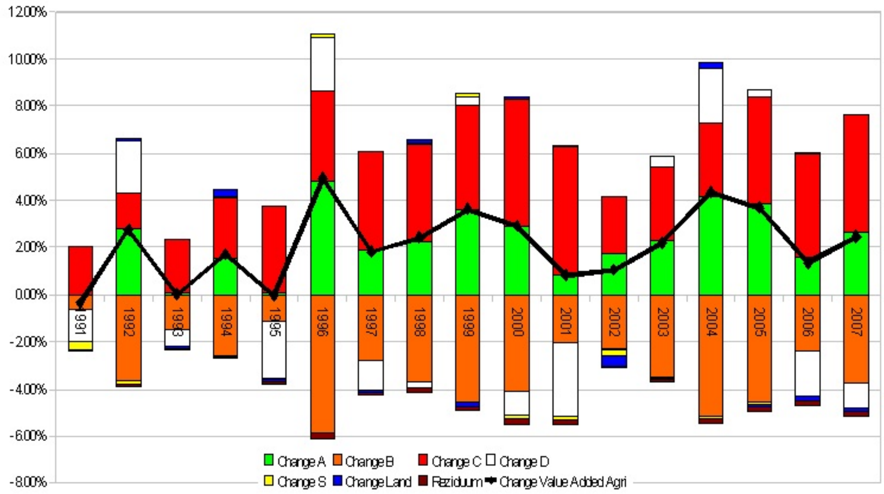

Fig. 4. Decomposition of changes in agricultural value added

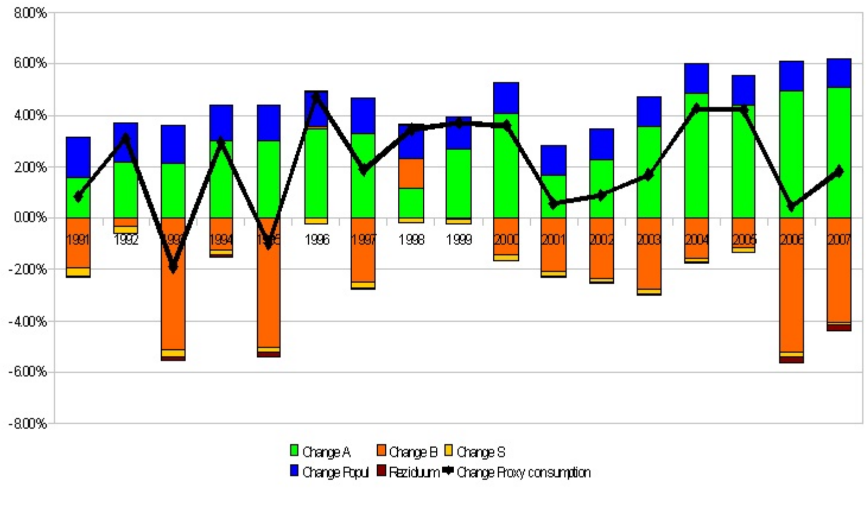

Fig. 5. Decomposition of changes in agricultural consumption

Table 1: Division of the world.

Region	Countries
Europe	Austria, Belgium, Bulgaria, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Italy, Ireland, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Norway, Poland, Portugal, Romania, Slovak Republic, Slovenia, Spain, Sweden, Switzerland, United Kingdom
Non European Developed	Australia, Canada, Iceland, Japan, Korea, New Zealand, United States
Middle East	Algeria, Egypt, Iran, Iraq, Israel, Kuwait, Lebanon, Libya, Oman, Qatar, Saudi Arabia, Syrian Arab Republic, Sudan, Tunisia, Turkey, United Arab Emirates, Yemen
former USSR	Azerbaijan, Belarus, Georgia, Kazakhstan, Russia, Ukraine, Uzbekistan
Asia	Bangladesh, China, Hong Kong, Indonesia, India, Malaysia, Pakistan, Philippines, Singapore, Sri Lanka, Thailand, Vietnam,
Latin America	Argentina, Bolivia, Brazil, Chile, Colombia, Costa Rica, Cuba, Dominican Republic, Ecuador, El Salvador, Guatemala, Honduras, Jamaica, Mexico, Panama, Paraguay, Peru, Puerto Rico, Uruguay, Venezuela
Africa	Angola, Botswana, Cameroon, Congo, Cote d'Ivore, Ethiopia, Kenya, Morocco, Nigeria, Tanzania, South Africa, Zambia, Zimbabwe