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by

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ABSTRACT

This study investigates the technical efficiency of BRIC-countries (Brazil, Russia, India, China) at the disaggregated level of six economic activities using stochastic frontier approach. Technical efficiency scores and efficiency externalities effects of international trade and foreign direct investment inflows are estimated based on the panel of sixteen countries - G20 members - over the period from 1995 to 2009. The results suggest that foreign direct investment is a conduit of the positive technological spillovers in all sectors under analysis. Once controlling for the domestic level of the human capital that captures technology absorptive capacity, the positive effect of the international trade is observed in the industrial sector in general and manufacturing in particular, as well as in trade, hotels and restaurants. The positive impact of the human capital on the level of technical efficiency is significant for all sectors, except for the agriculture, and robust for two different measures of human capital.

Keywords: BRIC(S) countries, technical efficiency, stochastic frontier approach, spillover effects

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I. INTRODUCTION

The idea of considering Brazil, Russia, India and China as a consolidated group of emerging economies, as the introduction of the acronym BRIC to refer to the implied group, is attributed to Goldman Sachs' chief economist Jim O'Neill. In his endeavor to forecast the global economic trends (O'Neil, 2001) he argued that "over the next 10 years, the weight of the BRICs and especially China in world GDP will grow, raising important issues about the global economic impact of fiscal and monetary policy in the BRICs"[1]. He also concluded that dynamic growth of the BRIC-countries called for the reorganization of the multilateral policymaking forums (G7, in particular) with the view of the wider representation of the emerging economies' interests in the political, economic, and financial decision making process. The later paper from Goldman Sachs series (Wilson, D., & Purushothaman, R. 2003) reinforced the prediction of BRIC countries becoming a major power by stating that "of the current G6, only the US and Japan may be among the six largest economies in US dollar terms in 2050".

Eventually the idea of development of the unified block of emerging economies was supported by national policymakers and the first official BRIC summit took place in Yekaterinburg, Russia, on June 16, 2009. South Africa officially became part of the BRIC nations in 2010, turning BRIC into BRICS. Annual summits conducted starting 2009 provide BRICS leaders with the opportunity to showcase their determination to increase cooperation in achieving consistent economic growth and in rebalancing global governance's architecture. One of the most notable developments in this area is an agreement reached by the members in 2013 to establish the BRICS Development Bank – a sui generis alternative for the World Bank and IMF. The Bank's goals include facilitation of the common infrastructure projects' funding, as well as the creation

[1] the dynamic of the BRICS-countries' share in the world GDP are presented in Appendix A

of the reserve "safety net" intended to smooth the potential financial shocks' consequences for participating countries.

BRICS countries account for almost 30% of the world's landmass (39.7 million sq.km in 2011) and 40% of the global population (2.9 billion people in 2011) [2]. Their share in the global GDP (in PPP terms) increased dramatically from 17% in 2000 up to 27% in 2011 and it is forecasted to grow further by the IMF specialists, primarily driven by the Chinese economy. The outrunning economic growth was partially attributed to the keen interest on the part of the investors and partners in the developed countries, which manifested in the intensification of the international trade and FDI. In comparison to 2000, the share of the BRICS countries in the world total inward FDI flows has almost doubled – from 5.4% up to 10.6%, while the share in the international trade – rose from 7% to 16.2%[3].

However, it's noteworthy that outstanding growth rates projected by the BRICS' adepts and observed during the first decade of 2000's have been influenced significantly by the world financial crisis of 2008[4]. Among some of the collateral damages of the economic conjuncture one might list the consequent outflow of the FDI from the emerging markets, partially driven by the U.S. Federal Reserve's decision to reduce its bond-buying program, intended for the stimulation of the domestic economy.

In addition the recent political crisis in Ukraine and the Crimea's annexation has put Russia under the serious risk of the further economic and financial sanctions from the developed countries, which will play a crucial role in the determination of the future trends in the

[2] Source: BRICS. Join Statistical Publication 2013
[3] Time series on BRICS shares in global trade, FDI and GDP are presented in Appendix A
[4] For the comprehensive discussion of the "great deceleration" phenomena one can see the Economist, Jul 27, 2013

international trade and FDI flows. From the author's point of view, recently observed turbulence in the economic and political sphere of the BRICS countries in the framework of increasing globalization underscores the importance of the analysis of the country-level productivity determinants, including both domestic and cross-border factors, which are key for the for understanding of the nature and the perspectives of the economic growth.

Taking into consideration the crucial role of the BRICS countries for the global development platform, surprisingly few researchers are focusing explicitly on the analysis of the productivity patterns underlying the economic growth of these countries. This study investigates the technical efficiency of the four BRIC countries (Brazil, Russia, India, China) during the period from 1995 to 2009, as well as the role of the international trade and FDI-inflows as a conduit of positive technological spillovers using stochastic frontier approach. The analysis is based on the methodology, proposed Battese and Coelli (1995), which allows for explicit modeling of the country-specific inefficiency function, and is conducted at the disaggregated level of six economic activities. The data on twelve of the G20 countries (Australia, Canada, France, Germany, Indonesia, Italy, Japan, Korea, Mexico, Turkey, United Kingdom, and United States of America) are pooled in the analysis as the reference group for the emerging economies. The choice of the sample and model specification are discussed in details in Chapter 2 of the Master's Thesis.

This study is intended to contribute to the stream of the research, dedicated to analysis of the nature of the emerging markets' economic growth and its perspectives by providing a new empirical evidence on the time patterns of the BRICS countries technical efficiency at the disaggregated level of six economic activities, measured using the stochastic frontier approach in comparison with these of the developed G20 countries. Moreover, the research is aiming to provide estimates of the spillover effects of the international trade and FDI – acknowledged conduits of the technological diffusion – on the domestic technical efficiency. The results of the research may then be applied for the analysis of the common characteristics of the technical efficiency of the countries of interest, as well as serving for the justification of the importance of the international spillover effect for the further development of the emerging markets.

The results suggest that foreign direct investment is a conduit of the positive technological spillovers in all sectors under analysis. The higher levels of the international trade are associated with the lower technical efficiency in agriculture, construction and transport. Once controlling for the domestic level of the human capital that captures technology absorptive capacity, the positive effect of the international trade is observed in the industrial sector in general and manufacturing in particular, as well as in trade, hotels and restaurants. The positive impact of the human capital on the level of technical efficiency is significant for all sectors, except for the agriculture, and robust for two different measures of human capital.

The master's thesis is organized as follows. Chapter 1 provides a literature review on the evolution of the theoretical approaches to the measurement of the country-level productivity, as well as on the previous empirical findings of interest. Chapter 2 presents detailed methodology and model specification, as well as describes the data set construction process. Chapter 3 outlines the findings of the undertaken research. Chapter 4 discusses potential limitations of the results and offers directions for the further related research.

II. LITERATURE REVIEW

As the empirical research designed to answer the master's thesis' research questions is building upon a wide base of previous theoretical and empirical work in the area of productivity growth and its comparability, the literature review is organized as follows. First, the evolution of the scientific approach to the productivity measurement is summarized, then the review of the literature on the stochastic frontier approach is provided. The literature review is completed with the outline of the related previous empirical research of the country-level technological efficiency analysis and those of the BRICS countries' productivity patterns in particular.

Productivity Measurement

The start of the active debate of the contribution of the different inputs to the economic growth is attributed to the classical Solow paper (1957), which introduced the way of segregating the fractions of the overall economic growth rate, achieved due to the increase in productivity, capital accumulation, population growth, and technological change. Since the article was published, numerous more sophisticated models were offered; but it is still crucial for understanding the basic concepts of the growth, the role of the productivity in it, and it can serve as a starting point for developing more complex models, which would consider wider range of the growth factors. Barro (1999) reconsiders the concept of the Solow residual with regard to spillover effects, increasing returns, taxes, and multiple types of factor inputs. He argues that it can also be interpreted as the measure of the endogenous technological progress.

His work is in line with the overall developments in the endogenous growth theory that outlined the crucial role of the technological progress, both domestic and through positive international spillover effects, as well as of the accumulation of the human capital in boosting economic growth (Romer (1990), Aghion and Howitt (1992)). Thus, in the modern globalized world the positive technological shock in one country can have observable positive impact on the other country's efficiency by the means of the technological diffusion achieved through interaction on product or capital markets.

The significant stream of the empirical research on the comparative productivities in OECD countries is attributed among others to Bernard and Jones (1996), Carree et al. (2000), Miller and Upadhyay (2002). The R&D spillover effects in particular were studied by Coe and Helpman (1995) and Coe et al (1997).

Although the seminal work by Solow set the way of thinking about technological change and efficiency for many years ahead, an implicit assumption that is made by this approach is quite limiting. All countries are thought to operate completely efficiently, or in other words, to be at their specific production frontier. While in some cases it could be relatively reasonable simplification for the set of highly developed countries, the stochastic frontier framework provides more robust results for the analysis of the BRICS countries' efficiency and their "catching-up" with more developed countries.

Stochastic frontier approach

The canonical stochastic frontier technique, introduced independently by Aigner et al. (1977) and Meeusen et al. (1977), initially was developed in the framework of the multiple firms operating in some production sector or industry. The main idea of the method is the decomposition of the error term in the production frontier model into two independently distributed structural parts:

$$Y_i = f(X_i, \beta) + v_i + u_i \qquad (1)$$

where Y_i is the firm i's output, $f(X_i, \beta)$ is the production frontier, X_i is the vector of inputs used and β is a vector of technology parameters to be estimated, error term v_i is independently and identically distributed as N $(0, \sigma^2)$ and represents stochastic factor, while non-positive disturbance term u_i captures firm-specific inefficiency level, as the difference between the observed output to the maximum feasible one. Thus, such modeling allows for distinguishing between firm's specific "technical and economic inefficiency" and "other sources of disturbance that are beyond the firm's control"[5].

In the latter empirical literature, extrapolating the stochastic frontier approach to the macro-level of the cross-country comparison these two terms are regarded as the county-specific inefficiency (which can be minimized over time through "catching-up" effects) and the frontier-shifting technological changes, generated by innovation process in one of the countries in the set. In other words, the productivity growth in this framework is seen as interplay between technological change (shift in the common production frontier, or potential output) and efficiency change (country's movement relative to the common production frontier, or differences in gap between potential and observed output).

The baseline stochastic frontier model has generated wide literature both on estimation methodology of stochastic production and cost frontier models and its empirical implications for the data analysis. The detailed broad study of the field can be found at Kumbhakar and Lovell (2000), Fried et al (2008) and Greene (2012). The rest of this section focuses specifically on the stream of the models that are relevant to the master's thesis' research question – that is panel-data.

[5] See Aigner et al., 1977, p. 25.

Table 1. Summary of the main model specifications of the time-varying efficiency for the panel data

Name	Author	Method of estimation	Distributional assumptions	Advantage
Inefficiency effects model	Battese and Coelli (1995)	Maximum likelihood	Truncated normal	Allows to explicitly model the impact on the exogenous factors on the inefficiency function
True-fixed effects model	Greene (2005)	Maximum-likelihood dummy variable	Estimation procedure allows for the following distributions: • Exponential • Half-normal • Truncated normal	Allows to distinguish between time-varying inefficiency and constant observation-specific heterogeneity
True-random effects model	Greene (2005)	Simulated maximum likelihood		

Green (2005) developed an extension to baseline model (1) by allowing the intercept to differ among the observations, providing the framework for the analysis of the heterogeneous data. It is noteworthy, however, that this specification presents one of the extremes in the “heterogeneity-inefficiency” argument, as all the time-invariant observation-specific unobserved effects are completely ruled out from the inefficiency estimates. Opposite disputing party is presented by Schmidt and Sickles (1984), Pitt and Lee (1981), and Battesse and Coelli (1988), who argue that all the unobserved heterogeneity is in fact the integral part of the inefficiency and should not be disentangled over the course of the analysis. Green (2004) has applied his “true” random and fixed effects approach to the estimation of the World Health Organization’s panel on the health care delivery systems’ quality of 191 countries. He found the evidence of the significant heterogeneity among countries that has been attributed by previous research to the differences in the inefficiency.

Initially the two-stage approach has been used for the purposes of the introduction of the exogenous inefficiency determinants into the general stochastic frontier model in the empiric literature. At the first stage, the inefficiency estimates were obtained without controlling for the exogenous factors, while at the second stage those estimates were regressed on the variables of the interest. However, this approach produces significantly biased estimates[6] due to the fact, that different assumptions on the inefficiency term’s distribution are required at different stages: the inefficiency scores are assumed to be normally identically distributed, while at the second – not identically distributed and truncated at zero.

The solution of this problem for the panel data analysis was proposed by Battesse and Coeli (1995) who developed a single-stage maximum likelihood technique, allowing for simultaneous estimation of the production and inefficiency functions. The likelihood ratio statistic is available to test whether the overall effect of the exogenous determinants (vector Z) on the efficiency is significant. When the hypothesis of the insignificance of the coefficients of Z-variables is rejected, Battesse and Coeli’s (1995) model is preferable for the purposes of the analysis. As this is the case for the current research, the detailed model specification and necessary assumptions of the method are further discussed in chapter III.

[6] see Wang and Schmidt (2002)

One of the most prominent applications of the baseline model is associated with the introduction of the openness measures, that could potentially determine the country's ability to adopt and effectively implement new technologies, and as the consequence - its ability to catch-up with the leaders. While some authors as Kneller & Stevens (2006), Mastromarco (2008) focused primarily on the direct impact of the openness factors on the productivity, others, such as Henry et al (2009), Mastromarco and Ghosh (2009), Wang et al (2012) considered imports and FDI as the channel for the positive R&D transfer.

More detailed overview of the empirical research conducted in the area of the international comparison of the productivity is presented in the following section.

Previous empirical findings

A series of recent empirical research focused on the role of international spillovers in the framework of the stochastic frontier models. Although model specifications and subsets of countries under analysis vary among the papers, the general conclusion, shared by the majority of them is that foreign direct investments, as well we international trade, have a significant positive effect on the domestic productivity[7], conditioned, however, on the country-specific absorptive capacity.

The research by Iyer et al (2008) and Wijeweera et al (2010) studied the direct impact of the FDI and trade on the technical efficiency, as opposed to the literature, which views them as channels of the international R&D transfer. Using 20 OECD countries' panel from 1982 to 2000, Iyer

[7] Although significant evidence in favor of positive openness effect is presented below, the literature on that topic is somewhat ambiguous. Some authors argue that FDI and trade can sometimes have negative impact through deteriorating the balance of payment or reducing domestic competition. (Loungani and Razin (2001), Alfaro (2003))

found that the effect of FDI inflows is only significant when conditioned on the country's relative level of R&D, which captures the technological gap between the country and the rest of the world. The results are replicated by Wijeweera for the wider set of 45 countries and when employing education as an absorptive capacity measure.

Wang and Wong (2012) adopted stochastic frontier approach to study the impact of the transfers of the foreign research and development on the domestic efficiency through two particular channels: imports and foreign direct investment. Following Coe and Helpman (1995) and Coe et al. (1997) 20 developed OECD countries are considered as a source of the international R&D for the rest of the set, as it's argued that these countries account for the significant share of the global R&D expenditure and are the world's leaders in knowledge generation and technological innovation. They find the evidence of the positive effect of both channels in their panel of 77 countries over the period 1986-2007 (almost 10% of the world technical efficiency is achieved due to the international R&D spillovers). In addition, they conclude that the certain "threshold" level of domestic human capital is necessary for the successful application of the transferred technology in the domestic production, as they observe the positive complementarity between R&D inflows transferred through FDI and the domestic human capital. The human capital is measured as average years of secondary schooling, as proposed by Barro and Lee (2000).

The study by Wang and Wong reinforced previous findings by Henry at al (2009) and Mastromarco and Ghosh (2009) that focused on the spillover analysis for the subset of the developing countries. The former employed Sachs-Warner openness index and machinery imports to capture the effect of international externalities, while the latter studied FDI, imports of machinery and equipment, and imports of R&D expenditures, as well as their complementarity effects with respect to the domestic level of education.

Finally, Ghosh and Mastromarco (2013) investigate the effect of three cross-border activities in the analogous set up for 24 OECD countries: international trade, foreign direct investment and migration. They conclude that all three increase the domestic efficiency; however the positive impact of migration is only observed in countries with higher levels of human capital.

Despite the observed variety of the methodological approaches to the estimation of the impact of the outward-oriented factors on the domestic productivity, to the author's knowledge there are no many studies, building on the stochastic frontier approach that would explicitly focus on the productivity analysis at the disaggregated sectoral level. One of the exceptions is the paper by Kneller and Stevens (2006) that investigates whether differences in human capital and stock of R&D – two measures that capture level of country's ability or willingness to absorb new technology - can explain the differences in technical efficiencies among 12 OECD countries at the disaggregated level of nine industries. They found the effect of the former is much more significant than the later in all of the three model specifications (assuming different levels of particular country's access to the stock of the frontier knowledge).

Among the researchers that address the topics of development, growth and productivity patterns of the BRICS countries are de Vries et al. (2012), Chansomphou et al. (2013), Goel et al. (2012), Leitao et al. (2010) and Chen (2010), however they follow a different methodological approach. These authors use labor productivity as the measure of efficiency and focus on the decomposition of the productivity growth, achieved due to within shift, static shift and dynamic shift effects.

De Vries' paper estimates the role of the structural transformation (reallocation of the labor between industries with time) on the labor productivity growth in BRIC countries for the period of 1980-2008. The authors have constructed a new database that provides times series of value added and employment at the level of 35-sector. According to the results of the structural decomposition analysis, the labor reallocation was efficient in providing aggregate productivity growth in China, India, and Russia, whereas it wasn't in Brazil.

Chansomphou's study is partially building on the work of de Vries, as the former employs the dataset, constructed in the latter. The authors estimate the contribution of within shift, static shift and dynamic shift effects on growth of labor productivity, as well as they test for the cross-country convergence at the level of in each economic sector.

Their estimation results imply that the main contributor to the aggregate growth at the industry level is the labor productivity itself, while the shift effect (labor movement) is less substantial. The convergence test show that service sectors in BRICs are catching-up at higher rates than industrial sectors, and there is no evidence found of convergence in agriculture. In general, the main conclusion of the paper is that service sectors are the main driving force of economic growth and economic convergence in BRICs countries.

Thus current research contributes to the literature by providing new sector-level estimates of the BRIC-countries' efficiency, measured as a country's "distance" to the production frontier in a given sector in comparison with subset of G20 countries, as well as investigates sector-specific international externalities' effects. The detailed model specification and dataset construction process are described in the following chapter.

III. DATA AND METHODOLOGY

Methodology

At the first stage of the analysis the production function and inefficiency effects on the mean technical inefficiency are simultaneously estimated using one-step maximum likelihood procedure[8]. The separate estimations are conducted at the level of six economic activities, defined according to the International Standard Industrial Classification of All Economic Activities (ISIC), Revision 3.1[9] (namely, Agriculture, hunting and forestry, and Fishing (A-B), Mining and quarrying, Manufacturing, and Electricity, gas and water supply (C-E), including Manufacturing (D), Construction (F), Wholesale and retail trade; repair of motor vehicles, motorcycles and personal and household goods, and Hotels and restaurants (G-H), and Transport, storage and communication (I)).

The production function at the stochastic frontier framework is specified as follows:

$$\ln Y_{it} = \ln X_{it} * \beta + (v_{it} - u_{it}) \qquad (2)$$

where Y_{it} is the observed output of country i's particular economic activity in the period t, X_{it} – is the corresponding vector of productive inputs in the period t, v_{it} – is the random noise (assumed to be iid distributed with the mean 0 and variance σ^2), u_{it} – is the country i's specific technical inefficiency in the economic activity under analysis in the period t (assumed to be normally distributed, truncated at zero, with the mean μ_{it} and the variance σ^2_u). Moreover, the inefficiency terms are assumed to be independently distributed among different time periods and countries.

[8] The estimations are obtained using *sfpanel* package in Stata

[9] The latest 4th revision of the ISIC classification has been released in 2008. The 3d revision is used for the purposes of this research due to the availability of the data on technological inputs

The mean of the technical inefficiency is modeled as a linear function of the country specific determinant factors, captured by vector Z_{it}.

$$\mu_{it} = Z_{it} * \delta \quad (3)$$

In this framework the technical inefficiency TE can be estimated as follows.

$$TE = E[\exp(-u_{it})|\varepsilon_{it}]$$

Kumbhakar, Glosh, and McGuckin (1991) developed a single-stage ML estimation procedure to estimate (2) and (3), which was later adopted for the panel data by Battese and Coelli (1995). The latter technic is employed in the current analysis.

Following the previous literature[10] on stochastic frontier analysis the translog form of the production function is used for the modeling specification. This form provides more flexibility as it doesn't imply constant elasticity of substitution of the production factors across countries. Giving that the traditional Cobb-Douglas specification is embedded in the translog form, we can test the hypothesis that the former is appropriate for the modeling purposes using the likelihood ratio test (the null hypothesis of the production process following the Cobb-Douglas specification can be tested as H_0: $\beta_3 = \beta_4 = \beta_5 = 0$, where β's are the coefficients from equation (4) below).

In the log-linear form the production function, used in this model specification, takes the following form:

$$\ln Y_{it} = \beta_0 + \beta_1 * \ln K_{it} + \beta_2 * \ln L_{it} + ½ \beta_3 * (\ln K_{it})^{2} + ½ \beta_4 * (\ln L_{it})^2 + \beta_5 * (K_{it} * L_{it}) +$$
$$+ \beta_6 * BRIC + \beta_7 * t + ½ \beta_8 * t^2 + \beta_9 * (\ln K_{it} * t) + \beta_{10} * (\ln L_{it} * t) + vit – uit \quad (4)$$

where K_{it} and L_{it} are corresponding to the country i's particular economic activity's capital stock and labor, t captures time trend, which is introduced in the model to control for non-country

[10] Wang & Wong (2012), Mastromarco & Ghosh (2009), among others

specific common shocks to the technological process or Hicks-neutral technical change, while the interaction terms of time trend with the production inputs represent the potential non-neutral technical change. The dummy variable BRICS is introduced to capture potential productivity effects, common for the countries of interest.

For the purposes of the current research country-specific vector of factors, influencing average technical inefficiency, includes outward-orientation measures and is specified as follows.

$$\mu_{it} = Z_{it} * \delta =$$

$$= \delta_0 + \delta_1 * FDI_{it} + \delta_2 *OPEN_{it} + \delta_3*HC_{it} + \delta_4 *(HC_{it}*FDI_{it}) + \delta_5 * (HC_{it}*OPEN_{it}) + \omega it$$

where FDI stands for inflow foreign direct investment in country i in period t, OPEN – for the trade openness parameter and HC – for the human capital measure. The intersection terms are included in the specification as it is often argued in the literature that the particular threshold level of domestic human capital is necessary for successful and efficient technological diffusion. The list of control variables are presented in more details in the following section.

While international trade and FDI are expected to be significant conduits of the efficiency externalities, it is possible to test whether the inefficiency effects are in fact observed in the data. At the second stage of the analysis the country-specific annual technical efficiency estimates are constructed separately at the level of 6 economic activities.

Construction of the dataset

The panel data is constructed for the set of 16 countries - G20 members (Australia, Brazil, Canada, China, France, Germany, India, Indonesia, Italy, Japan, Republic of Korea, Mexico, Russia, Turkey, United Kingdom and United States). The European Union, which enters the G20 membership list as one entity is excluded from the analysis for the purposes of keeping country level of aggregation consistent for all observations. Currently EU comprises 28 members states, including economies with quite diverse structural composition and growth paths (e.g. Greece and Germany), which implies that the aggregation of their performance measures provides no insight on the inefficiency factors, nor spillover effects. At the same time four of the EU countries directly enter the list of G20 members. During the period under analysis those countries together (France, Germany, Italy and United Kingdom) represented on average 53% of total EU population and 66% of total GDP[11]. Unfortunately, the three more G20 countries had to be dropped out from the analysis due to the absence of the reliable data on the main production inputs at the disaggregated level of economic activities. Those countries are Argentina, Saudi Arabia, and South Africa. Although the latter is a member of the current BRICS, it didn't enter the organization until 2009 – the last year in our panel. The coverage of the countries, as well as their membership in the major multilateral organizations is summed up in the Appendix B.

Due to the data availability and comparability issues, the time period under analysis is restricted to 15 years starting from 1995 to 2009. One of the main limiting factors is the availability of the national Socio Economic Accounts, provided by the World Input-Output Database[12] – the source of the methodologically consistent data on capital and labor inputs at the disaggregated level.

[11] average of the annual share during the period of 1990-2011 based on official population and GDP data provided by the World Bank

[12] http://www.wiod.org/new_site/home.htm

The overview of the variables used in the analysis is provided in the continuation of the current section. The complete list of definitions and sources of data on variables used in various model specifications can be found in the Appendix C.

Production function

Output. Annual data on value added by economic activity (at constant 2005 prices – millions US Dollars) for 1995-2009 period is obtained from The National Accounts Main Aggregates Database[13], which is the product of cooperation between the Economic Statistics Branch of the United Nations Statistics Division, several international statistical agencies and national statistical services. The comprehensive and comparable time series are constructed using National Accounts data and are uniform in the methodology.

Labor. The sector-level employment data from Socio Economic Accounts is used as a measure of the labor input in the production function at the disaggregated level. The employment is measured in thousands of persons engaged, which includes both employees and the self-employed people, who are engaged in productive activities in specific economic activity.

Capital. The sector-specific times series of real fixed capital stock in national constant prices are retrieved from the Socio Economic Accounts. The obtained structural composition of the capital stock is then applied to the PWT country-level data in order to insure comparability of the estimations.

The Penn World Tables' Version 8.0 estimation of the capital stock (at constant 2005 prices - millions US dollars) are obtained based on more sophisticated methodology, then this applied in the previous editions: authors implemented data on investment structure with respect to different

[13] http://unstats.un.org/unsd/snaama/introduction.asp

type of assets (structures, transport equipment, computers, etc), as well as estimated initial capital stock based on initial capital/output ratio, instead of the traditional steady state assumption (when latest available data on investment is used to compute initial capital stock). For more detailed methodology review one can see official documentation, provided on the dataset website.[14]

Inefficiency function

Human capital measures:

Education expenditure, as a share of GNI (HC-1) is estimated by the World Bank staff using data from the United Nations Statistics Division's Statistical Yearbook, and the UNESCO Institute for Statistics online database.

Index of human capital per person (HC-2) is retrieved from the Penn World Tables' Version 8.0 estimation based on years of schooling (Barro, R. J., & Lee, J. W, 2012) and returns to education (Psacharopoulos, 1994).

Channels of the international spillover effects:

Openness (OPEN) is measured as the share of the sum of exports and imports of goods and services in the national GDP.

Foreign direct investment (FDI) represents the stock of the annual inward foreign direct investment in the country, measured as a share of the country's GDP.

Time-series on both channels of the international spillover effects are obtained from the online World Bank Database[15].

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[14] http://www.rug.nl/research/ggdc/data/penn-world-table
[15] http://data.worldbank.org/

Table 2. Main descriptive statistics

Variable	Obs	Mean	Std. Dev.	Min	Max
Total Economy					
HC-1	240	4.0	1.1	0.6	6.9
HC-2	240	2.7	0.5	1.7	3.6
FDI	240	2.1	1.9	0.0	11.1
OPEN	240	49.2	18.0	14.9	107.2
Agriculture, hunting and forestry, and Fishing (A-B)					
y	240	56115.9	61196.8	11460.7	327209.7
l	240	43628.7	98234.4	349.1	368700.0
k	240	300315.3	365091.5	28495.7	2026480.0
Mining and quarrying, Manufacturing, and Electricity, gas and water supply (C-E)					
y	240	425915.1	496635.4	64569.1	2370749.0
l	240	18300.9	31743.5	1224.6	162926.3
k	240	1605309.0	1873430.0	234325.3	12300000.0
Manufacturing (D)					
y	240	334918.5	401043.6	53644.9	1924344.0
l	240	16721.5	28630.7	1044.7	148775.0
k	240	1017193.0	1253314.0	118362.7	8622459.0
Construction (F)					
y	240	113599.8	144626.1	13939.5	682687.2
l	240	7122.1	11304.3	585.7	53913.7
k	240	127353.6	121253.1	15240.1	664968.1
Wholesale and retail trade; repair of motor vehicles, motorcycles and personal and household goods, and Hotels and restaurants (G-H)					
y	240	291257.4	419939.9	32171.9	2115809.0
l	240	15556.3	16744.3	2106.5	75480.8
k	240	416732.0	523632.8	43081.2	2457124.0
Transport, storage and communications (I)					
y	240	145474.3	170276.0	10196.0	856225.3
l	240	5086.0	6771.4	543.5	31655.4
k	240	611241.9	688207.0	51628.9	3786517.0

IV. RESULTS

Before the main results of the empirical analysis are presented and discussed below, the present chapter opens with the overview of the likelihood-ratio tests, which validate essential model specification choices.

All tests are building on the comparison of the log-likelihoods of the basic model and several nested ones. The likelihood ratio statistics follows the mixed chi–squared distribution. The critical values are retrieved from Kodde and Palm (1986) for the degrees of freedom corresponding to the number of variables in which nested model differs from the basic one.

Table 3. Generalized log-likelihood tests

	Likelihood-ratio test statistic	Critical value	Decision
H_0: No technical inefficiency effect ($\delta_0 = \delta_1 = \delta_2 = \delta_3 = \delta_4 = \delta_5 = 0$)			
A-B	44.36	16.074	H_0 rejected
C-E	125.88		H_0 rejected
D	80.53		H_0 rejected
F	137.79		H_0 rejected
G-H	42.04		H_0 rejected
I	128.97		H_0 rejected
H_0: Cobb-Douglas specification ($\beta_3 = \beta_4 = \beta_5 = 0$)			
A-B	24.13	10.501	H_0 rejected
C-E	58.21		H_0 rejected
D	96.50		H_0 rejected
F	160.90		H_0 rejected
G-H	-13.11		H_0 accepted
I	107.53		H_0 rejected
H_0: Neutral technological change ($\beta_9 = \beta_{10} = 0$)			
A-B	22.13	8.273	H_0 rejected
C-E	46.58		H_0 rejected
D	63.83		H_0 rejected
F	39.61		H_0 rejected
G-H	-9.71		H_0 accepted
I	50.69		H_0 rejected

Note: critical values are at the 1% significance level and are retrieved from Kodde and Palm (1986) for the relevant number of degrees of freedom (six, three and two, respectively)

The first panel of the table above presents the results of the most crucial, from the present research' point of view, test: whether the inefficiency results are observed in the data at all. The null hypothesis of the inefficiency effects all being equal to zero is strongly rejected at the 1% level of significance. Thus, the Battese and Coelli (1995) model specification with explicit introduction of the international spillovers' effects on technical inefficiency is preferred to the other time-varying inefficiency specifications.

The flexible translog production function form allows for testing whether the nested Cobb-Douglas production function specification is acceptable, as well as whether the Hicks neutral technical change is observed in the data. In the first case the null hypothesis is that the coefficients on the production inputs' interaction term are simultaneously equal to zero, in the second – that the coefficients on the cross-products of time trend and production inputs are. The hypotheses of constant substitution elasticities and Hicks neutral technical progress are both rejected at the 1% level of significance for all sectors, except for the trade, accommodation and food service activities (G-H).

The table 4 below summarizes the estimates for the translog stochastic frontier production function for the six economic activities under the analysis. Although the estimates of the production frontier itself does not constitute the main topic of the research, they can provide additional background information, as well as serve as the comparison points with the existing benchmark in the literature. As the coefficients of the production inputs in the translog specification cannot be interpreted directly, the initial time series were mean differenced pre-estimation to obtain input elasticities coefficients at the sample mean.

Table 4. Estimates for the stochastic frontier production function

	A-B	C-E	D	F	G-H	I
k	.4142***	.4863***	.4456***	.08385***	.9379***	.7524***
	(.0084)	(.0727)	(0869)	(.01785)	(.0462)	(.0080)
l	.2846***	.5636***	.7585***	1.0467***	.0040	.1201***
	(.0032)	(.0710)	(.0874)	(.0118)	(.0522)	(.0061)
k^2	.0296	-1.016***	-1.010***	-.5537***	-	-.0614
	(.0437)	(.2787)	(.2849)	(.0534)		(.3821)
l^2	-.0150	-1.244***	-2.0794***	-1.4056***	-	-1.5319***
	(.0170)	(.1625)	(.2218)	(.0180)		(.2114)
t	-.0033***	.0099	.0117*	-.0033**	.0011	-.0128***
	(.0011)	(.0068))	(.0067)	(.0014)	(.0104)	(.0012)
t^2	.0009***	-.0020**	-.0021***	.0001	-.0006	.0021***
	(.0001)	(.0008)	(.0008)	(.0002)	(.0012)	(.0002)
l*k	-.0061	1.3176***	1.8359***	1.1713***	-	.4507
	(.0221)	(.1959)	(.2339)	(.0208)		(.2776)
l*t	-.0084***	-.0474***	-.0629***	-.0139***	-	.0124***
	(.0003)	(.0067)	(.0080)	(.0010)		(.0032)
k*t	.0234***	.0503***	.0493***	-.0033	-	-.0205***
	(.0006)	(.0080)	(.0089)	(.0021)		(.0063)
BRIC	-.3539***	-.5831***	-.6258***	-.8956***	-.1546***	-.3588***
	(.0056)	(.0256)	(.0243)	(.0043)	(.0373)	(.0549)
constant	.2479***	.4431***	.4242***	.5504***	.365***	.4383***
	(.0020)	(.0378)	(.0332)	(.0032)	(.0715)	(.0024)
log likelihood	211.897	222.857	219.101	204.042	115.049	188.165

Note: standard errors listed in parenthesis. For the trade, accommodation and food service activities (G-H) interaction terms are not included in the specification based on the LR test, discussed above
* - significance at 10% level
** - significance at 5% level
*** - significance at 1% level

The majority of the estimated coefficients of the production inputs is statistically significant at the conventional level (44 out of 55) and has the anticipated signs.

Estimated elasticities of output with respect to the capital and labor in the overall industrial sector (C-E), and manufacturing (D) in particular are consistent with the previous literature: at the sample mean the capital elasticity is 0.49 and 0.45, while the labor elasticity is 0.56 and 0.76, respectively.

Kneller and Stevens (2006), for example, found that depending on particular industrial sector those elasticities vary from 0.29 to 0.47 for physical capital and from 0.66 to 0.85 for the labor.

The construction (F) appears to be the most labor-sensitive sector among those under analysis, while the labor elasticity in agriculture (A-B) and transport (I) doesn’t exceed this of the capital and is not significant in trade, hotels and restaurants (G-H).

The coefficient on the BRIC-dummy is negative and highly significant for all sectors under analysis, implying that the technological frontier is shifted upwards by more developed G20 countries.

Finally, the estimates of the international externalities’ and human capital’s impact on the domestic inefficiency are presented below. Although the inefficiency factors vary across economic activities, there are several general observations that can be highlighted based on the estimation results.

The human capital has significant positive effect on the technical efficiency in all sectors, except for the agriculture (A-B), where it is not significantly different from zero.

Thus, the empirical evidence supports the endogenous growth theory, which underscores the importance of the human capital in securing a consistent economic growth. The second measure of the human capital (index of the human capital per person) provides the elasticity estimates much higher in magnitude than the first one does (education expenditure as a share of GNI).

The higher openness of the economy is associated with the lower levels of the domestic technical efficiency in agriculture (A-B), construction (F) and transport (I). The results for the other sectors are ambiguous and sensible to the model specification.

Table 5. Estimates of the inefficiency factors

	A-B		C-E		D	
	I	II	I	II	I	II
OPEN	.0086*** (.0019)	.0075*** (.0007)	-.0004 (.0005)	.0055*** (.0010)	-.0010* (.0005)	.0070*** (.0011)
FDI	-.0284** (.01279)	-.0016 (.0057)	-.0208*** (.0046)	-.0445*** (.0075)	-.0234*** (.0052)	-.0344*** (.0082)
HC	-.0404 (.0263)	-.0836 (.2582)	-.0879*** (.0096)	-2.6023*** (.3464)	-.1029*** (.0104)	-3.0923*** (.3368)
OPEN*HC	.0001 (.0013)	-.0367*** (.0078)	-.0009** (.0005)	-.0241*** (.0070)	-.0012** (.0005)	-.0165** (.0075)
FDI* HC	.0323*** (.0109)	-.0160 (.0740)	.0058 (.0044)	-.2345** (.0933)	.0063 (.0050)	-.3224*** (.1052)
constant	-.0670 (.0802)	.2196*** (.0224)	.2680*** (.0322)	.2128*** (.0187)	.2424*** (.0250)	.1651*** (.0241)
log likeli-hood	211.897	207.566	222.857	229.514	219.101	237.464
σ^2_u	.2200*** (.0278)	.1269*** (.0089)	.0877*** (.0108)	.1302*** (.0090)	.0982*** (.0082)	.1412*** (.0096)

	F		G-H		I	
	I	II	I	II	I	II
OPEN	.0366** (.0162)	.0251*** (.0045)	-.0013* (.0008)	.0060 (.0051)	.0164*** (.0038)	.0324*** (.0050)
FDI	-.0903 (.0593)	-.0828*** (.0307))	-.0084 (.0057)	-.0632* (.0369)	-.0791** (.0311)	-.0703** (.0311)
HC	-.8487** (.3381)	-5.1640*** (.9991)	-.1160*** (.0122)	-3.334*** (1.040)	-.3220*** (.0736)	-8.6906*** (1.2422)
OPEN*HC	.0163* (.0084)	-.1146*** (.0264)	-.0026*** (.0007)	-.0872** (.0377)	-.0005 (.0025)	.0105 (.0249)
FDI* HC	.0855** (.0415)	-1.045*** (.3565)	.0058 (.0056)	-.5566* (.3108)	.0598*** (.0232)	-.2238 (.3258)
constant	-1.5390 (.9396)	-.3786** (.1744)	.3010*** (.0669)	-.1313 (.1540)	-.4218** (.1972)	-.5291** (.1792)
log likeli-hood	204.042	201.340	115.049	104.773	188.165	187.326
σ^2_u	.5011*** (.1295)	.3271*** (.0406)	.0486* (.0291)	.1607*** (.0450)	.3384*** (.0458)	.3570*** (.0361)

Note: negative sign is observed when particular factor contributes to *reduction* in inefficiency. Standard errors listed in parenthesis. (I) represents model specification which uses education expenditure (% of GNI), as a measure of human capital (II) – index of human capital per person, based on years of schooling and returns to education.
* - significance at 10% level; ** - significance at 5% level; *** - significance at 1% level

After controlling for the domestic level of the human capital, the effect of the international trade becomes positive for the technical efficiency in industrial sector in general (C-E) and manufacturing in particular (D), as well as in trade, hotels and restaurants (G-H).

Even after controlling for the level of domestic human capital the openness' effect is not significant in transportation (I), and is somewhat ambiguous for the agriculture (A-B) and construction (F) depending on the specification.

FDI produces positive spillovers in all six sectors, which are statistically significant in nine out of twelve regressions. However the estimates on the complementarity effects between FDI and human capital are not consistent across sectors and specifications.

At the final stage of the empirical analysis the efficiency scores and the correspondent confidence intervals are constructed for all countries in the sample.[16] The dynamic of the BRIC countries' efficiency scores in six economic activities, as well as the average scores for the rest of the sample are presented in figure 1 below.

In general the efficiency scores for the BRIC-countries demonstrate moderate positive growth during the period under the analysis. However either stagnation or the decline in the level of efficiency is observed after 2008, which potentially could be attributed to the consequences of the global economic crisis. However, in order to avoid speculations on the nature of these consequences, further research is needed for establishing whether there is structural change in the efficiency patterns or the negative effects are temporarily.

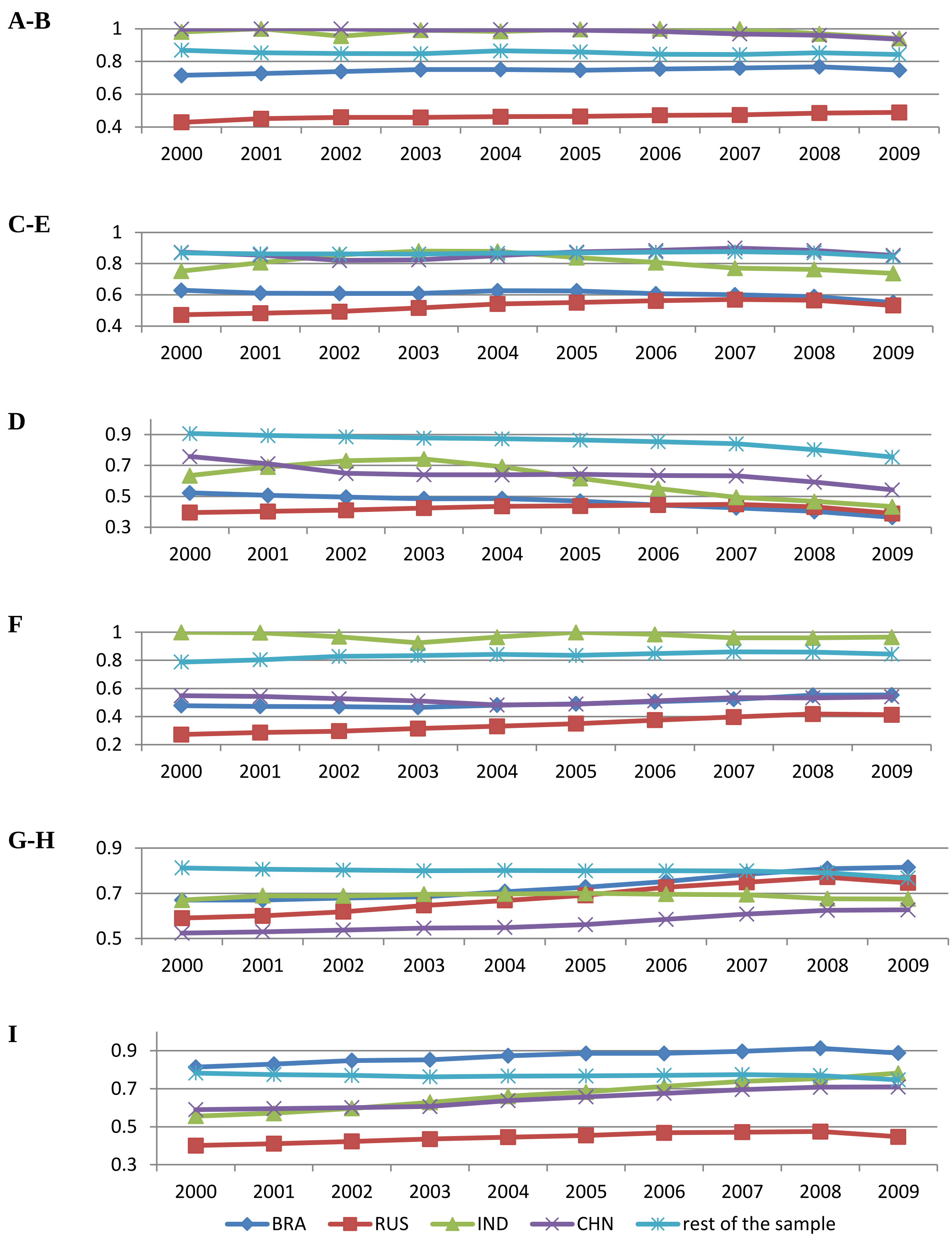
In industry, manufacturing and agriculture China demonstrates the highest efficiency among the BRIC-countries, followed by India, Brazil and Russia. India is leading in construction, while Brazil

[16] the detailed data on efficiency scores and corresponding confidence intervals are presented in the Appendix D

– in trade, hotels and restaurants, and transportation. Russia is the least effective among the BRIC-countries in all, but one sector – trade, hotels and restaurants.

It is noteworthy that despite the fact there is no benchmark available for comparing sector level efficiency scores, some of the estimations seem to be overstated (e.g. both China and India appear to perform very close to the frontier in the agricultural sector). This artifact of the dataset used calls for the further research on the economic activity – specific efficiency scores in order to obtain more robust estimation. More precision in the technical efficiency scores might be obtained, from the author's point of view, by developing sector-specific model specification in order to capture the differences in the associated technological process, as well as by allowing for the heterogeneity across countries. One of the useful tools for these purposes is the random coefficients stochastic frontier model' specification which allows to relax the assumption of the homogeneity of the technological capacities across production units.

Figure 1. Annual efficiency scores for the period 200-2009



V. DISCUSSION

While theoretically the analysis could benefit from including wider set of observations, in this case, countries that could be considered as the counterpart for the BRICS countries, in practice construction of such a voluminous data set and including all of the data into analysis becomes almost unfeasible due to the restrictions in data availability. To overcome the limitation it is decided to focus on the subset of developed G20 countries, as the research is aiming to study whether the BRICS countries are catching up with more developed countries, rather than on the initial reasons of their more advanced growth rates in comparison to less developed countries.
One of the potential developments of the present research is the extension of the timeline under analysis: due to the data availability of the Socio-Economic Accounts – main source of the disaggregated data for the present research – the persistent effects of the 2008' world financial crisis on the productivity levels and their elasticities with respect to the international externalities have left beyond the scope of the current research.
Another promising extension of the conducted research that would contribute to the higher precision in estimation of the sector-specific efficiency scores is the introduction of the model specification that allows for the heterogeneity across countries. One of the available tools to model heterogeneity is the random coefficients stochastic frontier framework that provides a method to disentangle the technical inefficiency from the variation in the technological possibilities of the different technological units.
The main limiting factor at this point is the availability of the methodologically consistent data for the large enough sample of countries and time period. This limitation can be overcome, however, mainly by the means of the careful examination and methodological alignment of the data, available at the national level.

VI. CONCLUSION

The present Master's Thesis aims to contribute to the existing literature on the technical efficiency and cross-border externalities through international trade and foreign direct investment by conducting the corresponding analysis at the disaggregated level of the six economic activities for the panel of sixteen G-20 countries for the period from 1995 to 2009, with particular focus on the emerging BRIC countries.

As anticipated, the evidence suggests that production frontier is shifted upwards by more developed G20 countries, as a coefficient of a dummy variable, capturing the effect of being a BRIC-country, is negative and significant for all sectors. Further the economic validity for the explicit modeling of the international externalities' effects on the domestic technical efficiency is confirmed by performing a likelihood-ratio test for the joint significance of the "inefficiency function" factors.

The important policy implication of the research results is that the effects of the factors under analysis vary across sectors not only in their magnitude, but also in their direction.

It is found that higher openness of the economy is associated with lower levels of the domestic technical efficiency in agriculture, construction and transport.

Moreover, positive complementarity effects between international trade and human capital, highlighted by previous research, focusing at the economy-level analysis, are observed only in industrial sector in general and manufacturing in particular, as well as in trade, hotels and restaurants. Even after controlling for the domestic level of the human capital, the effect of the international trade stays whether insignificant or ambiguous for the service sectors, such as construction or transportation.

Still there are several general finding, that are confirmed to hold for all sectors under analysis: both human capital and foreign direct investment inflows contribute to the increase in the domestic technical efficiencies, independent of the economic activity type.

Thus, while promoting the outward-oriented activities as a conduit of the positive technological spillovers, policy-maker should not only secure domestic human capital accumulation, necessary for the effective technological absorption, but also evaluate potential negative impact of such measures on the more vulnerable sectors, such as agriculture, transport and construction, and take the counter effort measures, if necessary.

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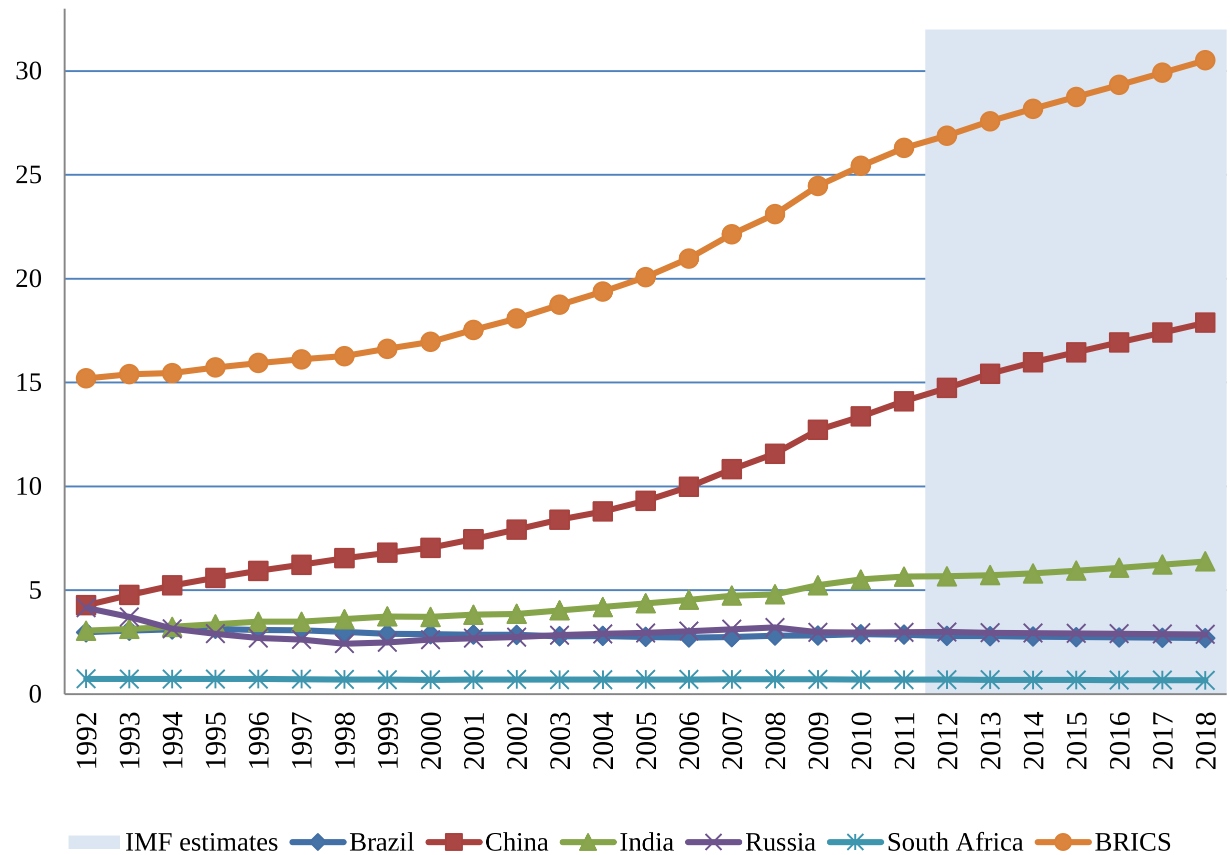
APPENDIX A.

DESCRIPTIVE STATISTICS ON BRICS

Figure 2. Gross domestic product based on purchasing-power-parity (PPP) share of world total



Data Source: International Monetary Fund, World Economic Outlook Database, October 2013

Figure 3. Annual percentage growth rate of GDP at market prices (constant 2005 US$)

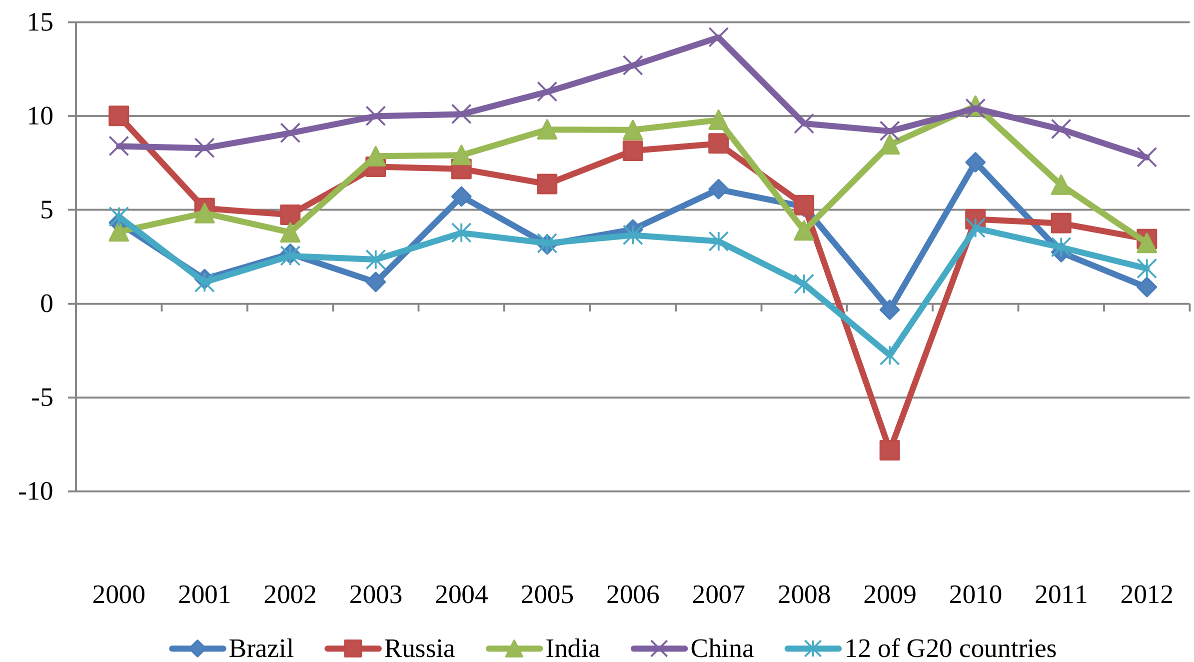
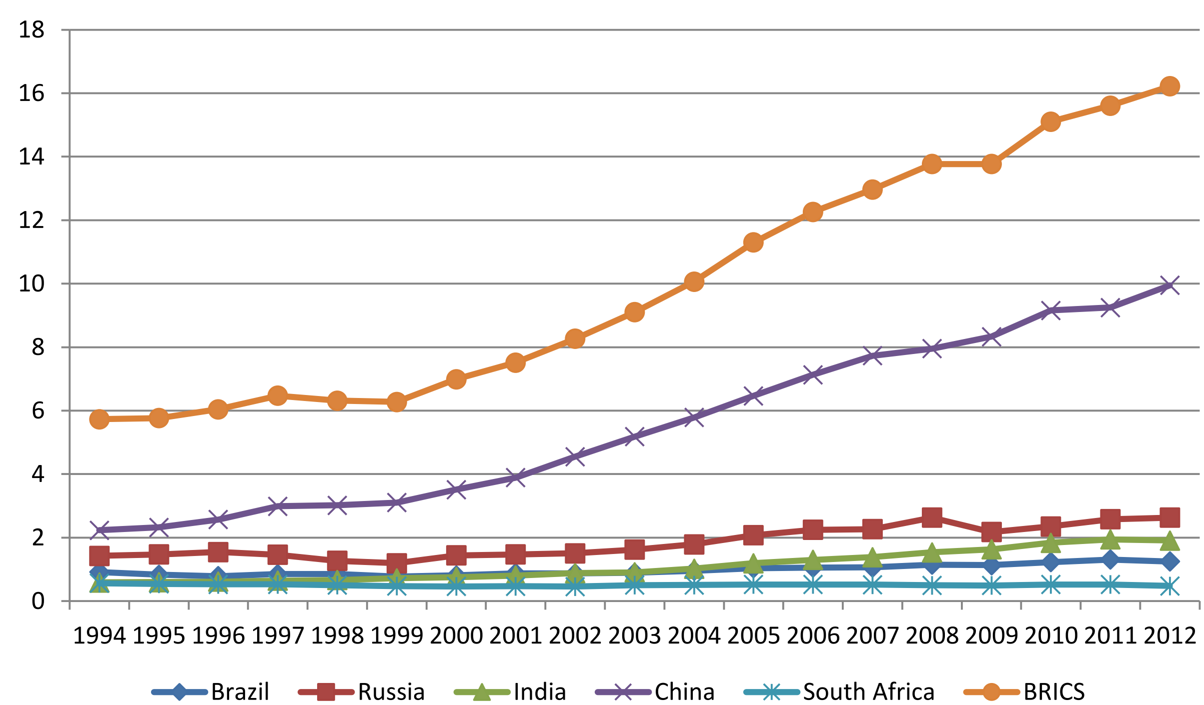
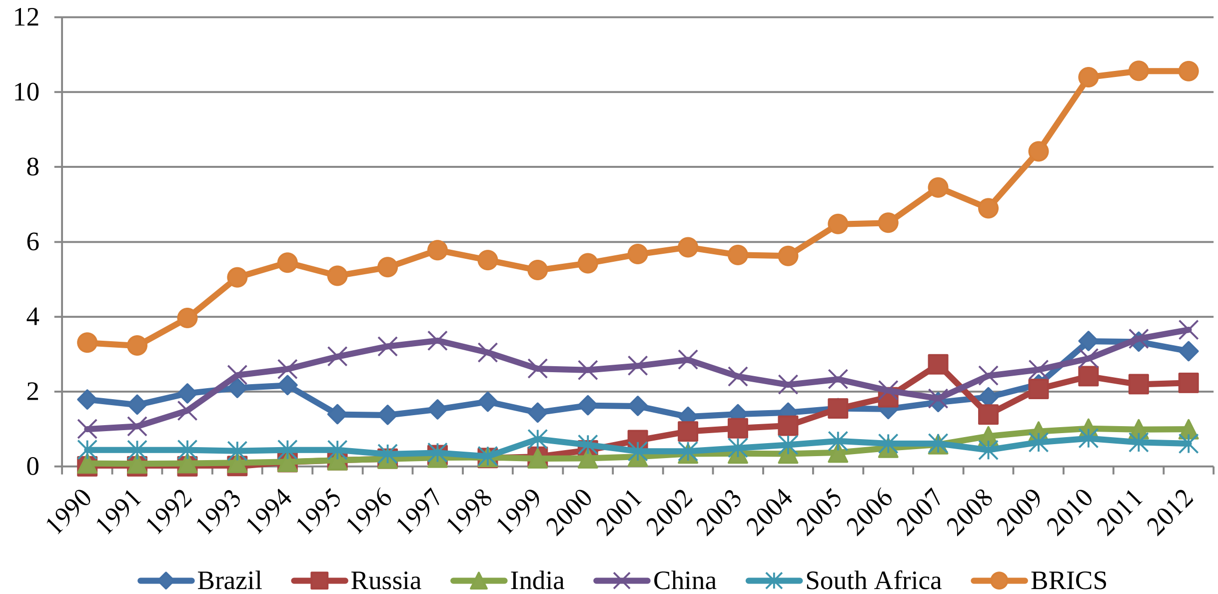


Figure 4. International trade: import and exports of goods and services, as a share of world total



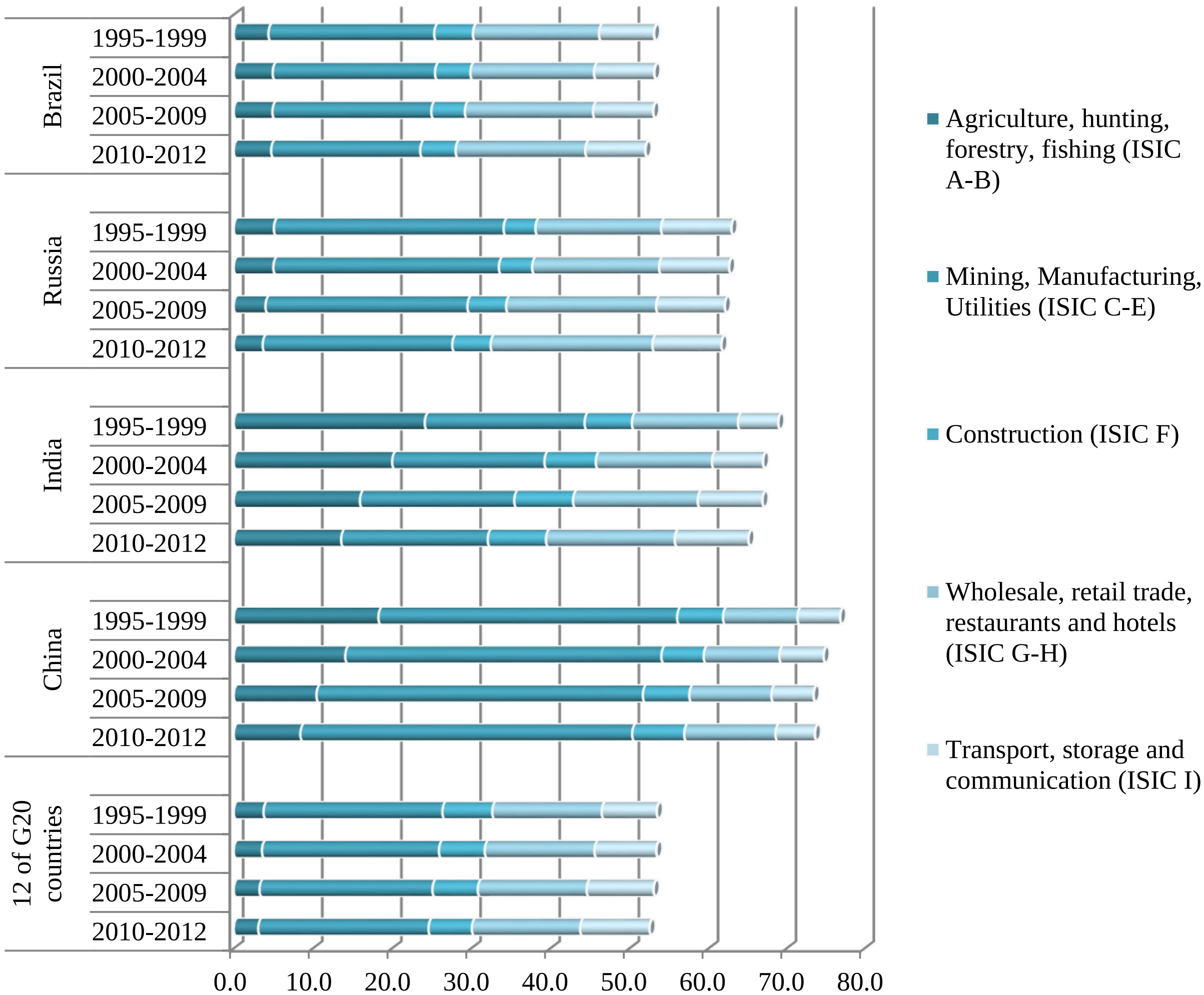
Data source: UNCTADstat

Figure 5. Inward foreign direct investment as a share of world total



Data source: UNCTADstat

Figure 6. Average shares of the value added in the economic activities under analysis in the GDP (constant 2005 prices, US$)



Data Source: National Accounts Estimates of Main Aggregates, United Nations Statistics Division

APPENDIX B

Table 6. Country coverage of the research

Country	Included in the research	G20	G7	BRICS	OECD	IMF classification
Argentina						Developing
Australia						Advanced
Brazil						Developing
Canada						Advanced
China						Developing
European Union						
France						Advanced
Germany						Advanced
India						Developing
Indonesia						Developing
Italy						Advanced
Japan						Advanced
Mexico						Developing
Russia						Developing
Saudi Arabia						Developing
South Africa						Developing
South Korea						Advanced
Turkey						Developing
United Kingdom						Advanced
United States						Advanced

APPENDIX C

Table 7. Construction of the dataset

Variable	Notation	Units	Data Source
Production Function			
Value added by sector	y	constant prices - millions US dollars	United Nations Statistics Division
Capital stock by sector		constant prices - millions US dollars	calculation based on (a) and (b):
(a) Real fixed capital stock by sector	k	constant prices - millions of national currency	Socio economic accounts, World Input-Output Database
(b) Capital stock, total		constant prices - millions US dollars	Penn World Tables Version 8.0
Number of persons engaged by sector	l	thousands	Socio economic accounts, World Input-Output Database
International spillover channels			
Foreign direct investment, net inflows	FDI	% of GDP	World Bank Open Data
Trade (imports plus exports of goods and services)	OPEN	% of GDP	World Bank Open Data
Human capital measures			
Education expenditure	HC-1	% of GNI	World Bank Open Data
Index of human capital per person, based on years of schooling and returns to education	HC-2	index	Penn World Tables Version 8.0

APPENDIX D

Table 8. BRIC-countries' efficiency scores and corresponding confidence intervals (95% level)

country	year	A-B			C-E			D		
		Score	LB	UB	Score	LB	UB	Score	LB	UB
BRA	1995	0.695	0.695	0.695	0.730	0.626	0.846	0.631	0.630	0.631
BRA	1996	0.701	0.701	0.701	0.696	0.597	0.807	0.600	0.599	0.600
BRA	1997	0.696	0.696	0.697	0.675	0.579	0.782	0.579	0.579	0.579
BRA	1998	0.701	0.701	0.701	0.641	0.550	0.743	0.547	0.547	0.547
BRA	1999	0.713	0.713	0.714	0.626	0.537	0.726	0.527	0.527	0.528
BRA	2000	0.716	0.715	0.716	0.630	0.540	0.730	0.523	0.522	0.523
BRA	2001	0.727	0.727	0.727	0.611	0.524	0.709	0.506	0.506	0.507
BRA	2002	0.739	0.739	0.739	0.610	0.523	0.707	0.495	0.495	0.496
BRA	2003	0.751	0.750	0.751	0.608	0.522	0.705	0.485	0.484	0.485
BRA	2004	0.751	0.751	0.751	0.626	0.537	0.725	0.485	0.485	0.485
BRA	2005	0.747	0.746	0.747	0.625	0.536	0.724	0.469	0.469	0.470
BRA	2006	0.755	0.754	0.755	0.607	0.520	0.704	0.444	0.444	0.444
BRA	2007	0.760	0.760	0.760	0.600	0.515	0.696	0.426	0.426	0.426
BRA	2008	0.768	0.768	0.768	0.588	0.504	0.682	0.403	0.403	0.403
BRA	2009	0.748	0.748	0.748	0.552	0.473	0.640	0.364	0.364	0.365
RUS	1995	0.407	0.407	0.408	0.430	0.368	0.498	0.360	0.359	0.360
RUS	1996	0.402	0.402	0.402	0.431	0.369	0.499	0.368	0.368	0.368
RUS	1997	0.409	0.408	0.409	0.437	0.375	0.507	0.376	0.376	0.376
RUS	1998	0.377	0.377	0.377	0.433	0.371	0.502	0.374	0.374	0.374
RUS	1999	0.405	0.405	0.405	0.451	0.387	0.523	0.381	0.381	0.381
RUS	2000	0.428	0.428	0.429	0.472	0.404	0.547	0.396	0.395	0.396
RUS	2001	0.451	0.451	0.451	0.482	0.414	0.559	0.403	0.403	0.403
RUS	2002	0.459	0.459	0.459	0.493	0.422	0.571	0.411	0.411	0.411
RUS	2003	0.458	0.458	0.459	0.516	0.442	0.598	0.425	0.425	0.425
RUS	2004	0.463	0.463	0.463	0.542	0.465	0.628	0.436	0.436	0.436
RUS	2005	0.465	0.464	0.465	0.551	0.472	0.638	0.438	0.438	0.439
RUS	2006	0.471	0.471	0.471	0.562	0.481	0.651	0.444	0.443	0.444
RUS	2007	0.474	0.474	0.474	0.570	0.488	0.660	0.449	0.449	0.449
RUS	2008	0.485	0.485	0.486	0.565	0.484	0.655	0.432	0.431	0.432
RUS	2009	0.489	0.489	0.489	0.532	0.457	0.617	0.390	0.390	0.390
IND	1995	0.926	0.926	0.926	0.683	0.586	0.792	0.629	0.629	0.630
IND	1996	0.970	0.969	0.970	0.703	0.603	0.816	0.641	0.641	0.642
IND	1997	0.963	0.962	0.963	0.705	0.604	0.817	0.621	0.620	0.621
IND	1998	0.990	0.990	0.990	0.695	0.596	0.806	0.594	0.593	0.594
IND	1999	0.983	0.983	0.984	0.698	0.599	0.810	0.583	0.583	0.584

country	year	A-B			C-E			D		
		Score	LB	UB	Score	LB	UB	Score	LB	UB
IND	2000	0.981	0.980	0.981	0.752	0.645	0.872	0.635	0.634	0.635
IND	2001	1.000	0.999	1.000	0.807	0.692	0.933	0.690	0.690	0.691
IND	2002	0.954	0.954	0.954	0.856	0.737	0.975	0.731	0.730	0.731
IND	2003	0.991	0.991	0.991	0.881	0.761	0.987	0.742	0.742	0.742
IND	2004	0.984	0.984	0.984	0.879	0.760	0.986	0.692	0.692	0.692
IND	2005	0.997	0.996	0.997	0.839	0.721	0.963	0.616	0.616	0.617
IND	2006	1.000	0.999	1.000	0.807	0.692	0.934	0.551	0.551	0.551
IND	2007	0.998	0.998	0.999	0.771	0.661	0.894	0.494	0.494	0.494
IND	2008	0.969	0.969	0.969	0.763	0.655	0.885	0.467	0.467	0.468
IND	2009	0.940	0.940	0.941	0.738	0.632	0.855	0.433	0.433	0.433
CHN	1995	0.953	0.953	0.953	0.940	0.838	0.997	0.999	0.999	1.000
CHN	1996	0.971	0.970	0.971	0.941	0.841	0.998	0.983	0.982	0.983
CHN	1997	0.982	0.982	0.982	0.938	0.836	0.997	0.945	0.944	0.945
CHN	1998	0.991	0.990	0.991	0.924	0.814	0.996	0.880	0.879	0.880
CHN	1999	0.996	0.996	0.997	0.898	0.781	0.992	0.809	0.809	0.809
CHN	2000	0.998	0.997	0.998	0.873	0.754	0.984	0.758	0.757	0.758
CHN	2001	1.000	0.999	1.000	0.855	0.736	0.974	0.711	0.711	0.712
CHN	2002	0.999	0.999	0.999	0.820	0.704	0.947	0.649	0.649	0.649
CHN	2003	0.991	0.991	0.991	0.824	0.707	0.950	0.640	0.639	0.640
CHN	2004	0.994	0.994	0.995	0.851	0.732	0.972	0.640	0.639	0.640
CHN	2005	0.991	0.991	0.991	0.875	0.755	0.985	0.643	0.643	0.644
CHN	2006	0.984	0.983	0.984	0.884	0.766	0.988	0.635	0.635	0.635
CHN	2007	0.968	0.968	0.969	0.900	0.783	0.992	0.632	0.632	0.633
CHN	2008	0.960	0.960	0.960	0.885	0.766	0.988	0.592	0.592	0.592
CHN	2009	0.936	0.936	0.936	0.853	0.734	0.973	0.542	0.542	0.543

country	year	F			G-H			I		
		Score	LB	UB	Score	LB	UB	Score	LB	UB
BRA	1995	0.471	0.471	0.471	0.639	0.639	0.639	0.717	0.717	0.718
BRA	1996	0.472	0.472	0.472	0.643	0.642	0.643	0.739	0.738	0.739
BRA	1997	0.483	0.482	0.483	0.652	0.652	0.652	0.760	0.759	0.760
BRA	1998	0.481	0.481	0.481	0.653	0.653	0.653	0.770	0.769	0.770
BRA	1999	0.474	0.474	0.474	0.654	0.654	0.654	0.778	0.777	0.778
BRA	2000	0.478	0.477	0.478	0.670	0.670	0.671	0.813	0.813	0.814
BRA	2001	0.473	0.473	0.473	0.670	0.670	0.670	0.829	0.829	0.830
BRA	2002	0.471	0.470	0.471	0.680	0.680	0.680	0.848	0.847	0.848
BRA	2003	0.465	0.465	0.465	0.684	0.684	0.684	0.852	0.851	0.852

country	year	F			G-H			I		
		Score	LB	UB	Score	LB	UB	Score	LB	UB
BRA	2004	0.481	0.481	0.482	0.708	0.707	0.708	0.873	0.873	0.874
BRA	2005	0.491	0.490	0.491	0.727	0.727	0.727	0.885	0.885	0.886
BRA	2006	0.505	0.505	0.505	0.752	0.752	0.752	0.886	0.885	0.886
BRA	2007	0.522	0.522	0.522	0.785	0.785	0.785	0.896	0.896	0.897
BRA	2008	0.552	0.551	0.552	0.809	0.809	0.809	0.912	0.912	0.913
BRA	2009	0.554	0.554	0.554	0.815	0.815	0.816	0.888	0.887	0.888
RUS	1995	0.242	0.241	0.242	0.539	0.539	0.539	0.369	0.369	0.369
RUS	1996	0.236	0.236	0.236	0.548	0.548	0.548	0.367	0.367	0.367
RUS	1997	0.235	0.235	0.235	0.570	0.570	0.570	0.369	0.369	0.369
RUS	1998	0.244	0.244	0.244	0.559	0.559	0.559	0.368	0.367	0.368
RUS	1999	0.251	0.251	0.251	0.560	0.560	0.560	0.388	0.388	0.388
RUS	2000	0.272	0.272	0.272	0.590	0.590	0.590	0.401	0.400	0.401
RUS	2001	0.286	0.286	0.287	0.601	0.601	0.601	0.411	0.411	0.411
RUS	2002	0.296	0.296	0.296	0.619	0.618	0.619	0.422	0.422	0.423
RUS	2003	0.315	0.314	0.315	0.646	0.646	0.646	0.435	0.435	0.436
RUS	2004	0.331	0.331	0.331	0.668	0.668	0.669	0.445	0.445	0.445
RUS	2005	0.349	0.349	0.349	0.691	0.691	0.692	0.454	0.454	0.455
RUS	2006	0.374	0.374	0.374	0.727	0.726	0.727	0.468	0.468	0.468
RUS	2007	0.396	0.396	0.396	0.749	0.749	0.749	0.472	0.471	0.472
RUS	2008	0.418	0.417	0.418	0.771	0.771	0.771	0.474	0.474	0.475
RUS	2009	0.413	0.413	0.413	0.746	0.746	0.746	0.447	0.446	0.447
IND	1995	0.922	0.922	0.922	0.614	0.614	0.615	0.487	0.487	0.487
IND	1996	0.964	0.963	0.964	0.628	0.628	0.628	0.498	0.498	0.499
IND	1997	0.941	0.941	0.941	0.640	0.640	0.640	0.515	0.515	0.516
IND	1998	0.941	0.941	0.941	0.653	0.653	0.653	0.531	0.531	0.532
IND	1999	0.933	0.933	0.933	0.670	0.669	0.670	0.545	0.544	0.545
IND	2000	1.000	0.999	1.000	0.670	0.670	0.670	0.556	0.555	0.556
IND	2001	0.996	0.996	0.997	0.689	0.689	0.689	0.571	0.570	0.571
IND	2002	0.968	0.968	0.969	0.689	0.689	0.689	0.596	0.596	0.597
IND	2003	0.925	0.924	0.925	0.696	0.696	0.696	0.628	0.628	0.629
IND	2004	0.965	0.965	0.965	0.697	0.697	0.698	0.660	0.660	0.661
IND	2005	1.000	0.999	1.000	0.700	0.700	0.700	0.683	0.683	0.683
IND	2006	0.985	0.985	0.985	0.696	0.696	0.696	0.712	0.711	0.712
IND	2007	0.961	0.961	0.961	0.694	0.694	0.694	0.738	0.738	0.739
IND	2008	0.960	0.960	0.960	0.676	0.676	0.676	0.753	0.752	0.753
IND	2009	0.965	0.965	0.965	0.675	0.675	0.675	0.781	0.781	0.782
CHN	1995	0.583	0.583	0.584	0.487	0.487	0.487	0.555	0.555	0.556
CHN	1996	0.583	0.583	0.583	0.494	0.494	0.495	0.561	0.561	0.561
CHN	1997	0.569	0.569	0.569	0.504	0.504	0.505	0.563	0.563	0.563

country	year	F			G-H			I		
		Score	LB	UB	Score	LB	UB	Score	LB	UB
CHN	1998	0.569	0.569	0.569	0.509	0.509	0.509	0.570	0.569	0.570
CHN	1999	0.560	0.560	0.560	0.516	0.516	0.516	0.582	0.581	0.582
CHN	2000	0.548	0.548	0.548	0.524	0.524	0.524	0.590	0.589	0.590
CHN	2001	0.543	0.542	0.543	0.530	0.530	0.530	0.595	0.595	0.596
CHN	2002	0.526	0.526	0.527	0.538	0.538	0.538	0.601	0.600	0.601
CHN	2003	0.511	0.511	0.511	0.546	0.546	0.546	0.607	0.606	0.607
CHN	2004	0.482	0.482	0.482	0.549	0.549	0.549	0.637	0.637	0.638
CHN	2005	0.489	0.489	0.489	0.562	0.562	0.562	0.657	0.657	0.658
CHN	2006	0.512	0.511	0.512	0.585	0.585	0.585	0.675	0.675	0.676
CHN	2007	0.534	0.534	0.535	0.608	0.608	0.608	0.695	0.695	0.696
CHN	2008	0.533	0.533	0.534	0.625	0.625	0.625	0.708	0.707	0.708
CHN	2009	0.541	0.540	0.541	0.627	0.627	0.627	0.709	0.709	0.710

Note: TE – technical efficiency score; LB – 95% confidence interval’s lower bound; UB – 95% confidence interval’s upper bound

Technical efficiency score varies from 0 to 1, the larger score corresponds to the higher technical efficiency

Calculations are performed using *sfpanel* package in Stata. Efficiency scores are constructed according to the Battesse and Coelli’s (1988) estimator. Confidence intervals are constructed based on the approach by Horacce and Schmidt (1996)