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# HOW R&D EXPENDITURES INFLUENCE TOTAL FACTOR PRODUCTIVITY AND TECHNICAL EFFICIENCY?

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# HOW R&D EXPENDITURES INFLUENCE TOTAL FACTOR PRODUCTIVITY AND TECHNICAL EFFICIENCY?[3]

In this paper we estimate the impact of R&D expenditures on the total factor productivity (TFP) and technical efficiency of two panels of countries in the period 1990-2011. We obtain TFP decomposition estimates using one- and two-step Stochastic Frontier Analysis (SFA) and a modified (O'Donnell, 2008) Data Envelopment Analysis (DEA) framework. Our estimates of TFP growth rates correlate highly with those of OECD, The Conference Board and PWT. The efficiency-based rankings of the countries are similar to those from the results of other studies.

The estimates of R&D's impact on TFP and technical efficiency were obtained controlling for various factors, including the structure of the economy, institutional and infrastructural development and R&D expenditures over a total of five hundred possible model specifications.

We found that the increase in total R&D expenditures by 1% of GDP in five years raises the average TFP growth rate by 5.0 to 7.7 percentage points, depending on the sample. Also, raising total R&D expenditures by $1,000 per researcher raises TFP growth five years later by 0.013 to 0.025 percentage points, depending on the sample. Also we have identified a significant impact of lagged R&D expenditures (up to ten years) on the dynamics of the global technology frontier component in the presence of a number of control variables.

JEL Classification: C51, O11, O33, O57

Keywords: DEA, SFA, total factor productivity, technical efficiency, R&D expenditures

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# 1. Introduction

Cross-country productivity studies widely use the growth accounting framework (Barro, 1999; Fernald, 2014). This framework defines total factor productivity (TFP) as a “Solow residual” while assuming full utilization of production factors. However, actual output often differs from that predicted by the estimated production function given the stocks of factors. This might be due to inefficiencies in production[4], as recognized by growth and productivity researchers (Jones, 2013).

Our analysis is structured in two stages.

First, we estimate the dynamics of TFP and technical efficiency in a panel of countries by using two methods: SFA (Stochastic Frontier Analysis) and DEA (Data Envelopment Analysis). Both approaches are applied to analyze the dynamics of the total factor productivity (TFP) change and its components (global technological index and technical efficiency change[5]), for each of the economies. We design five adequacy criteria and find our estimates conforming to them.

Despite the fact that this approach has been used for sectoral studies on cross-country samples for a long time (Hultberg et al., 2004), it is rarely used to compare the total factor productivity values (i.e. as an alternative to the “growth accounting”).

Second, we use the obtained TFP estimates to assess the effect of trends in R&D expenditures on TFP and technical efficiency growth rates by controlling for different structural, institutional, and infrastructural variables. We add technical efficiency to our analysis as an important determinant for the TFP trend.

Our contribution is as follows. First, this is the first detailed[6] comparative decomposition of the TFP dynamics with cross-country comparison on a macrolevel. Second, our TFP decomposition separately includes the dynamics of the global technological frontier, the dynamics of the national technological frontier and the dynamics of technical efficiency (the distance to the productive possibilities frontier, PPF) of the economy. Third, we define several adequacy criteria of the TFP estimates and verify the consistency of our TFP and its decomposition.

This paper is organized as follows. The second section contains the literature review. Section 3 describes the data and methodology used. Section 4 outlines the estimation results and tests them against the adequacy criteria. Section 5 outlines the results of the estimation of R&D expenditures influence on TFP and its components. Section 6 concludes.

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[4] This inefficiency may be interpreted both as the productive and allocative one.

[5] While we obtain the estimates of mixed and scale efficiency, they are not the primary focus of this paper.

[6] Earlier studies (such as Ceccobelli et al., 2012), based on Kumar and Russeell’s (2002) approach, use only SFA to estimate the TFP decomposition with technical efficiency.

# 2. Literature review

The growth accounting framework underlies both the studies on the historical productivity of a country (Fernald, 2014) and cross-country productivity studies (O'Mahony and Timmer, 2009; The Conference Board, 2015). On one hand, this literature assumes the full utilization and efficient use of production factors. On the other hand, firm-level sectoral studies usually estimate TFP via the approach of productive efficiency (Fried et al., 2008).

Several studies find that firm-level productive inefficiencies could be the drivers behind large cross-country differences in income and productivity, not only for a given sector but on a macroeconomic level as well (Färe et al., 1994; Hsieh and Klenow, 2009). The transmission mechanism is supposed to work via the input-output structure of the economy, resulting in the inefficiency multiplier (Bartelsman et al., 2013; Jones, 2013). Critics of this approach denote statistical difficulties of microdata sector aggregation associated with relative price change (Petrin and Levinsohn, 2012), which make the transition from firm level to macroeconomic level productive efficiency impossible.

Some authors indicate that TFP estimates obtained through the production inefficiency approach are more precise than those of standard growth accounting (Giraleas et al., 2012). However, this approach has only recently been applied at a macroeconomic level and is part of a growing trend in the research[7]. One of the important features of the production inefficiency approach is the decomposition of the TFP dynamics. This permits us to distinguish shifts of the global production frontier from the movements towards this frontier (Kumar and Russell, 2002; O'Donnell, 2008).

On a macrolevel, this approach is used particularly to analyze the role of ICT in the TFP dynamics (Ceccobelli et al., 2012), to separate "clubs of efficient economies" in terms of convergence theory (Mastromarco et al., 2015), or to research the factor neutrality of the technological progress (Chen and Yu, 2014).

There is one controversy in the studies of the role of R&D expenditures in increasing TFP and generating economic growth in general.

Studies from 1970 to the 1990s found evidence of a direct R&D impact on productivity at both macroeconomic and sectoral levels (Griliches, 1998). However, empirical tests for the prevalent endogenous growth framework have shown that R&D spending is not connected to either productivity or economic growth. In particular, an influential paper by Jones (1995) states, based on post-war OECD data, that in general there is no connection between R&D investment and productivity contribution in an AK-type endogenous economic growth model.

[7] In particular, based on bibliometric analysis of DEA literature, Liu et al. (2013) highlight that two-step method is prevalent in applied analysis using DEA.

However, in an environment of different science and technology development levels, R&D investment is expected to bring forth productivity improvements. Coe and Helpman (1995) and Guellec and De La Potterie (2002) reported that R&D expenditures create positive effects for productivity via international spillovers.

Thus, currently the approach to the impact of R&D spending is twofold: it clearly helps to perform a catch-up, but the literature does not support the hypothesis that along the frontier more R&D spending impacts productivity (CBO, 2005).

Kumar and Russell (2002) offered a framework to decompose TFP growth into the catch-up with the frontier and the shift of the frontier itself. Two studies use Kumar and Russell's TFP decomposition with SFA analysis on a panel of countries in order to study the determinants of growth in output (Henry et al., 2009) and technical efficiency (Wang and Wong, 2012), including technological improvements.

Our paper uses the same general "Kumar and Russell cross-country" approach but there are significant differences.

First, they use Coe and Helpman's (1995) technological transfer framework, implying that developing countries only obtain technological improvements via capital goods imports alone (Henry et al., 2009) or along with the FDI (Wang and Wong, 2012). We use a framework that explicitly focuses on the effects of R&D in developing countries on their TFP decomposition while controlling for merchandise trade.

Second, other studies focus only on one part of the picture, namely Henry et al. (2009) only study output growth and Wang and Wong (2012) only study technical efficiency. Our paper focuses on the whole picture, i.e., on determinants for both technical efficiency and TFP (and, consequently, output). Third, our methods allow for cross-sample, cross-method and cross-specification robustness. We use two varieties of SFA and DEA estimates over two samples. Both of the other studies mentioned above use only SFA over a single sample.

Most productivity (including TFP) studies on the Russian economy also rely on growth accounting with a twist. These include sectoral production functions allowing for differing capacity utilization under poor availability of data (Bessonov, 2004), removing endogeneity caused by oil and gas rents (Nazrullaeva, 2008) or comparative analysis of growth contribution from the oil and gas sector vis-à-vis other factors (Voskoboynikov and Solanko, 2014).

A productive efficiency approach on Russian data was only used for firm-level data, for example, in agriculture (Bokusheva et al., 2011), manufacturing (Bessonova, 2007), and rubber and plastic production (Ipatova and Peresetsky, 2013). The only study using methods similar to ours is Mamonov and Pestova (2015), who use SFA to estimate TFP at the macrolevel, and derive technical efficiency dynamics via Malmquist indices. In Subsection 4 we compare our rankings of TFP and technical efficiency with the results of that paper.

# 3. Data and estimation methods

## 3.1. Data

We use two samples of data, each consisting of a different selection of countries. The sample "OECD-1990+Russia" includes countries that were members of the OECD in 1990 plus Russia (twenty-two countries altogether). The sample "World" includes countries that contributed no less than 0.1% to the world GDP in 2011. There are seventy-five such countries, but ten lack any relevant data.

The choice of data followed several requirements:

1) compatibility of cost parameters in time and among countries; for this purpose appropriate deflators and constant purchasing power parities (PPP) were used;
2) a small number of missing values among the used indicators in the data series for a wide circle of countries starting from 1990;
3) comparable methodology of calculating particular indicators for different countries.

The database for the analysis was composed using the following sources (Table 1):

**Tab. 1. Data Sources**

| Database | Number of countries | Period | Indicators |
|---|---|---|---|
| PWT 8.0 (Feenstra et al., 2013) | 167 | 1950-2011 | GDP (PPP), capital stock (PPP), number of employed, Human Capital Index |
| WEO, IMF (IMF, 2014) | 189 | 1980-2013 | GDP (PPP), total investments, gross savings, inflation, employment, government income and expenditures, government debt, current account balance |
| WDI, WB (World Bank, 2015) | 214 | 1960-2013 | Agricultural, irrigated, arable land; structural, institutional (incl. total R&D expenditures) and infrastructural indices |
| UNSD (UN Data, 2015) | 219 | 1970-2013 | Added value in particular industries, export and import of goods and services |
| AMECO[8] | 37 | 1960-2013 | Capital stock |
| WIOD[9] | 40 | 1995-2011 | Capital stock |

As an institutional indicator, we also used the Economic Freedom Index of the Fraser Institute[10] which covers a wide variety of countries. This indicator characterizes the development of economic and, to a lesser extent, political institutions in a country.

[8] http://ec.europa.eu/economy_finance/db_indicators/ameco/
[9] http://www.wiod.org/new_site/home.htm
[10] http://www.fraserinstitute.org/

For OECD countries and three others, including Russia, total R&D expenditures were supplemented by government R&D expenditure from the OECD database[11].

The following were selected as measures of R&D expenditures:

1) expenditures intensity:
   a) total expenditures, % of GDP (WB database);
   b) business expenditures, % of GDP (computed by subtracting government R&D expenditures as listed in the OECD database (available for twenty-eight countries from the World sample) from the above value);
2) expenditures density:
   a) total expenditures per researcher ($M/person using constant prices and 2005 PPP);
   b) business expenditures per researcher ($M/person using constant prices and 2005 PPP).

Control variables for R&D expenditures models were subdivided into groups:

1) structural:
   a) manufacturing, value added, % of GDP;
   b) merchandise trade, % of GDP;
   c) oil and natural gas rents, % of GDP;
   d) real interest rate, %;
   e) school enrollment, tertiary, % gross;
   f) survival to age sixty-five, male, % of cohort;
   g) urban population, % of total;
2) institutional:
   a) index of economic freedom;
   b) physicians, per thousand people;
   c) researchers in R&D, per million people, five years lag;
   d) technicians in R&D, per million people;
3) infrastructural:
   a) internet users, per hundred people;
   b) telephone lines, per hundred people;
   c) passenger cars, per thousand people;
   d) rail lines, total route-km;
   e) railways, goods transported, million ton-km;
   f) railways, passengers carried, million passenger-km;

[11] http://stats.oecd.org/

g) roads, total network, km;
h) road density, km of road per hundred sq. km of land area;
i) roads, goods transported, million ton-km;
j) roads, passengers carried, million passenger-km;
k) roads and railways density adjusted to inhabited land (per person), (km-sq. km)-(ha-person);
l) roads and railways goods transported adjusted to goods trade, % of GDP, and total population.

## 3.2. Technical efficiency approaches and estimation methods

As mentioned above, we define total factor productivity as "Solow residual" – the ratio of the aggregate output to the aggregate input:[12]

$$TFP_{it} = \frac{Y_{it}}{X_{it}} \equiv \frac{Y(y_{it})}{X(x_{it})} \quad (1)$$

where $y_{it}$ and $x_{it}$ are output and input vectors for country $i$ in moment $t$, $Y(\cdot)$ and $X(\cdot)$ are nonnegative, nondecreasing and linearly homogeneous aggregation functions for outputs and inputs.

Since research of technical efficiency was initially conducted on intrabranch data, in the technical efficiency approach TFP was originally viewed as a non-price factor of the firm's profitability. We use the decomposition, which rests upon the paper of O'Donnell (2008):

$$TFP_{it} = TFP_t^* \cdot TE_{it} \cdot SME_{it} \quad (2)$$

where:

1) $TFP_t^*$ is a technological indicator (TFP maximum value of countries in moment $t$);
2) $TE_{it}$ is technical efficiency (proximity to the PPF with retention of proportions between inputs and outputs);
3) $SME_{it}$ is scale and mixed efficiency.

A TFP change is equal to the multiplication of changes in its components, correspondingly:

$$TFPI_{hs,it} = \left(\frac{TFP_t^*}{TFP_s^*}\right)\left(\frac{TE_{it}}{TE_{hs}}\right)\left(\frac{SME_{it}}{SME_{hs}}\right) \quad (3)$$

In this paper we use the two most commonly employed methods – Stochastic Frontier Analysis and Data Envelopment Analysis. Both are based on the approach of production

[12] The detailed description of the methods used is given in the paper (Ipatova, 2015).

frontiers and permit to assess the technical efficiency and total factor productivity of an economy in every moment of time. A detailed review of the existing methods of inefficiency estimation is adduced, for example, in (Fried et al., 2008).

### *3.2.1. Data Envelopment Analysis (DEA)*

DEA was first proposed by Charnes et al. (1978). It assumes that the TFP can be obtained by solving a mathematical programming optimization problem requiring either maximization of aggregate output under fixed inputs or minimization of aggregate input under fixed outputs. Thus, DEA does not require initial assumptions about error distribution. Examples of concrete DEA optimization problems may be found in the research of O'Donnell (2008).

The main DEA assumptions are the following:

1) all necessary volume and price variables are observed without errors;
2) productivity metafunction (common for all countries) is piecewise-linear;
3) smaller amounts of output and inputs are available;
4) production set is convex.

Technical efficiency (TE) is equal to the output distance function, i.e. ratio of the actual country's output to the maximum one with given inputs. The used notion of the distance function was introduced in Shephard (1953), and the formulas for calculating technical efficiency through the distance function values were presented by Farrell (1957). The highest feasible outputs for every input level form a deterministic production frontier. It is necessary to point out that TE is considered as a relative but not an absolute index in the framework of this method.

In order to obtain TFP estimates using DEA, the Färe-Primont aggregate function was applied.

### *3.2.2. Stochastic Frontier Analysis (SFA)*

The econometric model of Stochastic Frontier Analysis was proposed by Meeusen and Van den Broeck (1977) and Aigner et al. (1977). In this approach, inefficiency in the production function is conveyed through partition of the usual regression error $\varepsilon$ into two uncorrelated summands – a normally distributed error $v$ and a nonnegative error which ordinarily has one of the following distributions:

1) half-normal: $u \sim N^{+}(0, \sigma_u^2)$;
2) truncated normal: $u \sim N^{+}(a, \sigma_u^2)$, $a > 0$;
3) exponential: $u \sim Exp(\alpha)$.

For cross-section data, the SFA model with the Cobb-Douglas production function looks as follows:

$$\ln y_i = (\ln x_i)'\beta + v_i - u_i \tag{4}$$

where $y_i$ is the output of country $i$, $x_i$ is an input vector of country $i$, $\beta$ is a vector of the estimating parameters.

As a rule, SFA models are estimated by maximum likelihood method. The most commonly used formula for technical efficiency assessment is the formula proposed by Battese and Coelli (1988):

$$TE_i = \mathrm{E}\left(e^{-u_i} \mid \varepsilon_i\right)\Big|_{\varepsilon_i = \hat{\varepsilon}_i} \tag{5}$$

A row of SFA model specifications is used for panel data. The simplest one is the model where the technical inefficiency component plays the role of a country fixed effect (Time-Invariant Model, TI).

$$\ln y_{it} = (\ln x_{it})'\beta + v_{it} - u_i \tag{6}$$

The next one is the model in which it is also assumed that there is no country heterogeneity, but technical efficiency can alter over time according to some law (Time-Varying Decay Model, TVD).

$$\ln y_{it} = (\ln x_{it})'\beta + v_{it} - u_{it} \tag{7}$$

$$u_{it} = \gamma(t) \cdot u_i$$

$$\gamma(t) = \exp\left(-\alpha\left(T - t\right)\right)$$

The model that separates heterogeneity from the inefficiency component applying a two-step estimation procedure was first proposed by Heshmati et al. (1995). In the first step, a panel model with either random or fixed individual effects is estimated. In the second step, its errors $\varepsilon$ are regressed on a constant using the SFA model for cross-section data. Formula 8 describes the model in the case of fixed individual effects.

$$\ln y_{it} = \alpha_i + (\ln x_{it})'\beta + \varepsilon_{it} \tag{8}$$

$$\varepsilon_{it} = \delta + v_{it} - u_{it}$$

The last of the estimated models in this paper are the «True» Random Effect Model (TRE) and the «True» Fixed Effect Model (TFE) (Greene, 2005). The TFE model looks as follows:

$$\ln y_{it} = \alpha_i + (\ln x_{it})'\beta + v_{it} - u_{it} \tag{9}$$

For the chosen models, TFP estimates were found according to the formula of Solow residual using the estimates of production function parameters:

$$TFP_{it} = \frac{Y_{it}}{X_{it}} = y_{it} \Big/ \prod_k x_{k,it}^{\eta^{-1}\hat{\beta}_k}, \ \eta = \sum_k \hat{\beta}_k \tag{10}$$

where $Y_{it}$ and $X_{it}$ are aggregate output and input for country $i$ in moment $t$, $y_{it}$ is the GDP of country $i$ in moment $t$, $x_{k,it}$ is the $k$-th production factor for country $i$ in moment $t$, $\hat{\beta}_k$ is an estimate of the $k$-th parameter.

## 3.3. Empirical strategy

*3.3.1. TFP decomposition estimates*

The empirical strategy to obtain TFP decomposition estimates consisted of three steps:

1) estimation of production frontier (SFA and DEA approaches) and TFP, decomposed into technical efficiency and technological components;
2) verification of the statistical, econometric and economic adequacy of the obtained estimates;
3) modelling of production function specifications with conditional heteroscedasticity of the individual error (SFA approach).

TFP growth estimation via SFA and DEA was performed on both samples (“World” and “OECD-1990+Russia”).

In the first step, the estimated models were ordered by the following parameters:

1) production function specification: translog, Cobb-Douglas, or non-parametric (DEA);
2) pooled or panel regressions – for pooled regressions an equation for heteroscedasticity of an individual error $u$ was estimated;
3) distribution of the inefficiency component: half-normal, exponential and truncated normal (depending on the sample and the model).

The estimates of technical efficiency are calculated in accordance with Formula 5. Furthermore, we examine the conformity of TFP estimates and the technical efficiency among different SFA models using the following parameters:

1) convergence of the model specification (the estimates of error and technical efficiency variances must be successful);
2) production function coefficients must be significant and have positive signs;
3) technical inefficiency must be present in the sample (variance of the homoscedastic error $u$ must be significantly greater than zero);
4) coefficients must be significant and their signs and magnitudes must be economically adequate while modelling error heteroscedasticity.

*3.3.2. Modeling the effect of R&D expenditures on TFP and technical efficiency growth in one-step SFA, two-step SFA, and DEA*

While modelling variance of an individual heteroscedastic error $u$, we checked the dependence of the distribution parameter on the amount of R&D expenditures along with control variables. Models were estimated in several cycles for the log variance of error $u$:

1) the cycle with a single explanatory variable: R&D expenditures indicator (% GDP or per researcher) or a control variable;
2) the cycle with two explanatory variables:
   a) R&D expenditures indicator;
   b) one of the control variables;
3) the cycle with four explanatory variables:
   a) R&D expenditures indicator;
   b) three control variables from three categories (structural, institutional, infrastructural indicators).

We used the same three-cycle factor selection procedure for modelling TFP and technical efficiency from various two-step SFA and DEA estimators.

In order to reduce the total number of estimated models, the most significant control variables were selected from each category for the third cycle on the basis of the results of the first two cycles. The final models were to contain at least two significant control variables from two categories.

# 4. Estimation results

## 4.1. Production function estimates

We obtained both SFA and DEA decompositions for TFP for both samples. We used the three-factor Mankiw-Romer-Weil (Acemoglu, 2008) production function in both translog and Cobb-Douglas specifications: a GDP logarithm is endogenous variable and logarithms of capital stock, number of employed and human capital are exogenous.

In search of better specifications we tried the following:

- alternative estimates of capital stock for comparison to PWT from AMECO and WIOD databases;
- estimated four-factor models containing the "land" factor (a log of either arable or agricultural land in square meters);
- included linear and quadratic time trends in the translog and Cobb-Douglas functions.

All of these turned out to be insignificant for all the estimated models.

We expected the resulting estimates to have

- convergence;
- adequate signs and values of estimated coefficients;
- variance in the component of productive efficiency;
- high correlation among the estimation results.

The following models were excluded from subsequent examination for reasons of:

- nonconvergence: models with truncated normal distribution of error $u$ (apart from TI and TVD specifications);
- absence of adequate estimates (signs and values of coefficients): models including indices of capital stock from AMECO and WIOD data, because their estimates were inadequate, and TVD model;
- absence of the inefficiency component variance: panel regressions estimated using two-step SFA on “OECD-1990+Russia”;
- high correlation among the estimation results: translog specifications (with all this, the Cobb-Douglas function is more preferable because it contains fewer parameters) and models with the exponential distribution of error $u$.

Besides, individual country effects imply systematic bias owing to the factors which were not taken into consideration in the specification. This fact, as well as results of the Hausman tests, gives us grounds to exclude all types of models with random individual effects (RE, TRE) from examination.

The results of the selection from SFA production function estimates due to the above criteria are presented in Table 2.

**Tab. 2. Results of the production function estimation (SFA method) on different samples**

| Model | Distribution of error u | Cobb-Douglas function | | | | Translog function | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | “World” | “OECD-1990 +Russia” | AMECO | WIOD | “World” | “OECD-1990 +Russia” | AMECO | WIOD |
| Pooled regression | | | | | | | | | |
| | half-normal | | | | | | | | |
| | exponential | | | | | | | | |
| | truncated normal | | | | | | | | |
| Panel regression | | | | | | | | | |
| TI | truncated normal | | | | | | | | |
| TVD | truncated normal | | | | | | | | |
| RE-2S | half-normal | | | | | | | | |
| RE-2S | exponential | | | | | | | | |
| FE-2S | half-normal | | | | | | | | |
| FE-2S | exponential | | | | | | | | |
| TRE | half-normal | | | | | | | | |
| TRE | exponential | | | | | | | | |
| TRE | truncated normal | | | | | | | | |
| TFE | half-normal | | | | | | | | |
| TFE | exponential | | | | | | | | |
| TFE | truncated normal | | | | | | | | |

where:

presence of significant technical inefficiency, coefficients of production function are significant and have a correct signs
presence of significant technical inefficiency, coefficients of production function are insignificant
absence of significant technical inefficiency, coefficients of production function are significant and have a correct signs
absence of significant technical inefficiency, coefficients of production function are insignificant
MLE did not converge

Thus, in subsequent analysis, we will consider the following specifications of the SFA model with the Cobb-Douglas function and the half-normal distribution:

1) pooled regressions with heteroscedasticity (for both samples);
2) panel regressions:
   a) TI (for both samples);
   b) FE-2S (for sample "World");
   c) TFE (for sample "World").

The results of the panel regressions estimation are shown in Table 3. The coefficient for the log capital stock is sufficiently stable across models. On average, it is slightly larger than 0.5. The estimates of marginal product of labor (the coefficient for log employment) have larger variance, but for almost all of the models the estimate of marginal product of capital exceeds that of labor.

The estimates of log human capital index have the largest variance. In the TI model this coefficient for the sample "OECD-1990+Russia" is smaller than for the sample "World", however the intercept is larger. In the TFE model, a part of the human capital effect is passed to the fixed individual effects.

Standard deviation of error $u$ is significant in all models and exceeds standard deviation of error $v$, which means that productive inefficiency is detected for the countries and that it is necessary to take this component into account.

**Tab. 3. Results of panel regressions estimation, dependent variable is ln(GDP)**

| Explanatory variables | TI model, "World" | TI model, "OECD-1990+Russia" | FE-2S model, "World" | TFE model, "World" |
|---|---|---|---|---|
| ln(Capital) | 0.54*** | 0.50*** | 0.52*** | 0.56*** |
| | (0.02) | (0.04) | (0.02) | (0.02) |
| ln(Number of employed) | 0.36*** | 0.51*** | 0.43*** | 0.46*** |
| | (0.02) | (0.05) | (0.03) | (0.03) |
| ln(Human capital) | 0.83*** | 0.50*** | 0.80*** | 0.42*** |
| | (0.08) | (0.11) | (0.09) | (0.08) |
| Constant | 4.24*** | 4.80*** | 3.70*** | - |
| | (0.14) | (0.37) | (0.16) | - |
| $\sigma_u$ | 0.39*** | 0.21*** | 0.10*** | 0.17*** |
| | (0.05) | (0.04) | (0.01) | (0.01) |
| $\sigma_v$ | 0.11*** | 0.07*** | 0.08*** | 0.02*** |
| | (0.002) | (0.002) | (0.003) | (0.01) |
| Number of observations | 1430 | 484 | 1430 | 1430 |
| Number of countries | 65 | 22 | 65 | 65 |
| logL | 1010 | 580.2 | 1223 | 1332 |

*Note*. *, **, *** - estimate is significant at 10, 5, 1-% level, respectively. Standard errors of the estimated coefficients are in brackets.

Pooled regressions are estimated allowing for heteroscedasticity of error $u$. These models are estimated by means of three cycles described above (see Subsection 3.3.2).

Control variables were included in the cycle estimation by the groups of structural, institutional and infrastructural indicators (see Subsection 3.1).

In our models we use both the standard indicator of R&D intensity (ratio to GDP), and the indicator of "density" of R&D expenditures measured as mn USD per researcher. The latter serves as a proxy variable for the efficiency of funding channeled into R&D. This is borne out by the estimates for Spearman's rank correlation coefficients for estimated technical efficiency and business R&D expenditures being higher than the intensity measures for all models from Table 3 (see Table 4). The results are the same for estimated TFP (see Table 5).

**Tab. 4. Spearman correlations of panel regressions technical efficiency estimates and R&D expenditures indicators**

| R&D expenditures indicator | Model TI, "World" | Model TI, "OECD-1990+Russia" | Model FE-2S, "World" | Model TFE, "World" |
|---|---|---|---|---|
| Total R&D expenditures, % GDP | 0.18 | 0.14 | -0.02 | 0.16 |
| Business R&D expenditures, % GDP | 0.17 | 0.16 | 0.02 | 0.19 |
| Total R&D expenditures per 1 researcher, $M | 0.60 | 0.46 | -0.01 | 0.24 |
| Business R&D expenditures, $M | 0.49 | 0.42 | 0.03 | 0.25 |
| Number of observations | 380 | 281 | 380 | 380 |

**Tab. 5. Spearman correlations of panel regressions TFP estimates and R&D expenditures indicators**

| R&D expenditures indicator | Model TI, "World" | Model TI, "OECD-1990+Russia" | Model FE-2S, "World" | Model TFE, "World" |
|---|---|---|---|---|
| Total R&D expenditures, % GDP | 0.27 | 0.19 | 0.28 | 0.32 |
| Business R&D expenditures, % GDP | 0.23 | 0.17 | 0.25 | 0.29 |
| Total R&D expenditures per 1 researcher, $M | 0.46 | 0.48 | 0.48 | 0.56 |
| Business R&D expenditures, $M | 0.39 | 0.41 | 0.41 | 0.49 |
| Number of observations | 380 | 281 | 380 | 380 |

For the sake of comparability, R&D expenditures are expressed in constant prices and in terms of 2005 PPP. Only values of the deflator and PPP need to be known to measure the diminishing return effect of increased spending in current terms.

Both the intensity and the density of R&D expenditures measures were lagged in the models. For total R&D expenditures we used the fifth and the tenth lag terms while for business expenditures only the fifth lag term. This choice was made for several reasons:

1) R&D expenditures could affect productivity only after the full technology development cycle. This implies that the average number of years between R&D investments and real returns on such investments is about five years for business expenditures and about ten years for total expenditures, including government funding;
2) R&D expenditures variance is not large (to within several years);
3) the greatest robustness of results based on different specifications was observed in the fifth and the tenth lag terms;
4) lags of over ten years were not considered given the significantly smaller number of observations within the sample.

After the first two cycles (a), (b) and (c) were chosen out of the structural indicators, (a) out of the institutional ones, and (b), (k) and (l) out of the infrastructural ones (see Subsection 3.1). The percentage of men having survival to age sixty-five turned out to be significant in many models, but the sign of its impact on technical efficiency was unstable. The time series of Internet users has a considerable amount of omissions and a huge disparity in the distribution across countries, right up to the 2000s.

The estimation results of three chosen models are provided in Table 6. Coefficients of the production function differ substantially from the case of panel regressions. In Model 1 capital contributes the most to error variance; in Models 2 and 3 this refers to human capital, with capital being the last by marginal effects.

A negative sign of a parameter estimate in the equation of the logarithm of variance $u$ implies a positive influence on technical efficiency. R&D expenditures, merchandise trade as a share of GDP for the sample “OECD-1990+Russia”, the Economic Freedom Index and infrastructural indicators belong to such factors. An increase in the percentage of merchandise trade in GDP for the sample “World” has a negative impact on technical efficiency.

**Tab. 6. Results of pooled regressions estimation allowing for heteroscedasticity, dependent variable is ln(GDP)**

| Explanatory variable | Model 1, "World" | Model 2, "World" | Model 3, "OECD-1990+Russia" |
|---|---|---|---|
| ln(Capital) | 0.73*** | 0.29*** | 0.33*** |
| | (0.03) | (0.05) | (0.05) |
| ln(Number of employed) | 0.20*** | 0.64*** | 0.66*** |
| | (0.02) | (0.06) | (0.05) |
| ln(Human capital) | 0.16* | 1.22*** | 0.96*** |
| | (0.09) | (0.15) | (0.11) |
| Constant | 2.16*** | 6.34*** | 6.16*** |
| | (0.28) | (0.64) | (0.63) |
| $\ln\sigma_u^2$ | | | |
| Total R&D expenditures per researcher, 5 years lag | -11.11*** | - | - |
| | (3.01) | - | - |
| Business R&D expenditures per researcher, 5 years lag | - | -22.91*** | -39.21*** |
| | - | (6.11) | (7.52) |
| Merchandise trade, % GDP | 0.01*** | 0.04*** | -0.16*** |
| | (0.01) | (0.01) | (0.04) |
| Index of economic freedom | -1.43*** | -2.71*** | - |
| | (0.43) | (0.54) | - |
| Telephone lines | -0.048** | - | -0.16*** |
| | (0.02) | - | (0.04) |
| Adjusted roads density | - | -0.0008* | - |
| | - | (0.0004) | - |
| Constant | 7.55*** | 14.97*** | 12.36*** |
| | (2.60) | (3.47) | (2.76) |
| $\ln\sigma_v^2$ | | | |
| Constant | -3.37*** | -4.06*** | -4.66*** |
| | (0.09) | (0.12) | (0.13) |
| Number of observations | 401 | 223 | 185 |
| logL | 68.03 | 94.06 | 139.5 |

*Note*. *, **, *** - estimate is significant at 10, 5, 1-% level, respectively. Standard errors of the estimated coefficients are in brackets.

Based on the estimates of the production function coefficients of seven models from Table 3 and Table 4, we found TFP and technological component estimates. DEA of two samples supplement the obtained results with two additional country rankings. The estimates of technical efficiency and TFP obtained from various models and methods need to be verified for adequacy and compared to analogous estimates acquired in other studies.

## 4.2. Design and testing of adequacy criteria

We formulated several criteria to check the adequacy of the obtained estimates of technical efficiency and TFP:

1) significant correlation of estimates obtained using different specifications and methods;
2) similarity of country rankings based on our estimates and the estimates obtained in other studies;
3) correlation with other TFP estimates, namely the ones from OECD, PWT and the Conference Board databases.

The following specifications were verified:

- Models 1 and 2 (pooled regressions with heteroscedasticity, sample "World");
- Model 3 (pooled regression with heteroscedasticity, sample "OECD-1990+Russia");
- TI models (panel regressions with constant technical efficiency over time, samples "World" and "OECD-1990+Russia");
- FE-2S model (panel regression, sample "World");
- TFE model (panel regression, sample "World");
- DEA (samples "World" and "OECD-1990+Russia").

*4.2.1. Correlation of estimates across various models and methods*

The correlations of technical efficiency estimates from different SFA models and DEA are far from being large and positive across the board (see Appendix, Table 20). The estimates of panel regression models with fixed effects on the sample "World" – FE-2S and TFE – rarely correlated with other estimates, but they show a strong correlation among each other. Correlations among the vast majority of estimates are higher if the same sample is used.

Correlations among the technological component estimates are high (exceed 0.9) across different specifications of models and methods[13].

On the whole, TFP estimates are sufficiently robust and have a strong connection across all models and methods – all correlations are not less than 0.6 with the exception of Model 1 and DEA on the sample "World" – not less than 0.9 (see Appendix, Table 21). By all appearances, regardless of production function coefficients in different models the contributions of factors reallocate in the way that TFP estimates alter inconsiderably.

*4.2.2. Comparison of country rankings by the estimates obtained in other studies*

We parallel ten countries with the greatest technical efficiency from Model 1 on the sample "World" (see Table 7), which closely correlate with the ones from Model 2, and the ten most efficient countries within the framework of the three-factor production function introduced in the study of Mamonov and Pestova (2015).

[13] In purpose of brevity estimates are not adduced, the authors are ready to grant them on request.

Analogous comparisons for the sample “World” and other SFA models are not adduced, because in the TI model technical efficiency is assumed to be constant over time (this can distort ranking results for particular years); models with fixed effects generate rankings that are complex to interpret and are not linked with other models.

Comparing the data from Table 7 and Table 8 it is possible to note that in each period five or six countries steadily belong to the number of leaders in both researches. According to Table 7 Australia, Great Britain, Germany, Canada and the USA belonged to the ten most efficient countries in all periods, but according to Table 8, in place of Australia were the Netherlands and France in the same periods. In the first case, the USA is in the lead, in the second case Great Britain is the leader.

Russia’s position in the ranking by value of technical efficiency estimates is lower in our analysis. In this paper we use different data about capital and human capital (from the PWT database) than Mamonov and Pestova (2015). Moreover, the estimates of technical efficiency in Model 1 were found while allowing for heteroscedasticity.

**Tab. 7. The 10 most efficient countries by Model 1, sample "World"**

| № | 2000-2004 | | 2005-2009 | | 2010-2011 | |
|---|---|---|---|---|---|---|
| | Country | TE estimate | Country | TE estimate | Country | TE estimate |
| 1 | The USA | 0.996 | Switzerland | 0.994 | The USA | 0.990 |
| 2 | Switzerland | 0.995 | The USA | 0.993 | Germany | 0.986 |
| 3 | Kuwait | 0.993 | Germany | 0.987 | Canada | 0.983 |
| 4 | Great Britain | 0.990 | Canada | 0.986 | Australia | 0.982 |
| 5 | Canada | 0.988 | Great Britain | 0.985 | France | 0.980 |
| 6 | Germany | 0.987 | Kuwait | 0.984 | Japan | 0.980 |
| 7 | Denmark | 0.985 | Australia | 0.981 | Great Britain | 0.978 |
| 8 | Sweden | 0.984 | Sweden | 0.981 | Sweden | 0.976 |
| 9 | Australia | 0.981 | Ireland | 0.981 | Ireland | 0.974 |
| 10 | Austria | 0.980 | France | 0.980 | Korea | 0.972 |
| For reference: Russia | | | | | | |
| | 39 | 0.658 | 36 | 0.819 | 33 | 0.846 |

**Tab. 8. The 10 most efficient countries in the framework of three-factor production function**[14]

| Period | 1985-1989 | | 1990-1994 | | 1995-1999 | | 2000-2004 | | 2005-2009 | | 2010-2011 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Country | TE estimate | Country | TE estimate | Country | TE estimate | Country | TE estimate | Country | TE estimate | Country | TE estimate |
| 1 | The USA | 0.995 | The USA | 0.997 | The USA | 0.999 | Great Britain | 0.999 | Great Britain | 0.999 | Great Britain | 0.967 |
| 2 | Germany | 0.995 | Saudi Arabia | 0.951 | Great Britain | 0.994 | Canada | 0.986 | Canada | 0.938 | Singapore | 0.946 |
| 3 | Great Britain | 0.944 | Great Britain | 0.941 | Saudi Arabia | 0.965 | The USA | 0.985 | Сингапур | 0.925 | Saudi Arabia | 0.906 |
| 4 | France | 0.896 | Germany | 0.926 | Canada | 0.944 | France | 0.965 | Saudi Arabia | 0.924 | Hong Kong | 0.895 |
| 5 | Belgium | 0.895 | Belgium | 0.922 | France | 0.942 | Saudi Arabia | 0.943 | France | 0.918 | Canada | 0.880 |
| 6 | Canada | 0.887 | France | 0.911 | Belgium | 0.921 | Australia | 0.924 | The USA | 0.905 | The Netherlands | 0.861 |
| 7 | Australia | 0.886 | Canada | 0.888 | Germany | 0.917 | The Netherlands | 0.920 | The Netherlands | 0.898 | France | 0.856 |
| 8 | Greece | 0.873 | Italy | 0.880 | Italy | 0.917 | Belgium | 0.918 | Australia | 0.880 | The USA | 0.856 |
| 9 | The Netherlands | 0.845 | Australia | 0.877 | The Netherlands | 0.916 | Italy | 0.915 | Germany | 0.880 | Germany | 0.852 |
| 10 | Spain | 0.843 | The Netherlands | 0.875 | Australia | 0.906 | Germany | 0.905 | Hong Kong | 0.877 | Sweden | 0.837 |
| For reference: Russia | | | | | | | | | | | | |
| | n/a | n/a | 15 | 0.811 | 37 | 0.608 | 29 | 0.690 | 24 | 0.761 | 26 | 0.707 |

[14] Mamonov and Pestova (2015).

*4.2.3. Correlation of the obtained TFP estimates with the estimates from OECD, PWT and the Conference Board databases*

Many organizations provide TFP growth rate estimates obtained via various methods. We compare our estimates for both samples with those of OECD, PWT and the Conference Board databases (see Appendix, Table 22 and Table 23). By SFA we mean the estimates from Models 1 ("World") and 3 ("OECD-1990+Russia"). Correlations with the estimates obtained from other SFA models are equal to those given, up to the second decimal digit.

All the correlations are high with the rare exception of certain countries or columns (for example, China – the Conference Board, Spain – all providers, the US – OECD). The high consistency of the TFP estimates obtained and the estimates of other organizations is worth noting, as we perceive it to be a sign of adequacy for our estimates.

The growth rate dynamics of different TFP estimates for the USA and China is provided in Figure 1 and Figure 2. For the USA, despite low coefficients of correlation with the OECD estimates, the dynamics of various estimates is quite similar. The estimates of China's TFP growth rates from the Conference Board resemble the ones obtained in this study and by PWT only starting from 2004.

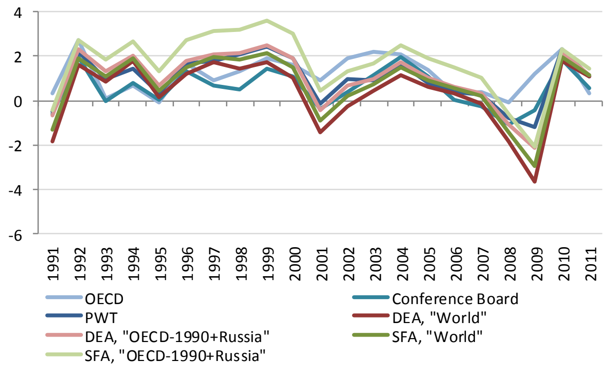


Fig. 1. The TFP growth rates in the USA

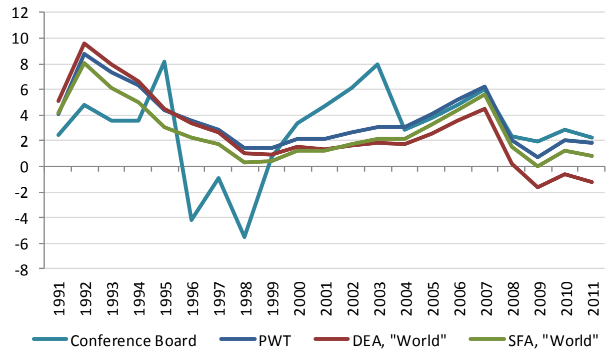


Fig. 2. The TFP growth rates in China

# 5. Estimating the impact of R&D expenditures on TFP growth decomposition

## 5.1. Modelling the effect of R&D expenditures on technology index

The technology index is defined by O'Donnell (2008) as the highest possible production value given the quantities of factors or, in the other words, the best available technology. Therefore, the dynamics of the technology index could be perceived as an indicator of the shift in the global technology frontier. As our global technology frontier estimates are largely based on the level of technological advancement in the US, this approach looks valid.

This subsection uses estimates of the trends associated with the technology index for those models that meet the economic adequacy criteria as stated in Subsection 4.2.

We follow a creative destruction paradigm assuming that the phase of the economic cycle depends on the change in the production possibility frontier. Thus, modelling the technology index should be done with the objective of separating the effects of the global economic cycle (based on the US economic cycle) from the effects of technology advancement. In addition, we assume that the global technology frontier, unlike national ones, depends on fundamental research results and thus implies a greater effect of government versus business R&D expenditures.

Therefore, the following factors were selected for modelling the technology index:

- US R&D expenditures intensity (amounts spent over GDP, %);
- US output gap (% of potential GDP);
- world economy growth rates, %.

Judging from the correlations (see Table 9), the most obvious connection is observed with the ninth lag term in government spending while specifications use both the ninth and the tenth lag terms. Thus, the effect of increased R&D expenditures may transfer into TFP growth with a ten-year lag. The correlation between the factors is sufficiently low: in particular, the correlation between the US output gap and the world economy growth rate is -0.1.

**Tab. 9. Correlations of factors for technology index models**

| Exogenous variable | Gov. R&D expenditures, 9 years lag, % GDP | Gov. R&D expenditures, 10 years lag, % GDP | World economic growth rates | Output gap 1 year lag, % potential GDP |
|---|---|---|---|---|
| Government R&D expenditures, 9 years lag, % GDP | 1 | | | |
| Government R&D expenditures, 10 years lag, % GDP | 0.92 | 1 | | |
| World economic growth rates | -0.09 | -0.04 | 1 | |
| Output gap 1 year lag, % potential GDP | 0.45 | 0.57 | -0.11 | 1 |

Regressions were evaluated for specifications with the above factors, and the coefficients are shown in Table 10 and Table 11. Regression errors are stationary. The robustness of this result was verified by adding individual control variables to the regression (see Table 12 and Table 13). This did not change the coefficients' signs and magnitude, which indicates the robustness to a choice of control variables. Almost all the regressions are characterized by a high coefficient of determination, even taking into account the small number of observations, which is evidence of a good sample fit, especially along with the weak correlation between the regressors.

The estimation results outline a significant effect of all the regressors used on the dependent variables for all the models considered. An increase of 1% of GDP in US government R&D expenditures in ten years increases the growth rates of the technology index by 7.5-8.5 percentage points. At the same time, the economic cycle has a significant effect on the global technology frontier: an acceleration in the growth of the global economy by 1 percentage point hastens growth in the technology index by 0.7 percentage points whereas an increase in the US output gap by 1% of the potential GDP causes the technology measure to grow by 0.2 percentage points.

**Tab. 10. Estimation results for different technology index estimates and government R&D expenditures, 10 years lag, % GDP**

| Exogenous variables | Model 1, "World" | Model 2, "World" | Model 3, "OECD-1990+Russia" | Model TI, "World" | Model TI, "OECD-1990+Russia" | Model FE-2S, 'World" | Model TFE, "World" | DEA, "World" | DEA, "OECD-1990+Russia" |
|---|---|---|---|---|---|---|---|---|---|
| Government R&D expenditures, 10 years lag, % GDP | 7.37*** | 8.67*** | 8.43*** | 8.40*** | 7.92*** | 8.33*** | 7.79*** | 7.37*** | 7.50*** |
| | (0.94) | (1.23) | (1.21) | (1.13) | (1.12) | (1.13) | (1.08) | (0.95) | (1.06) |
| World economic growth rates | 0.73*** | 0.75*** | 0.71*** | 0.78*** | 0.68*** | 0.76*** | 0.69*** | 0.82*** | 0.62*** |
| | (0.05) | (0.06) | (0.06) | (0.06) | (0.06) | (0.06) | (0.06) | (0.05) | (0.05) |
| Output gap 1 year lag, % potential GDP | -0.29*** | -0.18*** | -0.19*** | -0.21*** | -0.23*** | -0.21*** | -0.24*** | -0.32*** | -0.27*** |
| | (0.04) | (0.05) | (0.05) | (0.05) | (0.05) | (0.05) | (0.05) | (0.04) | (0.05) |
| Constant | -9.69*** | -9.87*** | -9.56*** | -10.1*** | -9.32*** | -9.91*** | -9.33*** | -10.4*** | -9.05*** |
| | (0.91) | (1.19) | (1.18) | (1.10) | (1.09) | (1.10) | (1.05) | (0.93) | (1.03) |
| Number of observations | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 12 |
| R-squared | 0.97 | 0.96 | 0.96 | 0.97 | 0.96 | 0.97 | 0.96 | 0.98 | 0.96 |

*Note*. *, **, *** - estimate is significant at 10, 5, 1-% level, respectively. Standard errors of the estimated coefficients are in brackets.

**Tab. 11. Estimation results for different technology index estimates and government R&D expenditures, 9 years lag, % GDP**

| Exogenous variables | Model 1, "World" | Model 2, "World" | Model 3, "OECD-1990+Russia" | Model TI, "World" | Model TI, "OECD-1990+Russia" | Model FE-2S, 'World" | Model TFE, "World" | DEA, "World" | DEA, "OECD-1990+Russia" |
|---|---|---|---|---|---|---|---|---|---|
| Government R&D expenditures, 9 years lag, % GDP | 8.77*** | 10.00*** | 9.72*** | 9.79*** | 9.22*** | 9.69*** | 9.10*** | 8.90*** | 8.79*** |
| | (1.75) | (2.05) | (2.00) | (1.98) | (1.89) | (1.96) | (1.85) | (1.76) | (1.76) |
| World economic growth rates | 0.74*** | 0.76*** | 0.72*** | 0.79*** | 0.69*** | 0.77*** | 0.69*** | 0.82*** | 0.63*** |
| | (0.10) | (0.12) | (0.11) | (0.11) | (0.11) | (0.11) | (0.10) | (0.10) | (0.10) |
| Output gap 1 year lag, % potential GDP | -0.18** | -0.05 | -0.07 | -0.08 | -0.11 | -0.09 | -0.13 | -0.21** | -0.16** |
| | (0.07) | (0.08) | (0.08) | (0.08) | (0.08) | (0.08) | (0.07) | (0.07) | (0.07) |
| Constant | -10.7*** | -10.8*** | -10.5*** | -11.1*** | -10.2*** | -10.9*** | -10.3*** | -11.5*** | -9.97*** |
| | (1.71) | (2.01) | (1.96) | (1.94) | (1.85) | (1.92) | (1.81) | (1.72) | (1.73) |
| Number of observations | 13 | 13 | 13 | 13 | 13 | 13 | 13 | 13 | 13 |
| R-squared | 0.90 | 0.88 | 0.87 | 0.89 | 0.87 | 0.88 | 0.88 | 0.91 | 0.87 |

*Note*. *, **, *** - estimate is significant at 10, 5, 1-% level, respectively. Standard errors of the estimated coefficients are in brackets.

**Tab. 12. Robustness check of estimation results for different technology index estimates and government R&D expenditures, 10 years lag, % GDP**

| Exogenous variables | Model 1, "World" | Model 1, "World" | Model 1, "World" | Model 2, "World" | Model 2, "World" | Model 2, "World" | Model 3, "OECD-1990 +Russia" | Model 3, "OECD-1990 +Russia" | Model 3, "OECD-1990 +Russia" |
|---|---|---|---|---|---|---|---|---|---|
| Government R&D expenditures, 10 years lag, % GDP | 3.04 | 3.48 | 7.37*** | 5.85 | 6.30*** | 8.67*** | 5.45 | 5.87*** | 8.43*** |
| | (4.15) | (2.00) | (0.94) | (4.03) | (1.48) | (1.23) | (3.87) | (1.54) | (1.21) |
| World economic growth rates | - | 0.74*** | 0.73*** | - | 0.75*** | 0.75*** | - | 0.71*** | 0.71*** |
| | - | (0.13) | (0.05) | - | (0.09) | (0.06) | - | (0.10) | (0.06) |
| Output gap 1 year lag, % potential GDP | - | - | -0.29*** | - | - | -0.18*** | - | - | -0.19*** |
| | - | - | (0.04) | - | - | (0.05) | - | - | (0.05) |
| Constant | -2.49 | -5.85** | -9.69*** | -4.09 | -7.54*** | -9.87*** | -3.79 | -7.05*** | -9.56*** |
| | (3.83) | (1.93) | (0.91) | (3.72) | (1.43) | (1.19) | (3.57) | (1.49) | (1.18) |
| Number of observations | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 12 |
| R-squared | 0.05 | 0.80 | 0.97 | 0.17 | 0.90 | 0.96 | 0.17 | 0.88 | 0.96 |

*Note*. *, **, *** - estimate is significant at 10, 5, 1-% level, respectively. Standard errors of the estimated coefficients are in brackets.

**Tab. 13. Robustness check of estimation results for different technology index estimates and government R&D expenditures, 10 years lag, % GDP**

| Exogenous variables | Model 1, "World" | Model 1, "World" | Model 1, "World" | Model 2, "World" | Model 2, "World" | Model 2, "World" | Model 3, "OECD-1990 +Russia" | Model 3, "OECD-1990 +Russia" | Model 3, "OECD-1990 +Russia" |
|---|---|---|---|---|---|---|---|---|---|
| Government R&D expenditures, 9 years lag, % GDP | 5.66 | 6.74*** | 8.77*** | 8.33* | 9.44*** | 10.00*** | 7.92* | 8.97*** | 9.72*** |
| | (3.99) | (1.95) | (1.75) | (3.99) | (1.77) | (2.05) | (3.82) | (1.76) | (2.00) |
| World economic growth rates | - | 0.74*** | 0.74*** | - | 0.76*** | 0.76*** | - | 0.72*** | 0.72*** |
| | - | (0.12) | (0.10) | - | (0.11) | (0.12) | - | (0.11) | (0.11) |
| Output gap 1 year lag, % potential GDP | - | - | -0.18** | - | - | -0.05 | - | - | -0.07 |
| | - | - | (0.07) | - | - | (0.08) | - | - | (0.08) |
| Constant | -4.75 | -8.70*** | -10.7*** | -6.19 | -10.2*** | -10.8*** | -5.88 | -9.72*** | -10.5*** |
| | (3.69) | (1.91) | (1.71) | (3.69) | (1.73) | (2.01) | (3.53) | (1.72) | (1.96) |
| Number of observations | 13 | 13 | 13 | 13 | 13 | 13 | 13 | 13 | 13 |
| R-squared | 0.15 | 0.82 | 0.90 | 0.28 | 0.87 | 0.88 | 0.28 | 0.86 | 0.87 |

*Note*. *, **, *** - estimate is significant at 10, 5, 1-% level, respectively. Standard errors of the estimated coefficients are in brackets.

Therefore, the global technology frontier trend depends both on the change in R&D expenditures and the effects of the economic cycle, including changes in the global economy. In particular, results are consistent with the creative destruction hypothesis, and technological development rises as recession deepens. The technology frontier shifts faster as the global economy expands, hi-tech markets grow, and, probably, as US government spends more on R&D (which could be seen a proxy for developed countries' R&D spending).

## 5.2. Modeling the effect of R&D expenditures on technical efficiency

In this section, we proceed to the second stage: modelling the relationships between previously obtained TFP growth and technical efficiency estimates, on one hand, and, on the other hand, R&D expenditures measures (as % of GDP or per researcher in $M) in the presence of a number of control variables. The procedure is described in Subsection 3.3.2.

Subsection 3.2 above identifies three groups of models as a function of the method used to model technical efficiency estimates (see Subsection 4.1, Table 3 and Table 4):

1) Models 1, 2, and 3 (pooled regressions) help model the variance of an individual error $u$;
2) time-constant technical efficiency for TI models was modeled in its levels;
3) for FE-2S and TFE models as well as the DEA method, models were built for the growth rates of technical efficiency estimates because of the integrated nature of the first-order series.

Let us look at each of these subgroups in greater detail.

### *5.2.1. Models accounting for heteroscedasticity*

Subsection 3.3.2 described a procedure to evaluate and select the best models taking account of heteroscedasticity. Cycle three evaluations were used to select the best specification for each R&D expenditures measure provided the evaluation process converged and the model contained a minimum of two control variables.

Table 4 (see Subsection 4.1) shows the resulting estimates of the coefficients of the production function for the selected models based on the two samples. Marginal effects were evaluated to analyze the effect of the various factors (including R&D expenditures) on the inefficiency component $u$ (see Table 14).

It should be noted that the negative sign of the marginal effect resulting from a factor corresponds to lower inefficiency and is interpreted as an indication that the factor in question has a positive effect on efficiency.

As stated previously, it is expected in models of this type that the index of economic freedom, regarded as an indicator of the level of a country's institutional development, has a positive effect on technical efficiency. Increasing infrastructure measures (telephone lines and adjusted road density) should also be conducive to a more efficient use of the factors of production.

The merchandise trade ratio has a stable negative sign for its effect on technical efficiency in the sample “World” whereas for the sample “OECD-1990+Russia” the sign is positive. It is possible that for countries less developed than those in the OECD, the distortion was introduced by the greater GDP contribution of foreign trade in raw materials.

The measures of business R&D expenditures per researcher have a positive effect on technical efficiency. At the same time, if one were to compare Models 1 and 2, the effect of business expenditures is somewhat more pronounced than total expenditures, and if one were to compare Models 2 and 3, the average effect of business expenditures is greater for the sample “OECD-1990+Russia” than for the sample “World”.[15]

**Tab. 14. Average marginal effects of factors on inefficiency component $u$ in pooled regressions with heteroscedasticity**

| Exogenous variables | Model 1, “World” | Model 2, “World” | Model 3, “OECD-1990+Russia” |
|---|---|---|---|
| Total R&D expenditures per 1 researcher, 5 years lag, \$M | -0.37 | - | - |
| | (0.31) | - | - |
| Business R&D expenditures per 1 researcher, 5 years lag, \$M | - | -0.41 | -0.50 |
| | - | (0.39) | (0.63) |
| Merchandise trade, % of GDP | 0.0005 | 0.0007 | -0.002 |
| | (0.0004) | (0.0007) | -0.003 |
| Index of economic freedom | -0.05 | -0.05 | - |
| | (0.04) | (0.05) | - |
| Telephone lines | -0.002 | - | -0.002 |
| | (0.001) | - | (0.003) |
| Adjusted road and railway density | - | -0.00001 | - |
| | - | (0.00001) | - |
| Number of observations | 401 | 223 | 185 |

*Note*. Standard errors of the estimated coefficients are in brackets.

Table 14 presents the values of the mean marginal effects; however the issue of their breakdown per country is of equal importance, and in particular, what would happen if R&D expenditures per researcher were increased considerably in countries where it is already high. Figure 3, Figure 4, and Figure 5 show the relationships between the marginal effects and the R&D expenditures measures for Models 1, 2, and 3. With the exception of several observations,

[15] These observed effects may also result from differences in the specifications and the number of observations.

marginal effects are reduced with higher spending which is consistent with the law of diminishing marginal returns.

Figure 5 shows a considerable number of observations with business R&D expenditures of at least $0.1 million per researcher which fall in an area of near-zero marginal effects. In other words, many countries in the sample "OECD-1990+Russia" (such as, Belgium, Germany, and the Netherlands in 2001-2011) found it impossible to increase technical efficiency with respect to other nations by increasing business R&D expenditures per researcher.

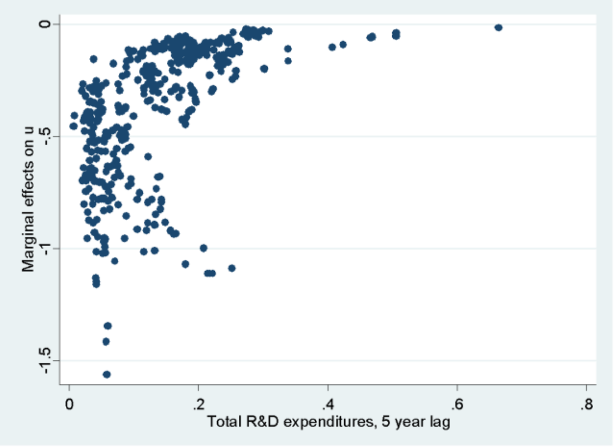


Fig. 3. Marginal effects for Model 1, sample "World"

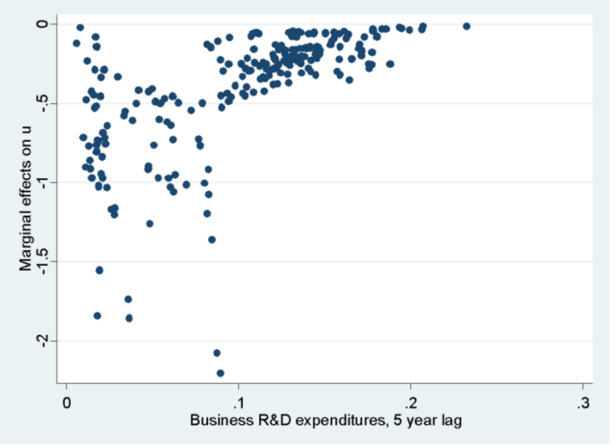


Fig. 4. Marginal effects for Model 2, sample "World"

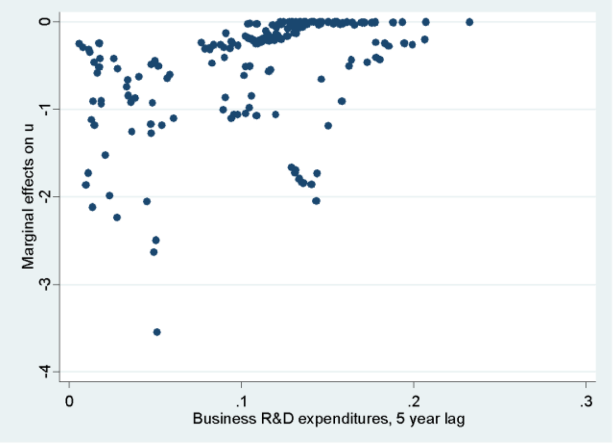


Fig. 5. Marginal effects for Model 3, sample "OECD-1990+Russia"

*5.2.2. Models with Time-Invariant technical efficiency*

An estimation of TI models for the two samples (see Table 3) was utilized to model technical efficiency indices. The procedure for building and selecting the most appropriate models is similar to that presented in the previous section and is described in Subsection 3.3.2. Initially, a cycle with a single independent variable was evaluated, then two independent variables: the R&D expenditures measure and one control variable. The final models were selected from a cycle with four explanatory variables: R&D expenditures and three control variables from three different groups. The collection of parameters was left unchanged.

The estimation used conventional least squares regression because the model specification does not provide for individual effects (technical efficiency does not change over time). Dependent variable lag is excluded from the models for the same reason.

Estimation results for the selected models are shown in Table 15. The specifications are similar to those developed when modeling the variance of the inefficiency component. For the sample “World”, the TI-2 model is identical to Model 2 from Table 14 whereas the others (TI-1 and TI-3) use the same control variables as TI-2 but different expenditures measures. For the sample “OECD-1990+Russia”, the TI-4 model is identical to TI-3 with business R&D expenditures.

The parameter estimate of the economic freedom index is stable for models based on the sample “World” whereas for the sample “OECD-1990+Russia”, the value of the coefficient is double: apparently, the level of institutional development in the various countries has a strong effect on the allocative efficiency of resources.

The coefficient in front of the infrastructure terms is also higher for “OECD-1990+Russia”, although it would have been logical to expect the reverse when using telephone lines. They may be a proxy variable for another infrastructural measure that has a significant effect on efficiency.

The same result as in the previous section was obtained for both the samples for the variable representing merchandise trade (as a percentage of GDP).

As in the case of models with heteroscedasticity, R&D expenditures intensity measures (as a percentage of GDP) are less explanatory for countries' technical efficiency than the retained business R&D expenditures per researcher. Total R&D expenditures per researcher with lags of five and ten years and business expenditures with a five-year lag proved to be significant for the sample “World”. Only business expenditures were found to be significant for “OECD-1990+Russia”.

The coefficients in front of R&D expenditures are higher for the sample “World”. The result is the reverse of the result in Table 14 but correlates well with Figure 3-Figure 5: the sample “OECD-1990+Russia” contains a greater proportion of observations with near-zero marginal effects related to R&D expenditures returns than the sample “World”.

The value of the coefficient in front of the spending term in the sample “World” models, frequently greater than one, may appear paradoxical. Indeed, it implies that increasing R&D expenditures per researcher by $1 million would lead to the technical efficiency index incrementing by one while the technical efficiency measure itself falls in the interval between zero and one. However, it should be noted that the sample level of R&D expenditures per researcher is under $700,000; therefore, in practical terms, variations of a much smaller magnitude are to be estimated.

**Tab. 15. Results of technical efficiency model estimations, model TI estimates**

| Exogenous variables | TI-1, "World" | TI-2, "World" | TI-3, "World" | TI-4, "OECD-1990+Russia" |
|---|---|---|---|---|
| Total R&D expenditures per 1 researcher, 10 years lag, $M | 1.02*** | - | - | - |
| | (0.08) | - | - | - |
| Total R&D expenditures per 1 researcher, 5 years lag, $M | - | 1.07*** | - | - |
| | - | (0.07) | - | - |
| Business R&D expenditures per 1 researcher, 5 years lag, $M | - | - | 0.94*** | 0.38** |
| | - | - | (0.17) | (0.17) |
| Merchandise trade, % of GDP | -0.001*** | -0.001*** | -0.001*** | 0.001*** |
| | (0.0002) | (0.0001) | (0.0002) | (0.0002) |
| Index of economic freedom | 0.05*** | 0.04*** | 0.04*** | 0.09*** |
| | (0.02) | (0.01) | (0.02) | (0.02) |
| Telephone lines | 0.001** | 0.001*** | 0.001* | 0.002** |
| | (0.0006) | (0.0004) | (0.0007) | (0.0008) |
| Constant | 0.10 | 0.18*** | 0.21** | -0.19* |

*Note*. *, **, *** - estimate is significant at 10, 5, 1-% level, respectively. Standard errors of the estimated coefficients are in brackets.

*5.2.3. Modeling estimated technical efficiency growth rates*

Estimates of the production function for the FE-2S and TFE models as well as the DEA method were used to build regressions for estimated technical efficiency growth rates. The Dickey-Fuller test for the level of error pointed to the integrated nature of first-order series. Following an adjustment for non-stationarity, a procedure was also utilized that was similar to that in the previous two sections and is described in Subsection 3.3.2: the best models were selected following three cycles (see Table 16).

The procedure did not result in the selection of significant models for the DEA method. This method was used in the initial stage of the project whose results served as basis for subsequent analysis. Unfortunately, technical efficiency estimates produced by DEA turned out to be unstable in the face of the data which is an argument in favor of using SFA.

During the selection of an estimation method, tests indicated that there were no random individual effects but there were fixed ones. Alongside the R&D expenditures measure and the control variables, the model included both the dependent variable and the technical efficiency level with a one-year lag. Both the variables proved to be significant. The coefficient in front of the TE index with lag is negative which is an indication that countries are $\beta$-convergent in technical efficiency.

Estimate specifications for the FE-2S and TFE models with respect to the R&D expenditures measure and the control variables are similar to Model 1 from Table 14 and Model TI-2 from Table 15. At the same time, when explanatory variables are added to the models in a step-wise manner, the coefficients are relatively stable for the same dependent variable but differ significantly for FE-2S and TFE.

Estimated R&D expenditures parameters and control variables for the TFE models are approximately three times those for FE-2S. At the same time, all the control variables have a positive effect on the growth rates of estimated technical efficiency.

For all models, only the total R&D expenditures per researcher with a five-year lag proved significant (sample “World”). For FE-2S models, as the spending value increases by $1,000, the technical efficiency growth rate will gain 0.005 percentage points whereas for TFE models, the gain is 0.013 percentage points.

**Tab. 16. Results of technical efficiency growth rate model estimations, models FE-2S and TFE estimates, sample "World"**

| Exogenous variables | Model FE-2S-1 | Model FE-2S-2 | Model FE-2S-3 | Model FE-2S-4 | Model TFE-1 | Model TFE -2 | Model TFE -3 | Model TFE -4 |
|---|---|---|---|---|---|---|---|---|
| Total R&D expenditures per 1 researcher, 5 years lag, $M | 4.68*** | 5.02*** | 5.03*** | 4.67*** | 12.63*** | 13.83*** | 14.07*** | 12.99*** |
| | (1.78) | (1.75) | (1.74) | (1.73) | (4.77) | (4.69) | (4.64) | (4.59) |
| Merchandise trade, % of GDP | - | 0.02*** | 0.02*** | 0.02*** | - | 0.05*** | 0.05*** | 0.06*** |
| | - | (0.01) | (0.01) | (0.01) | - | (0.01) | (0.01) | (0.01) |
| Index of economic freedom | - | - | 0.50*** | 0.51*** | - | - | 1.43*** | 1.42*** |
| | - | - | (0.19) | (0.18) | - | - | (0.49) | (0.48) |
| Telephone lines | - | - | - | 0.03*** | - | - | - | 0.09*** |
| | - | - | - | (0.01) | - | - | - | (0.03) |
| Technical efficiency growth rates, 1 year lag | 0.18*** | 0.18*** | 0.21*** | 0.20*** | 0.24*** | 0.23*** | 0.26*** | 0.24*** |
| | (0.05) | (0.05) | (0.05) | (0.05) | (0.05) | (0.05) | (0.05) | (0.05) |
| Technical efficiency index, 1 year lag | -20.92*** | -22.77*** | -26.86*** | -27.86*** | -18.72*** | -21.13*** | -25.06*** | -26.03*** |
| | (2.71) | (2.71) | (3.09) | (3.08) | (2.44) | (2.47) | (2.79) | (2.77) |
| Constant | 18.88*** | 19.44*** | 19.76*** | 19.53*** | 15.46*** | 14.07*** | 7.592** | 4.792 |
| | (2.53) | (2.50) | (2.48) | (2.46) | (2.29) | (2.27) | (3.16) | (3.24) |
| Number of observations | 401 | 401 | 401 | 401 | 401 | 401 | 401 | 401 |
| R-squared | 0.18 | 0.21 | 0.22 | 0.24 | 0.19 | 0.23 | 0.24 | 0.27 |
| Number of countries | 51 | 51 | 51 | 51 | 51 | 51 | 51 | 51 |

*Note*. *, **, *** - estimate is significant at 10, 5, 1-% level, respectively. Standard errors of the estimated coefficients are in brackets.

## 5.3. Modelling the effect of R&D expenditures on TFP growth rates

TFP estimates from different models proved to be highly correlated (see Table 5). TFP growth rates were also modeled using the three cycles. As far as this indicator is concerned, models that have a stable specification in either sample for TFP estimates obtained in the previous phase of the analysis were selected (see Subsection 3.3.2).

Dependent variable and TFP level lags were included in the models alongside the R&D expenditures measure and control variables. For most of the final specifications, only the TFP level lag proved significant. Moreover, its coefficient is negative, which is further evidence in favor of the converging economic development hypothesis in TFP this time.

Based on the outcome of the Hausman test, fixed individual effects were included when modeling TFP growth rates. The results based on stable specifications for the two samples (six individual TFP estimates for the sample "World" and three for "OECD-1990+Russia") are shown in Table 17.

In the case of TFP estimates unlike those of technical efficiency, there is no reason to suppose that business R&D expenditures per researcher are more explanatory of TFP growth rates than the intensity metric (% GDP). However, there are individual indicators associated with both the dependent variable types for which stable specifications have not been identified (highlighted in red in Table 17).

Most of the models selected contain only two control variables (a structural indicator and an institutional development one were the most often used). All of the resulting estimates are not shown. For a sample comparison, identical specifications were selected containing total R&D expenditures (as a % of GDP) with a ten-year lag, whereas the comparison with Table 16 used specifications with total R&D expenditures per researcher with a five-year lag (the models selected are highlighted in green).

**Tab. 17. Results of TFP growth rate model estimations for two samples**

| R&D expenditures indicator | "World" | | | "OECD-1990+Russia" | | |
|---|---|---|---|---|---|---|
| | struct. indic. | ind. of ec. fr. | infrastr. indic. | struct. indic. | ind. of ec. fr. | infrastr. indic. |
| Total R&D expenditures, 10 years lag, % GDP | 1 | + | | 1 | + | |
| | 2 | + | | | | |
| Total R&D expenditures, 5 years lag, % GDP | | | | 1 | + | |
| Business R&D expenditures, % GDP | 2 | + | | | | |
| Total R&D expenditures per 1 researcher, 10 years lag, $M | | | | 1 | + | 4 |
| Total R&D expenditures per 1 researcher, 5 years lag, $M | 1 | + | | 2 | + | |
| | 2 | | 3 | | | |
| Business R&D expenditures per 1 researcher, 5 years lag, $M | | | | | | |

*Note.* 1 – manufacturing value added, % of GDP, 2 – merchandise trade, % of GDP, 3 – telephone lines, 4 – adjusted roads and railways density.

Estimates from the models selected from Table 17 are shown in Table 18 and Table 19.

It follows from Table 18 that the manufacturing value added (% GDP) contribution has a larger positive effect on TFP growth rates for the sample "OECD-1990+Russia" than for the sample "World" (the difference in the marginal effects is about 0.5 percentage points). The situation with the economic freedom index is the same.

Total R&D expenditures (as % GDP) with a ten-year lag also, on average, have a larger coefficient in models associated with the "OECD-1990+Russia" sample than with the "World". On average, a 1.0 percentage point increase in spending results in a 7.7 percentage point increase in TFP growth rates for the "OECD-1990+Russia" sample (countries and three models). Coefficients in the six models associated with the "World" sample have greater variance with the mean of the marginal effect standing at 5.0 percentage points.

All estimated control variable parameters in Table 19 have a positive sign. And again, the control variable representing merchandise trade as a percentage of GDP has a larger coefficient in models associated with the "OECD-1990+Russia" sample (on average, twice that of the "World" sample). At the same time, if one were to make a comparison with the results presented in Table 16, an increase in the share of merchandise trade has a greater effect on TFP growth rates than on technical efficiency growth. The estimates obtained are not sufficient to make conclusions with respect to the nature of the effect associated with the infrastructure indicator. Neither does it appear possible to compare the various other coefficients in front of the control variables, either by sample or by table.

Total R&D expenditures per researcher with a five-year lag have a greater effect on efficiency growth rates in the "OECD-1990+Russia" countries than in those included in the

"World" sample. The mean marginal effect based on the models is 0.025 percentage points for every $1,000 per researcher whereas for the "World" sample, it is only 0.013 percentage points for every $1,000 per researcher.

It should be noted that the models associated with the "OECD-1990+Russia" sample explain most of the variance in the dependent variable (about two thirds for R&D expenditures intensity and one third for business R&D expenditures) given the greater uniformity of the countries included in the sample with respect to those in the "World" sample (about one third for R&D expenditures intensity and some 10% for business R&D expenditures).

More heterogeneous development level indicators will likely have to be taken into account in the future to explain TFP growth in other countries.

**Tab. 18. Results of TFP growth rate model estimations and government R&D expenditures, 10 years lag, % GDP**

| Exogenous variables | Model 1, "World" | Model 2, "World" | Model 3, "OECD-1990+Russia" | Model TI, "World" | Model TI, "OECD-1990+Russia" | Model FE-2S, "World" | Model TFE, "World" | DEA, "World" | DEA, "OECD-1990+Russia" |
|---|---|---|---|---|---|---|---|---|---|
| Total R&D expenditures, 10 years lag, % GDP | 3.06* | 6.20*** | 7.69*** | 6.04*** | 6.98*** | 5.94*** | 4.70*** | 4.30** | 8.00*** |
| | (1.82) | (2.00) | (1.96) | (1.96) | (1.78) | (1.94) | (1.80) | (2.00) | (2.01) |
| Manufacturing value added, % of GDP | 1.06*** | 1.16*** | 1.52*** | 1.16*** | 1.59*** | 1.14*** | 1.03*** | 1.10*** | 1.61*** |
| | (0.16) | (0.18) | (0.22) | (0.18) | (0.20) | (0.17) | (0.16) | (0.18) | (0.23) |
| Index of economic freedom | 3.89*** | 3.34** | 4.67*** | 3.53** | 5.39*** | 3.36** | 3.05** | 4.94*** | 6.23*** |
| | (1.39) | (1.50) | (1.55) | (1.48) | (1.43) | (1.46) | (1.37) | (1.52) | (1.62) |
| TFP level, 1 year lag | -1.61*** | -0.0004*** | -0.003*** | -0.006*** | -0.03*** | -0.01*** | -0.04*** | -90.65*** | -102.2*** |
| | (0.25) | (0.0001) | (0.0004) | (0.001) | (0.004) | (0.001) | (0.01) | (13.81) | (13.92) |
| Constant | -16.45 | -40.22*** | -13.99 | -36.19*** | -11.62 | -33.52*** | -15.51 | -24.56* | -30.29** |
| | (11.26) | (11.76) | (14.39) | (11.71) | (12.72) | (11.63) | (11.33) | (12.69) | (14.09) |
| Number of observations | 229 | 229 | 109 | 229 | 109 | 229 | 229 | 229 | 109 |
| R-squared | 0.37 | 0.27 | 0.64 | 0.30 | 0.69 | 0.31 | 0.36 | 0.38 | 0.65 |
| Number of countries | 48 | 48 | 22 | 48 | 22 | 48 | 48 | 48 | 22 |

*Note*. *, **, *** - estimate is significant at 10, 5, 1-% level, respectively. Standard errors of the estimated coefficients are in brackets.

**Tab. 19. Results of TFP growth rate model estimations and government R&D expenditures per 1 researcher, 5 years lag, $M**

| Exogenous variables | Model 1, "World" | Model 2, "World" | Model 3, "OECD-1990+Russia" | Model TI, "World" | Model TI, "OECD-1990+Russia" | Model FE-2S, "World" | Model TFE, "World" | DEA, "World" | DEA, "OECD-1990+Russia" |
|---|---|---|---|---|---|---|---|---|---|
| Total R&D expenditures per 1 researcher, 5 years lag, $M | 14.10*** | 13.73** | 25.97** | 14.16** | 25.04** | 13.86** | 12.58** | 10.55* | 24.01* |
| | (5.38) | (5.93) | (13.09) | (5.86) | (12.23) | (5.81) | (5.49) | (6.08) | (12.69) |
| Merchandise trade, % of GDP | 0.07*** | 0.06*** | 0.14*** | 0.06*** | 0.14*** | 0.06*** | 0.07*** | 0.08*** | 0.16*** |
| | (0.02) | (0.02) | (0.03) | (0.02) | (0.03) | (0.02) | (0.02) | (0.02) | (0.03) |
| Index of economic freedom | - | - | 3.16*** | - | 4.05*** | - | - | - | 4.98*** |
| | - | - | (0.73) | - | (0.72) | - | - | - | (0.77) |
| Telephone lines | 0.10*** | 0.08** | - | 0.08** | - | 0.07** | 0.07** | 0.07* | - |
| | (0.03) | (0.04) | - | (0.04) | - | (0.04) | (0.03) | (0.04) | - |
| TFP growth rates, 1 year lag | 0.22*** | 0.14*** | - | 0.14*** | - | 0.14*** | 0.15*** | 0.18*** | - |
| | (0.05) | (0.05) | - | (0.05) | - | (0.05) | (0.05) | (0.05) | - |
| TFP level, 1 year lag | -0.93*** | -0.0001*** | -0.001*** | -0.002*** | -0.02*** | -0.002*** | -0.02*** | -37.26*** | -54.01*** |
| | (0.12) | (0.00005) | (0.0002) | (0.001) | (0.002) | (0.001) | (0.003) | (6.15) | (6.38) |
| Constant | 9.23*** | -3.48 | -14.95** | -1.70 | -12.13** | -1.05 | 5.74** | 5.40* | -21.69*** |
| | (2.75) | (2.28) | (6.25) | (2.39) | (5.80) | (2.42) | (2.67) | (2.98) | (5.95) |
| Number of observations | 401 | 401 | 201 | 401 | 201 | 401 | 401 | 401 | 201 |
| R-squared | 0.22 | 0.10 | 0.28 | 0.12 | 0.35 | 0.12 | 0.17 | 0.18 | 0.37 |
| Number of countries | 51 | 51 | 22 | 51 | 22 | 51 | 51 | 51 | 22 |

*Note*. *, **, *** - estimate is significant at 10, 5, 1-% level, respectively. Standard errors of the estimated coefficients are in brackets.

## 6. Conclusion

This study estimates the impact of R&D spending on productivity in the two-sample country group framework of productive efficiency. We can sum up our results as follows.

First, we obtained the estimates of TFP decomposition into the technology index, technical efficiency, and the rest, for the largest global economies. The TFP estimates conform to the designed adequacy criteria, including high correlation with the estimates obtained in other studies. The technology index, which is our estimate of the global technological frontier, has similar dynamics over both samples used, as do technical efficiencies, country-wise.

Second, our estimates indicate that lagged R&D expenditures significantly impact on productivity. US government R&D expenditures lagged ten years significantly impact the technology index, as well as the US output gap. Both total R&D expenditures (lagged five or ten years) and business R&D expenditures (lagged five years) impact technical efficiency and TFP in the presence of various structural, infrastructural and institutional indicators. This contrasts with the research on semi-endogenous models, which does not allow for direct impact for R&D expenditures, and technological transfer literature, which does not allow for an R&D impact in developing countries without technological transfer.

Third, the size of the influence of various factors on TFP dynamics differs considerably between the two samples we used. These differences cannot be explained solely by the difference in GDP per capita. However, the determination coefficient for the "OECD-1990+Russia" sample is two or three times as large as that for the "World" sample.

Our results do not necessarily mean that the R&D expenditures increase productivity directly. Whether this can be tested directly is a matter of further research, and probably requires product or sectoral decomposition. Thus, the results of R&D spending could also be due to the increase in unobserved environment variables, which in turn lead to an increase in productivity.

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# Appendix

**Tab. 20. Pair correlations of TE estimates model-wise and method-wise**

| | Model 1, “World” | Model 2, “World” | Model 3, “OECD-90 +Russia” | Model TI, “World” | Model TI, “OECD-90 +Russia” | Model FE-2S, “World” | Model TFE, “World” | DEA, “World” | DEA, “OECD-90 +Russia” |
|---|---|---|---|---|---|---|---|---|---|
| Model 1, “World” | 1 | | | | | | | | |
| Model 2, “World” | 0.95 | 1 | | | | | | | |
| Model 3, “OECD-90 +Russia” | 0.87 | 0.96 | 1 | | | | | | |
| Model TI, “World” | 0.77 | 0.75 | 0.68 | 1 | | | | | |
| Model TI, “OECD-90 +Russia” | 0.65 | 0.78 | 0.81 | 0.74 | 1 | | | | |
| Model FE-2S, “World” | -0.12 | -0.17 | -0.08 | 0.04 | 0.14 | 1 | | | |
| Model TFE, “World” | 0.17 | 0.35 | 0.40 | 0.12 | 0.34 | 0.87 | 1 | | |
| DEA, “World” | 0.68 | 0.57 | 0.51 | 0.85 | 0.71 | 0.25 | 0.31 | 1 | |
| DEA, “OECD-90 +Russia” | 0.52 | 0.56 | 0.63 | 0.48 | 0.66 | 0.43 | 0.55 | 0.50 | 1 |

**Tab. 21. Pair correlations of TFP estimates model-wise and method-wise**

| | Model 1, "World" | Model 2, "World" | Model 3, "OECD-90 +Russia" | Model TI, "World" | Model TI, "OECD-90 +Russia" | Model FE-2S, "World" | Model TFE, "World" | DEA, "World" | DEA, "OECD-90 +Russia" |
|---|---|---|---|---|---|---|---|---|---|
| Model 1, "World" | 1 | | | | | | | | |
| Model 2, "World" | 0.60 | 1 | | | | | | | |
| Model 3, "OECD-90 +Russia" | 0.73 | 1.00 | 1 | | | | | | |
| Model TI, "World" | 0.65 | 0.99 | 1.00 | 1 | | | | | |
| Model TI, "OECD-90 +Russia" | 0.82 | 0.98 | 0.99 | 0.99 | 1 | | | | |
| Model FE-2S, "World" | 0.67 | 0.99 | 1.00 | 1.00 | 0.99 | 1 | | | |
| Model TFE, "World" | 0.80 | 0.92 | 0.97 | 0.93 | 1.00 | 0.95 | 1 | | |
| DEA, "World" | 0.59 | 0.87 | 0.89 | 0.92 | 0.92 | 0.91 | 0.84 | 1 | |
| DEA, "OECD-90 +Russia" | 0.75 | 0.94 | 0.95 | 0.96 | 0.97 | 0.96 | 0.96 | 0.98 | 1 |

**Tab. 22. Correlations between TFP growth rate estimates (Model 1 and DEA) for sample "World" and estimates from OECD, PWT and Conference Board databases**

| | SFA | | | DEA | | |
|---|---|---|---|---|---|---|
| Country | OECD | Conference Board | PWT | OECD | Conference Board | PWT |
| Argentina | - | 0.71 | 0.99 | - | 0.68 | 0.97 |
| Australia | 0.83 | 0.86 | 0.93 | 0.73 | 0.79 | 0.81 |
| Austria | 0.56 | 0.70 | 0.96 | 0.55 | 0.67 | 0.96 |
| Bangladesh | - | 0.85 | - | - | 0.38 | - |
| Belgium | 0.58 | 0.73 | 0.96 | 0.52 | 0.67 | 0.93 |
| Brazil | - | 0.76 | 0.95 | - | 0.72 | 0.92 |
| Bulgaria | - | 0.88 | 0.98 | - | 0.65 | 0.76 |
| Canada | 0.82 | 0.93 | 0.95 | 0.80 | 0.90 | 0.94 |
| Chile | - | 0.95 | 0.98 | - | 0.93 | 0.94 |
| China | - | 0.38 | 0.99 | - | 0.24 | 0.94 |
| Colombia | - | 0.84 | 0.93 | - | 0.82 | 0.85 |
| Czech Republic | - | 0.95 | 0.99 | - | 0.88 | 0.97 |
| Denmark | 0.84 | 0.85 | 0.96 | 0.73 | 0.75 | 0.88 |
| Dominican Republic | - | 0.95 | 0.97 | - | 0.87 | 0.84 |
| Ecuador | - | 0.86 | 1.00 | - | 0.82 | 0.95 |
| Egypt | - | 0.83 | 0.98 | - | 0.59 | 0.80 |
| Finland | 0.92 | 0.92 | 0.93 | 0.83 | 0.82 | 0.83 |
| France | 0.72 | 0.82 | 0.95 | 0.70 | 0.81 | 0.94 |
| Germany | 0.85 | 0.85 | 0.96 | 0.81 | 0.81 | 0.95 |
| Greece | - | 0.90 | 0.97 | - | 0.89 | 0.92 |
| Guatemala | - | 0.82 | 0.93 | - | 0.63 | 0.74 |
| Hungary | - | 0.67 | 0.95 | - | 0.51 | 0.86 |
| India | - | 0.80 | 0.99 | - | 0.77 | 0.97 |
| Indonesia | - | 0.98 | 0.99 | - | 0.98 | 0.97 |
| Iraq | - | 0.78 | 1.00 | - | 0.80 | 1.00 |
| Ireland | 0.91 | 0.97 | 0.98 | 0.79 | 0.81 | 0.72 |
| Iran | - | 0.93 | 0.99 | - | 0.92 | 0.96 |
| Israel | - | 0.79 | 0.97 | - | 0.53 | 0.84 |
| Italy | 0.87 | 0.87 | 0.96 | 0.80 | 0.81 | 0.90 |
| Japan | 0.87 | 0.95 | 0.99 | 0.86 | 0.94 | 0.98 |
| Kazakhstan | - | 0.97 | 0.99 | - | 0.79 | 0.94 |
| Kenya | - | 0.93 | 0.91 | - | 0.91 | 0.95 |
| Korea | 0.75 | 0.89 | 0.98 | 0.77 | 0.82 | 0.93 |
| Kuwait | - | 0.96 | 1.00 | - | 0.98 | 0.99 |
| Malaysia | - | 0.97 | 0.97 | - | 0.89 | 0.86 |
| Mexico | - | 0.98 | 1.00 | - | 0.98 | 0.99 |
| Morocco | - | 0.99 | 0.99 | - | 0.98 | 0.99 |
| Netherlands | 0.88 | 0.91 | 0.96 | 0.81 | 0.84 | 0.90 |
| New Zealand | 0.72 | 0.83 | 0.97 | 0.60 | 0.68 | 0.81 |
| Norway | - | 0.95 | 0.98 | - | 0.69 | 0.79 |
| Pakistan | - | 0.73 | - | - | 0.67 | - |
| Peru | - | 0.95 | 0.99 | - | 0.96 | 0.86 |

| | | | | | | |
|---|---|---|---|---|---|---|
| Philippines | - | 0.96 | 0.98 | - | 0.93 | 0.95 |
| Poland | - | 0.91 | 0.92 | - | 0.77 | 0.83 |
| Portugal | 0.89 | 0.90 | 0.93 | 0.72 | 0.81 | 0.83 |
| Qatar | - | 0.90 | 0.99 | - | 0.87 | 0.53 |
| Romania | - | 0.97 | 0.98 | - | 0.94 | 0.94 |
| Russia | - | 0.96 | 1.00 | - | 0.96 | 1.00 |
| Saudi Arabia | - | 0.74 | 0.97 | - | 0.83 | 0.86 |
| Slovak Republic | - | 0.90 | 0.99 | - | 0.89 | 0.93 |
| South Africa | - | 0.79 | 0.86 | - | 0.63 | 0.96 |
| Spain | -0.17 | 0.40 | 0.39 | -0.35 | 0.20 | 0.36 |
| Sri Lanka | - | 0.37 | 0.72 | - | 0.07 | 0.59 |
| Sudan | - | 0.27 | - | - | 0.59 | - |
| Sweden | 0.85 | 0.90 | 0.94 | 0.75 | 0.80 | 0.83 |
| Switzerland | 0.80 | 0.80 | 0.90 | 0.78 | 0.77 | 0.87 |
| Taiwan | - | - | 0.97 | - | - | 0.91 |
| Thailand | - | 0.96 | 0.99 | - | 0.95 | 0.93 |
| Tunisia | - | 0.96 | 0.99 | - | 0.96 | 0.97 |
| Turkey | - | 0.98 | 0.99 | - | 0.96 | 0.96 |
| Ukraine | - | 0.96 | 1.00 | - | 0.94 | 1.00 |
| United Kingdom | 0.80 | 0.77 | 0.96 | 0.78 | 0.73 | 0.94 |
| United States | 0.42 | 0.79 | 0.95 | 0.37 | 0.76 | 0.93 |
| Venezuela | - | 0.96 | 1.00 | - | 0.96 | 0.99 |
| Vietnam | - | 0.83 | - | - | 0.89 | - |

**Tab. 23. Correlations between TFP growth rate estimates (Model 1 and DEA) for sample "OECD-1990+Russia" and estimates from OECD, PWT and Conference Board databases**

| | SFA | | | DEA | | |
|---|---|---|---|---|---|---|
| Country | OECD | Conference Board | PWT | OECD | Conference Board | PWT |
| Australia | 0.82 | 0.81 | 0.94 | 0.76 | 0.79 | 0.86 |
| Austria | 0.64 | 0.71 | 0.99 | 0.58 | 0.68 | 0.97 |
| Belgium | 0.64 | 0.77 | 0.98 | 0.54 | 0.68 | 0.94 |
| Canada | 0.82 | 0.92 | 0.96 | 0.81 | 0.91 | 0.95 |
| Denmark | 0.82 | 0.83 | 0.96 | 0.73 | 0.75 | 0.89 |
| Finland | 0.94 | 0.93 | 0.94 | 0.84 | 0.83 | 0.84 |
| France | 0.69 | 0.81 | 0.97 | 0.71 | 0.81 | 0.97 |
| Germany | 0.87 | 0.86 | 0.98 | 0.88 | 0.87 | 0.98 |
| Greece | - | 0.92 | 0.97 | - | 0.90 | 0.94 |
| Italy | 0.89 | 0.89 | 0.96 | 0.88 | 0.88 | 0.96 |
| Japan | 0.93 | 0.95 | 0.96 | 0.92 | 0.97 | 0.99 |
| Netherlands | 0.88 | 0.89 | 0.96 | 0.83 | 0.85 | 0.92 |
| New Zealand | 0.75 | 0.83 | 0.94 | 0.62 | 0.69 | 0.81 |
| Norway | - | 0.90 | 0.97 | - | 0.68 | 0.79 |
| Portugal | 0.79 | 0.87 | 0.92 | 0.72 | 0.81 | 0.84 |
| Russia | - | 0.94 | 0.98 | - | 0.95 | 0.99 |
| Spain | -0.34 | 0.20 | 0.46 | -0.36 | 0.19 | 0.41 |
| Sweden | 0.86 | 0.91 | 0.94 | 0.77 | 0.82 | 0.85 |
| Switzerland | 0.83 | 0.82 | 0.95 | 0.79 | 0.78 | 0.89 |
| Turkey | - | 0.96 | 0.99 | - | 0.96 | 0.99 |
| United Kingdom | 0.81 | 0.78 | 0.97 | 0.82 | 0.79 | 0.97 |
| United States | 0.45 | 0.76 | 0.95 | 0.48 | 0.81 | 0.98 |

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