Econometric Estimation of Capital-Labor Substitution Elasticities for Ukrainian CGE Model

Maksym Chepeliev[1]

Institute for Economics and Forecasting, Ukrainian National Academy of Sciences[2]

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chepeliev@ief.org.ua

Summary

The paper presents econometric estimates of the capital-labor substitution elasticities in terms of 10 economic activities based on the 2003-2009 data. Elasticities are estimated in the context of computable general equilibrium (CGE) methodology, particularly, based on the constant elasticity of substitution in production functions and cost minimization assumptions.

Selection of methods and approaches to elasticities estimation is based on the literature review. Thus the paper considers several issues: minimum amount of statistical data, required to obtain reliable estimates; choice of functional forms; and specification of economic indicators for production functions variables representation.

According to the received estimates, values of Ukrainian capital-labor substitution elasticities are rather low – 0,13-0,82. Service industries are characterized by lower elasticity values, compared to the real sector of Ukrainian economy, which can be explained by the fact that services have higher labor intensity.

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[1] Research officer, Department of Energy Sector Development and Forecasting.

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Despite the availability of relatively small amount of historical data and some methodological aspects, obtained estimates call into question the appropriateness of application of certain production functions for modeling the investigated processes. In particular, this includes the case of Cobb-Douglas production functions that have unitary elasticity of substitution.

Key words: substitution elasticities, labor, capital, econometric estimation, computable general equilibrium model, Ukraine

JEL: E23, C50, C68

Introduction

Among modelling tools that are applied for economic, social and environmental policies analysis an important role is played by Computable general equilibrium (CGE) models. A broad set of investigated issues, including a comprehensive empirical basis and consistent representation of key economic processes have made this type of models an essential research tool on national and international levels.

Unlike some other economic models, both methodological assumptions, and input data set significantly determine CGE's features, as well as received results. However, while in the case of methodological assumptions a set of widely accepted assumptions can be identified, the values of exogenous parameters are usually determined separately for each country (region), considering the specific characteristics of a particular model. In most cases input dataset can be divided into two groups.

The first one includes Social accounting matrix (SAM) – an extended version of input-output (IO) table, which represents transactions which took place in the economy of a country (region) over a certain period. Values of the most CGE parameters are based on the SAM data; including the weight coefficients of production functions, output volumes, benchmark prices, tax rates, subsidies etc.

However, not all exogenous parameters can be estimated based on the SAM data of the base year. This leads to the necessity to use additional information sources, which constitute the second group. These parameters include, in particular, elasticities of substitution and transformation, which values show the percentage change in the relative amount of input goods when relative prices for these goods are changed by 1%. The economic essence of elasticities causes significant dependence of both quantitative and qualitative results on the values of these parameters (Taylor et al (2006), Dissou et al (2012), Fragiadakis et al (2012) and Koesler et al (2012)).

A frequent lack of reliable statistical data, which is particularly important for developing countries, necessitates the elasticity assessment based on expert assumptions and literature review. Although the aforementioned approach has some advantages – does not require significant resources, allows to estimate elasticities for different nesting structures and avoids Lucas critique[3] – its use in applied studies is often followed by valid criticism on empirical inconsistency, as well as geographical and temporal discrepancy.

According to the literature review, calibration of CGE models for Ukraine is usually based on the adoption of elasticities' values from external sources or expert assumptions (Pavel et al (2004), Eromenko (2010)). Thus, even in spite of all the disadvantages of econometric approach, empirical estimation of capital-labor substitution elasticities for Ukrainian economy is a crucial task, especially in the context of additional statistically justified source of data.

[3] Critical comment presented in Lucas (1976): "…given that the structure of an econometric model consists of optimal decision rules of economic agents, and that optimal decision rules vary systematically with changes in the structure of series relevant to the decision maker, it follows that any change in policy will systematically alter the structure of econometric models".

Ukrainian CGE model

Estimation of substitution elasticities in this paper is performed in the context of corresponding indicators of Ukrainian CGE model, which was developed with the emphasis on investigation of energy policy measures. Therefore, it would be beneficial to take into consideration key characteristics of the model, which can be found in Institute for economics and forecasting (2012). Key emphasis should be made on the production block structure.

In order to include substitution possibilities of different energy products a nested constant elasticity of substitution (CES) production function is used in the model. Energy products, other intermediate inputs and value added components are divided into separate groups (Image 1)

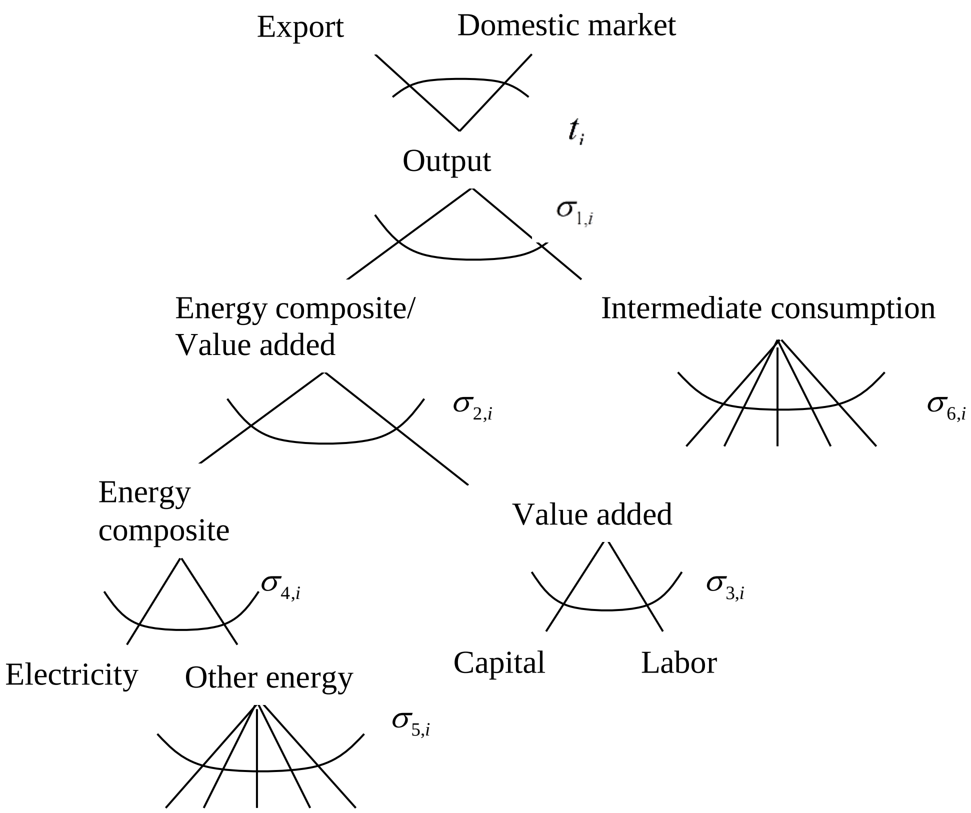

Image 1. Production block structure for Ukrainian CGE model

Note: σ – substitution elasticity, t – elasticity of transformation, i – industry index

Equilibrium is defined via system of nonlinear equations which is formed through solving the optimization problems for production functions. For example, in the process of production, enterprises have to define optimal structure of intermediate consumption. Using initial substitution/transformation elasticities and share parameters (together they define production function) a cost minimization problem for new exogenous parameters values is solved (e.g. production tax change, subsidies elimination etc.). In Ukrainian CGE model calibrated share forms of production functions are adopted. CES function for the production block can be represented in a following form

$$Y_i = \bar{Y}_i \left[\theta_{1,i} \left(\frac{IO_i}{\overline{IO}_i} \right)^{\rho_{1,i}} + (1-\theta_{1,i}) \left\{ \theta_{2,i} \left[\theta_{3,i} \left(\frac{K_i}{\bar{K}_i} \right)^{\rho_{3,i}} + (1-\theta_{3,i}) \left(\frac{L_i}{\bar{L}_i} \right)^{\rho_{3,i}} \right]^{\frac{\rho_{2,i}}{\rho_{3,i}}} + \right. \right.$$

$$\left. \left. + (1-\theta_{2,i}) \left[\theta_{4,i} \left(\frac{EL_i}{\overline{EL}_i} \right)^{\rho_{4,i}} + (1-\theta_{4,i}) \left(\frac{EN_i}{\overline{EN}_i} \right)^{\rho_{4,i}} \right]^{\frac{\rho_{2,i}}{\rho_{4,i}}} \right\}^{\frac{\rho_{1,i}}{\rho_{2,i}}} \right]^{\frac{1}{\rho_{1,i}}}, \tag{1}$$

where i – denotes industry; Y_i – output; IO_i – intermediate goods (excluding energy); K_i – capital; L_i – labor; EL_i – electricity; EN_i – energy composite (excluding electricity); $\theta_{k,i}$ – distribution parameter, which denotes the share of inputs, for example, $\theta_{4,i}$ defines the share of electricity consumption in the total energy consumption; « $\bar{}$ » symbol corresponds to the benchmark parameter values; $\rho_{k,i}$ – substitution parameter, using $\rho_{k,i}$ substitution elasticity is defined as $\sigma_{k,i} = 1/(1-\rho_{k,i})$.

As long as equation (1) does not include separate intermediate consumption and energy goods, there is no explicit representation of substitution elasticities for these products in contrast to the graphical notation (Image 1).

In the process of cost minimization, in the model a unit cost functions are calculated, they give the minimum production cost of one unit of good. After that a

Shepard lemma is applied to define optimal demand for inputs (capital, labor, electricity, etc.) per unit of output. During this process a first order conditions are derived. For value added component they can be represented in a following form:

$$\frac{\hat{L}_i}{\hat{K}_i} = \left(\frac{1-\theta_{3,i}}{\theta_{3,i}}\right)^{\frac{1}{1-\rho_{2,i}}} \left(\frac{\hat{p}_{K,i}}{\hat{p}_{L,i}}\right)^{\frac{1}{1-\rho_{2,i}}}, \qquad (2)$$

де $\hat{K}_i = \frac{K_i}{\overline{K}_i}$, $\hat{L}_i = \frac{L_i}{\overline{L}_i}$, $\hat{p}_{L,i} = \frac{p_{L,i}}{\overline{p}_{L,i}}$, $\hat{p}_{K,i} = \frac{p_{K,i}}{\overline{p}_{K,i}}$; $p_{L,i}$ – price of labor for i-th activity; $p_{K,i}$ – price of capital for i-th activity; $\overline{p}$ – benchmark year prices.

Under any production block structure, which is defined via CES function, if value added component constitute a separate nest, these first order conditions would hold. Following Image 1, Ukrainian CGE model production block has 6 substitution parameters, but due to the shortage of available data, only capital-labor substitution elasticity (σ_{KL}) will be estimated in this paper.

Approaches to substitution elasticities estimation

According to the existing literature on σ_{KL} estimation, it is hard to find even two papers with the same approximation approach. Difference between approaches may arise simultaneously on several stages, starting from the functional forms choice and underlying economic variables and ending with parameters' estimation approaches, which is particularly important in case of nonlinear functions' employment (Table 1).

In some papers σ_{KL} was estimated together with other substitution elasticities within production block. And although due to the lack of empirical data, this approach currently can not be applied for Ukraine, such papers where included into analyzed set as long as they have beneficial information about utilized data and estimation approaches.

In the context of conducted literature analysis several aspects of σ_{KL} econometric estimation can be highlighted and taken into account:

1. *Minimum size of data set.* This issue should be viewed, taking into consideration the number of estimated parameters. On the average, minimum number of observations per one unknown parameter equals 5-7. The most commonly used method of observations' number increase is regional aggregation – it is assumed that elasticity value for particular economic activity is the same for different countries/regions. Another method is evaluating a single elasticity for all sectors of the economy, a particular sector (industrial sector, services, etc.).

2. *Choice of functional forms.* Among the analyzed papers, only one estimates parameters based on the nonlinear forms, while others use linearized functions. In some cases researchers made an attempt to estimate elasticities based on nonlinear CES functions but did not receive reliable results. Most researchers (the only exception is paper Okagawa et al (2008)) utilized production functions, which include only part of the production block inputs. Usually estimated function does not include intermediate inputs or elasticities are estimated separately for different nests (Koesler et al (2012)).

Since CES production function represents weighted average of input indices (Shumska (2007)), the more input arguments it has the more flexible it is in approximation of output index. In this context it is not quite correct to separately estimate parameters of value-added function $VA = C(\alpha_{KL}K^{\rho} + (1-\alpha_{KL})L^{\rho})^{1/\rho}$, which represents one of the nests, since the whole CES function does not necessarily include this relationship. Furthermore, application of the aforementioned value-added function does not account for cost minimization assumptions, which are included into most CGE models including model for Ukraine.

3. *Technological change.* Nearly half of the reviewed papers included technological change into production functions. As far as we are concerned this step should be in line with CGE model production functions' structure.

4. *Choice of underlying data.* σ_{KL} estimates may substantially depend on the underlying time series, which correspond to the production function's variables. For example, input labor can be measured in man hours, total number of employees, full-time equivalent employees etc. Different approaches can be adopted to measure capital and labor prices. At the same time, it is almost impossible to define the best indicator to represent each of these variables. In this context it is beneficial to understand the influence of different indicators choice on the resulted econometric estimates. It is advisable to choose indicators in direct correspondence to the CGE model variables.

Table 1

Comparison of approaches to capital-labor elasticity estimation

Characteristic \ Source	Dissou et al (2012)	Fragiadakis et al (2012)	Koesler et al (2012)	Turner et al (2012)	Okagawa et al (2008)	van der Werf (2007)	Balistreri et al (2002)	Kemfert et al (1998)
Nesting structure[4]	(KL)E	KL	((KL)E)M	(KL)E	((KL)E)M	(KL)E	KL	(KL)E
Regions	Canada	3 regions[5]	33 countries[6]	Great Britain	14 countries[5]	12 countries	USA	Germany
Industries	10	6	35	27	19	7	28	7[7]
Timeframe	1962-1997	1995-2009	1995-2006	1970-2005	1995-2004	1978-1996	1947-1998	1970-1988
Number of observations[8]	36	30-225	312-396	36-972	140	84-144	52	19
Number of parameters	5	3	9	7	2	2-3	3-5	6
Methodological approach	Linearized demand functions (LDF); include technological change	LDF; include technological change and exogenous rate of growth	Value-added functions with technological change are separately considered; nonlinear estimation approach	Nonlinear approach did not lead to reliable results; LDF were used	Linearized first order conditions	LDF; include technological change	Linearized first order conditions functions	Direct CES functions estimation; a neutral technological progress is assumed
Features of empirical estimation	Seemingly unrelated regressions were used	An integration test is applied – different specification of equations	A set of optimization algorithms is used	–	Elasticities are estimated separately for each nest	Pooled regressions approach was applied	An integration test is applied – different specification of equations	–

[4] For the cases when σ_{KL} was estimated simultaneously with other elasticities, a nesting structure with K, L within one nest was represented. K denotes capital, L – labor, E – energy, M – other intermediate inputs. Brackets identify the nesting structure.
[5] USA, Canada, EU-15, China, India and Japan. It was assumed that within different regions for a specific economic activity elasticities have same values.
[6] For specific industries elasticities were assumed equal for different countries.
[7] Sector specific as well as industry-aggregate elasticity values are estimated.
[8] Denotes the length of the dataset for elasticity estimation. Interval defines minimum and maximum length of the dataset.

Characteristic \ Source	Dissou et al (2012)	Fragiadakis et al (2012)	Koesler et al (2012)	Turner et al (2012)	Okagawa et al (2008)	van der Werf (2007)	Balistreri et al (2002)	Kemfert et al (1998)
σ_{KL} **estimates**[9]	0,1549-0,4650	0,1748-4,4166	0,1973-2,72[10]	-0,13-0,79[11]	0,023-0,46	0,2246-0,6161	-0,017-0,268; -1,597-22,45	0,17-0,793
Data[12]								
K	No description in the paper, but there is link to the database[13]	CAP / P_K	Capital stock (CS)[14]	CS	No description in the paper, but there is link to the EU-KLEMS project[15]	CS	CS index	Gross stock of fixed assets
L		LAB / P_L	Number of employees	Number of employees		Total employment in men hours	Full-time equivalent employees	Number of employees
$\mathbf{P_K}$		$\frac{CAP/K\_GFCF}{CAP_{1995}/K\_GFCF_{1995}}$	–	Gross fixed capital formation price index		Nominal bond rate + depreciation – capital gains	Property type income[16]	–
$\mathbf{P_L}$		$\frac{LAB/H\_EMP}{LAB_{1995}/H\_EMP_{1995}}$	–	Compensation of employees index		Compensation of employees, per man hour	Compensation of employees[17]	–

[9] Lower and higher bounds for parameters estimates are presented. In case of paper Okagawa et al (2008) the short and long-term elasticities are shown.
[10] For PORT method estimates.
[11] Negative elasticity value indicates that the goods are complements. That is, when price of one good increases consumption volumes of the second (other) good(s) decrease.
[12] CAP - capital compensation, LAB - labor compensation, H_EMP - total hours worked per persons engaged, K_GFCF - real fixed capital stock.
[13] Productivity program database of Statistics Canada // http://www.statcan.gc.ca/start-debut-eng.html
[14] A perpetual inventory method is applied to estimate capital stock.
[15] EU KLEMS Growth and Productivity Accounts // www.euklems.net
[16] Includes corporate profits, proprietor's income, rental income, net interest, private capital consumption allowances, business transfer payments, and government consumption of fixed capital.
[17] Is defined as the sum of wages, salary, and supplements to wages and salaries.

As long as represented elasticity estimates not only utilize different underlying assumptions (functional forms, estimated approaches, etc.) and input data but also have distinct geographical, temporal and sectoral features, their direct comparison should be done very carefully. At the same time this capital-labor substitution elasticities values can be utilized in the context of the most probable set of values, which can be adopted during the sensitivity analysis phase.

Data and estimation approach

Capital-labor substitution elasticities estimation in this paper is based on the linearized form of function (2)

$$\ln\left(\frac{\hat{L}_i}{\hat{K}_i}\right)_t = a_{1,i} + b_{1,i} \ln\left(\frac{\hat{p}_{K,i}}{\hat{p}_{L,i}}\right)_t + u_{it}, \quad (3)$$

where $a_{1,i} = \frac{1}{1-\rho_{2,i}} \ln\left(\frac{1-\theta_{3,i}}{\theta_{3,i}}\right)$, $b_{1,i} = \frac{1}{1-\rho_{2,i}}$.

K_i – general indexes of fixed assets (FA)[18] dynamics, based on the data of State Statistics Service of Ukraine. Since these indicators are available only starting from 2004, benchmark year can not be earlier than 2003.

L_i – annual average full-time equivalent employees/the average number of regular employees (State Statistics Service of Ukraine). Due to the fact that before 2004, the number of regular employees included military personnel who received allowance, the number of employees for “Public Administration” (section L) in 2003 was obtained by linear extrapolation of 2004-2009 data (R^2 for the linear model equals 0,98).

Before 2009 the average number of regular employees is provided excluding employees of statistically small enterprises and individual entrepreneurs, while since 2010 the average number of regular employees is estimated for the enterprises with 10 or more employees (State Statistics Service of Ukraine (2015)). Due to the change

[18] Unlike net fixed assets growth index, which can be considered as an alternative to general index of fixed assets, the latter one accounts not only for commissioning of new and decommissioning of old FA, but for the overall FA commissioning/decommissioning.

of methodology, a direct comparison of 2010 and previous years data is incorrect (Directive on the number of employees statistics (2005)). Thus, capital-labor substitution elasticities can be estimated only for the 2003-2009 period.

$p_{L,i}$ – average monthly salary of full-time equivalent employees/ regular employees by economic activities (EA) (State Statistics Service of Ukraine (2011a)).

$p_{K,i}$ – FA price indexes. Where calculated by dividing nominal value of FA at the end of the year by the cost of FA in base year prices at the end of the corresponding year. (State Statistics Service of Ukraine (2011b)). Denominator was obtained through multiplication of the cost of FA at the end of the base year by general indexes of FA.

Elasticity estimates are conducted for two labor datasets – full-time equivalent employees and regular employees.

Given that for each industry a dataset of only 6 periods is available, to increase the size of the set per parameter, elasticities were estimated for 2-5 EA simultaneously. In other words it was assumed that for some sets of industries capital-labor substitution elasticities have the same values.

Results

Prior to elasticity estimates results analysis it would be beneficial to examine the questions of input data selection and grouping. K_i, L_i, $p_{L,i}$ and $p_{K,i}$ values were evaluated for 30 EA. Then for each EA parameters estimates were found based on equation (3) and ordinary least squares (OLS) approach, in addition, coefficients of determination (R^2) were calculated. For four out of thirty investigated industries R^2 value was below 0,3, which indicates a low consistency of constructed econometric models with empirical data. These EA included "Manufacture of coke, refined petroleum products and nuclear fuel", "Manufacture of rubber and plastic products", "Manufacture of machinery and equipment n.e.c." and "Transport, storage and communication". The remaining economic activities were grouped by industry criteria (Table 2).

Table 2

Capital-labor industry level elasticity estimates for Ukraine

Economic activities	**NACE Rev 1.1 code**	**Number of observations**[19]	**Full-time equivalent employees**			**Regular employees**		
			σ_{KL}	**s**[20]	R^2	σ_{KL}	**s**	R^2
Agriculture, hunting and forestry. Fishing.	01; 02; B	18	0,721	0,042	0,916	0,701	0,039	0,926
Mining and quarrying of energy producing materials. Mining and quarrying, except of energy producing materials.	CA; CB	12	0,443	0,090	0,657	0,454	0,097	0,633
Manufacture of textiles and textile products. Manufacture of leather and leather products.	DB; DC	12	0,482	0,070	0,756	0,579	0,070	0,826
Manufacture of wood and wood products. Manufacture of pulp, paper and paper products; publishing and printing.	DD; DE	12	0,823	0,162	0,720	0,794	0,221	0,563
Manufacture of chemicals, chemical products and man-made fibres. Manufacture of other non-metallic mineral products.	DG; DI	12	0,691	0,111	0,678	0,680	0,163	0,545
Manufacture of basic metals and fabricated metal products. Manufacture of machinery and equipment n.e.c. Manufacture of electrical and optical equipment.	DJ; DK; DL	17	0,286	0,057	0,736	0,348	0,052	0,833
Manufacturing n.e.c. Electricity, gas and water supply.	DN; E	12	0,346	0,059	0,711	0,384	0,096	0,703
Construction. Wholesale and retail trade; repair of motor vehicles, motorcycles and personal and household goods. Hotels and restaurants. Transport, storage and communication. Financial intermediation. Real estate, renting and business activities.	F-K	30	0,696	0,082	0,621	0,646	0,057	0,603
Public administration and defence; compulsory social security. Education.	L; M	12	0,138	0,029	0,691	0,134	0,029	0,686
Health and social work. Other community, social and personal service activities.	N; O	11	0,338	0,097	0,605	0,347	0,092	0,642

[19] All analyzed EA were divided into 10 groups. Thus, there are 5-6 observations per each unknown parameter, which corresponds to the minimum number of observations applied in other papers.
[20] Standard error.

According to the applied von Neumann and Durbin-Watson criterions 7 out of 10 equations had positive autocorrelation. For these cases Newey–West estimator was applied.

In general, received capital-labor elasticity estimates for Ukrainian economy are in line with estimates for other countries. All EA within national economy are characterized by relatively low capital-labor substitution possibilities: for six out of ten sectors σ_{KL} value is lower than 0,5. Furthermore, for all EA elasticity values does not exceed “1”. These results differ from some other studies presented in Table 1, for example, in paper Fragiadacis et al (2012) σ_{KL} values exceed 4,4.

Obtained in this paper elasticity estimates should be considered in the context of several issues. Firstly, since elasticities are estimated on the annual data, they correspond to the short term substitution trends, which are usually applied for dynamic CGE models. While, within static models it is assumed that equilibrium is reached within 3-5 years. Secondly, it was assumed that during analyzed time period (2003-2009) substitution elasticities were constant. Given the nature of Ukraine's economic development over the years there is a high probability that characteristics of economic processes as well as substitution elasticities values were changing. However, due to the lack of necessary statistical data, it is not possible to verify this assumption. Finally, considering the number of issues associated with the specifics of input statistical data, a relatively short period of seven years was available for the analysis, which is not sufficient to obtain reliable parameters’ estimates. In order to solve this issue this paper adopted an assumption of uniform substitution elasticities for selected economic activities, which can be considered as a justified approach in the context of this research.

Conclusions

According to the received estimates, values of Ukrainian capital-labor substitution elasticities are rather low – 0,13-0,82. Furthermore, service industries are characterized by relatively lower elasticity values, compared to the real sector of Ukrainian economy, which can be explained by the fact that services have higher intensity of labor employment.

Comparison of elasticities estimates based on different economic indicators – labor was represented via full-time equivalent employees as well as regular employees – did not show any significant changes in results. Difference between elasticity estimates was within standard errors, which can be considered as an evidence of results' robustness.

Despite the availability of relatively small amount of historical data and some methodological aspects, obtained estimates call into question the appropriateness of certain production functions utilization for modelling capital-labor substitution in Ukraine. In particular, this includes the case of Cobb-Douglas production functions that have unitary elasticity of substitution.

In general, given the characteristics of CGE modelling approach, obtained elasticity's point estimates should be used as initial values of exogenous parameters, which should be reconsidered and changed during the sensitivity analysis and verification of results reliability.

References

Balistreri, E. J. McDaniel, C. A. Wong, E. V. (2002) An estimation of U.S. industry-level capital-labor elasticities: Cobb-Douglas as reasonable starting point? Retrieved from http://econmodels.com/upload7282/5b64cdcaeeae6c312ce74e75eb19e2ed.pdf.

Directive on the number of employees statistics (2005) Approved by the State statistics service of Ukraine order of 28.09.2005 № 286. Retrieved from http://zakon.nau.ua/doc/?uid=1092.1470.3&nobreak=1 [in Ukrainian].

Dissou, Y. Karnizova, L. Sun, Q. (2012) Industry-level Econometric Estimates of Energy-capital-labour Substitution with a Nested CES Production Function. University of Ottawa, Working Paper №1214E. Retrieved from http://sciencessociales.uottawa.ca/sites/default/files/public/eco/1214e.pdf.

Eromenko, I. (2010) Accession to the WTO: Part II – Computable General Equilibrium Analysis: The Case of Ukraine. Ventus Publishing ApS. Retrieved from http://library.ku.ac.ke/wp-content/plugins/download-monitor/download.php?id=135.

Fragiadakis, A. Paroussos, L. Kouvaritakis, N. Capros, P. (2012) A Multi – Country Econometric Estimation of the Constant Elasticity of Substitution. WIOD Conference. Retrieved from http://www.wiod.org/conferences/groningen/Paper_Fragiadakis_et_al.pdf.

Kemfert, C. Welsch, H. (1998) Energy-Capital-Labor Substitution and the Economic Effects of CO_2 Abatement: Evidence for Germany. Retrieved from http://www.feem.it/userfiles/attach/Publication/NDL1998/NDL1998-076.pdf.

Koesler, S. Schymura, M. (2012) Substitution Elasticities in a CES Production Framework. An Empirical Analysis on the Basis of Non-Linear Least Squares Estimations. ZEW – Centre for European Economic Research Discussion Paper No. 12-007. Retrieved from http://papers.ssrn.com/sol3/papers.cfm?abstract_id=2014655.

Lucas, R. (1976) Econometric policy evaluation: A critique. Carnegie-Rochester Conference Series on Public Policy 1 (1). Retrieved from http://pareto.uab.es/mcreel/reading_course_2006_2007/lucas1976.pdf.

Okagawa, A. Ban, K. (2008) Estimation of substitution elasticities for CGE models. Discussion Paper 08-16. Retrieved from http://www2.econ.osaka-u.ac.jp/library/global/dp/0816.pdf.

Pavel, F. Burakovsky, I. Selitska, N. Movchan, V. (2004) Economic Impact of Ukraine's WTO Accession: First Results from a Computable General Equilibrium. Institute for Economic Research and Policy Consulting. – Working Paper No. 30. Retrieved from http://www.ier.com.ua/files/publications/WP/2004/WP_30_eng.pdf.

Shumska, S.S. (2007) Tools of the production function in the study of the Ukrainian economy. Economy and forecasting. № 4, 2007, pp. 104-123 [in Ukrainian].

SI "Institute for economics and forecasting, Ukrainian NAS" (2012) Scientific report "Implementation of energy strategic planning into the state management system of social and economic development". Kyiv, pp. 84-106 [in Ukrainian].

State Statistics Service of Ukraine (2015) Demographic and social statistics. Retrieved from http://ukrstat.gov.ua/.

State Statistics Service of Ukraine (2011a) Labor in Ukraine in 2010. Kyiv, 2011 [in Ukrainian].

State Satistics Service of Ukraine (2011b) Statistical yearbook of Ukraine 2010. Ed. O.H. Osaulenko. Kyiv, 2011 [in Ukrainian].

Taylor, L. von Arnim, R. (2006) Computable General Equilibrium Models of Trade Liberalization: The Doha Debate. Retrieved from http://62.58.77.233/sn2/training%20docs/Lecture%20Missaglia/Lecture%20Missaglia_Taylor%20CGE%20Models%20of%20Tarde%20Liberalization%20Doha%20Debate.pdf.

Turner, K. Lange, I. Lecca, P. Ha, S. J. (2012) Econometric estimation of nested production functions and testing in a computable general equilibrium analysis of economy-wide rebound effects. Stirling Economics Discussion Paper 2012-07. Retrieved from http://papers.ssrn.com/sol3/papers.cfm?abstract_id=2054122.

Werf van der, E. (2007) Production functions for climate policy modeling: an empirical analysis. Climate change modeling and policy. Retrieved from http://ageconsearch.umn.edu/bitstream/9549/1/wp070047.pdf.