ECONOMIC ANNALS, Volume LXIII, No. 217 / April – June 2018
UDC: 3.33 ISSN: 0013-3264

https://doi.org/10.2298/EKA1817007P

*Predrag Petrović**
*Goran Nikolić***

SCHUMPETERIAN GROWTH THEORY: EMPIRICAL TESTING OF BARRIERS TO COMPETITION EFFECT***

ABSTRACT: *This study is dedicated to empirical testing of barriers to competition effect on productivity growth, taking into account the hypothesis that different policies improve economic growth in countries at different levels of technological development. The results of econometric analysis of two panel data sets comprising 144 countries (not controlled for education) and 128 countries (controlled for education) have demonstrated that when approaching the technology frontier, countries with high barriers to competition lose their productivity growth much faster than countries with a low barrier, which is the direct result of the decreasing but positive influence of barriers to competition on productivity growth, regardless of whether the economy is underdeveloped or advanced. This positive effect of barriers can be rationalized by Romer's (1990) product variety model; or possibly by the inverted-U pattern between competition and innovation proved by Aghion et al. (2005), under the assumption that these sample countries are on the downward slope. Finally, the positive effect of barriers, irrespective of the degree of the countries' technological development, implies that the theory is not completely consistent with empirical data.*

KEY WORDS: *Schumpeterian growth theory, productivity growth, barriers to competition, proximity to frontier, technology frontier, education*

JEL CLASSIFICATION: O47, C23, C26

* Ph.D, Institute of Social Sciences, E-mail: ppetrovic@idn.org.rs
** Ph.D, Institute of European Studies, E-mail: goranvnikolic@gmail.com
*** The paper presents the results of a study conducted as a part of projects III47010 and 179014, funded by the Ministry of Education, Science and Tehnological Development, Republic of Serbia.

1. INTRODUCTION

This study empirically tests the Acemoglu, Aghion and Zilibotti (2006) theory, which emphasises that non-competitive arrangements, like large firms and state intervention, can increase investment and adoption of frontier technologies, resulting in the fast convergence of relatively underdeveloped economies with more advanced economies. If this theory is correct, institutions and policies that create market rigidities and a less competitive environment are appropriate for relatively underdeveloped countries where convergence and economic growth are based on massive investment and technology adoption, and are inappropriate for more advanced economies whose development is based on innovation.

According to Acemoglu et al. (2006), economic growth and increased productivity in economies far from the technological frontier are dominated by technology adoption, copying, and imitation, while in countries at a high level of technological development the influence of innovation is decisive. This theory suggests that policies pertaining to technologically underdeveloped countries should be based on encouraging investment and technology adoption, while policies for technologically more developed countries should be based on stimulating innovation. In other words, policies that encourage economic growth in underdeveloped countries differ from those suitable for developed economies.

Acemoglu et al's (2006) theory implies that non-competitive arrangements are appropriate for relatively underdeveloped nations because they can accelerate their convergence to the frontier, while they are detrimental and harmful to productivity growth in more advanced economies. This research tests the hypothesis that barriers to competition have negligible costs (or even benefits) for productivity growth in underdeveloped economies but they become much more destructive in the case of developed countries.

The paper consists of five sections. Sections 1 and 2 cover the introduction and the theoretical background, respectively. Section 3 includes both the basic Schumpeterian theoretical growth model and the analytical framework with data. Section 4 discusses the results and section 5 concludes.

2. THEORETICAL BACKGROUND

Schumpeterian growth theory is a theory of economic growth based on the Schumpeterian concept of creative destruction in which every innovation generates new technology that replaces previous technological solutions and leads to economic growth and increased productivity (Aghion, Akcigit, and Howitt 2013). This theory provides possibility of better understanding of growth underlying causal factors, emphasising incentives, policies and organisations, all of these strongly encouraging research and development (R&D) activities and innovations as a consequence thereof. Economic growth largely depends on policies related to intellectual property rights, competition, economic openness, business barriers, research education, democracy, etc., but it is important to stress that the impact of these factors and policies differs significantly depending on a country's level of technological development.

Aghion et al. (2013) propose the following four areas in which Schumpeterian growth theory offers specific results: (1) the effect that competition and market structure have on the process of economic growth, (2) the dependence between growth and firm dynamics, (3) the impact of long-term technological waves on economic growth, and (4) the relationship between growth and technological development, based on the hypothesis that different policies incite economic growth at different levels of technological development.

The theory of Acemoglu et al. (2006) starts from a simple imaginary economy based on the following three assumptions: (1) entrepreneurs possess greater or lesser ability, (2) the loan market is characterised by limited loan potential and thus introduces restrictions on the amount of total investments, and (3) entrepreneurs participate in both innovation and imitation and the adoption of technology. This theory introduces the notion of selection, which pertains to the possibility of replacing low-skilled entrepreneurs with high-skilled entrepreneurs if such need exists. Due to the assumption of restricted loan potential, insider entrepreneurs are more advantaged than outsiders. Profits retained from current business enable insider entrepreneurs to realise considerably higher investment, which is very important for technology adoption and imitation. This factor can influence the decision to sensibly retain less-skilled entrepreneurs so that investment and imitation support strong economic growth. Such decisions mean consciously sacrificing selection in favour of investment, imitation, and technology adoption.

Since imitation and technology adoption are relatively simple and routine operations compared to the innovation process, Acemoglu et al. (2006) are of the opinion that by gradual technological and economic development, as innovation becomes more important for economic growth, giving up the selection of highly skilled entrepreneurs becomes more harmful and less probable. Observed dynamically, economies start from a low level of technological development, basing their economic growth on investment, imitation, and technology adoption. At this stage the skills of entrepreneurs and selection are far less important, while the emphasis is much more on the greater investment possibilities of insider entrepreneurs (investment-based strategy). Greater investment capacity protects insider entrepreneurs from selection. Investment, imitation, and technology adoption gradually lead to technological progress, which leads to economic and productivity growth. Technological progress and convergence towards the technological frontier make innovation ever more important, so that entrepreneurs' skills and selection become important factors of growth. Economies gradually move to an innovation-based strategy and low-skilled entrepreneurs are replaced by highly skilled entrepreneurs.

In relation to this theory, it is very important to define two key effects (Acemoglu et al. 2006, p.39). The first, known as the appropriability effect, occurs in conditions of monopolistic competition where companies bear the total investment cost leading to GDP growth and increased productivity but enjoy only part of the positive effects. Such relationship between costs and benefits results in partiality against great investments, which inhibits implementation of the investment-based strategy.

The presence of an appropriability effect leads to the conclusion that state support is needed in the form of investment subsidies and anti-competition policies so as to reduce some of the investment costs borne by companies and to increase their investment benefits. In other words, for an investment-based strategy to be successfully implemented, states should intervene. Otherwise, this strategy could fail even if it is useful for economic growth. The second effect is the rent-shield effect, which is a consequence of the fact that retained profits (rents) enable insider entrepreneurs to realise the considerably greater investments that are of key importance for technology adoption, thus protecting them from being replaced by more efficient entrepreneurs. If this effect prevails over the appropriability effect the, economy will rely on investment-based strategy and imitation for far too long. This will reduce economic growth, since the option of innovation is not used to its best advantage. Moreover, it is important to stress that there is a certain level of technological development, i.e., distance from the technological frontier, where convergence stops if the economy does not re-orient to an innovation-based strategy. This phenomenon is known as the non-convergence trap.

Technological development in many less developed countries is based on innovations created in technologically superior economies. This phenomenon, known as the technology spillover effect, played an important role in Germany, France, and Russia's economic convergence process towards being technologically more advanced economies in the 19th century (Gerschenkron, 1962). Their convergence was realised primarily due to extensive investment and the adoption of advanced technological solutions from the most economically and technologically developed countries. According to Howitt (2000), in the long run all countries implementing R&D activities will grow at the same rate, while economies without such activities will not grow at all. Moreover, technologically underdeveloped countries can record higher economic growth rates than developed countries, given the possibility of realising greater technological progress every time they implement technology adoption and imitation. Barro and Sala-i-Martin (1997) deem that in the long term the global economic growth rate is determined by discoveries in the technologically most developed countries. Less developed countries base economic growth and convergence towards more developed economies on imitation and copying, the cost of which is to a certain extent lower than that of innovation. The tendency of the cost of copying to gradually increase decreases growth rates in following countries so that they slowly converge to the growth rates of technologically more developed countries. On the other hand, certain models of economic growth lead to the conclusion that technology adoption that reduces labour requirements but raises capital requirements increases productivity gaps, which explains the large and constant international differences in the level of per capita income (Zeira 1998). Finally, models belonging to the Schumpeterian growth theory add to our understanding of why some countries stagnate while others converge to the level of income that is specific to the world technology frontier (Howitt and Mayer 2005).

According to Acemoglu et al. (2006), highly developed skills and the selection of appropriate entrepreneurs play a far more important role in the innovation process than in the process of imitation and technology adoption. The opinion on great importance of entrepreneurs' skills for research and development (innovation) is consistent to the existing models of growth which potentiate great role of human capital in technological progress. Nelson and Phelps (1966) develop a model which formalises the relationship between capital structure and technological development, starting from the opinion that education is a process of investing in people and that educated people are leaders of human capital. According to this growth model, the more technologically progressive the economy the greater the benefit of education and human capital (rate of return to education). Such a relationship implies that the degree of technological development influences the optimal capital structure. If technology is dynamic and progressive, societies should increase human capital rather than physical capital. According to Galor and Tsiddon (1997), times of great technological discovery bring increased inequality, greater mobility, and concentration of highly skilled individuals in technologically progressive sectors, encouraging future technological progress and economic growth. When this technology becomes more available there is a decline in the concentration of highly skilled individuals in technologically progressive sectors, which significantly reduces the probability of further technological progress and slows down future economic growth. Hassler and Rodriguez Mora (2000) suggest that high economic growth increases a return to innate cognitive ability in which allocation of individuals depends more on innate ability and less on social origin. According to these authors, individuals with better innate cognitive abilities are better adapted to less known productive technologies and master them more easily, thus encouraging greater economic growth in the future. Taking into account the mentioned interdependence, it can be concluded that dynamic economic growth and allocation of individuals based on innate ability are mutually intensified. In addition, Aghion and Howitt (1992) develop a Schumpeterian growth model which implies that economic growth is solely a consequence of technological progress based on the competition between R&D firms generating innovation. According to this model, the average growth rate and the variance in the growth rate are growing functions of innovation, the size of the highly skilled labour force, and research productivity.

3. METHODOLOGY AND DATA

3.1. Basic theoretical growth model

The basic theoretical growth model according to Aghion et al. (2013, pp.2–6), belongs to Schumpeterian growth theory and is characterised by the following three general properties: (1) innovation triggers economic growth, (2) innovation is the consequence of entrepreneurial investment motivated by the possibility of realising post-innovation monopoly rents, and (3) every innovation generates new technology that replaces the old, meaning that creative destruction is an inherent component of economic growth. Time dimension and population (composed of infinitely lived individuals) are continual variables. Individuals have linear preferences and discount future values at the rate of ρ. Also, linear preferences imply that equilibrium interest rate r is equal to time preference rate ρ. Each individual possesses one work unit in the time unit, which can be allocated either to research and development activities or to the production of the intermediate good. The theoretical model implies production of one final and one intermediate good. The final good is produced in conditions of perfect competition based on the following production function:

$$Y_t = A_t y_t^{\alpha} \tag{1}$$

where Y, y, A and α respectively present the volume of production of the final good in moment t, quantity of the intermediate good that is used for the production of the final good at moment t, productivity (quality) of the intermediate input, and elasticity of production with respect to the intermediate good.

At the same time the production of the intermediate good is carried out under monopoly conditions, using labour as the only production input in a one-to-one proportion, which means that for each unit of the intermediate good of frontier quality one labour unit is spent. Taking into account this assumption, it is clear that y_t at the same time denotes production volume of the intermediate good at moment t and number of labour units spent in production of the intermediate good. As already stated, Schumpeterian growth theory implies that economic growth appears as a consequence of innovation and creative destruction. The economic growth mechanism in this model is based on innovation, which consequently results in more productive (quality) intermediate good, the use of which results in greater production of the final good. In other words, if level of quality (productivity) of the intermediate good used at the moment is A, the first following innovation will generate the new intermediate good productivity, which will be γA, where $\gamma > 1$. The innovator who generated the new intermediate good pushes the previous innovator out of the market, since he can produce a more productive (quality) good with identical labour unit costs, which is a process of creative destruction, implying both positive and negative external effects. According to Aghion and Howitt (1992, p.330), positive external effects, or 'intertemporal knowledge spillover', are reflected in the fact that innovation permanently increases productivity, thus generating new knowledge which is the basis for future innovations. Negative external effects, known as 'business-stealing effects', result from the fact that every new innovation destroys the post-innovation monopoly rent of the previous innovator (Aghion and Howitt 1992, p.325). The probability that innovation occurs within time interval *[t, t+dt]* is equal to $\lambda z_t dt$, where λ stands for probability of innovation if R&D activities engage one labour unit, z_t stands for total number of labour units engaged in the R&D sector at moment *t,* and *dt* stands for very short time interval.

This model of economic growth is based on two key equations. The first is known as the labour market clearing equation and can be simply presented as:

$$L_t = y_t + z_t \quad (2)$$

where L_t, y_t, and z_t respectively denote continuous population at moment *t* composed of infinitely lived individuals (L_t), total number of labour units engaged in the production of the intermediate good at moment *t* (y_t), and total number of labour units engaged in R&D operations at moment *t* (z_t). The labour market clearing equation implies that the total number of labour units (number of individuals) engaged in the production of the intermediate good and in the R&D sector in every time unit is equal to the total population (total labour supply). The model focuses on constant allocation of labour between the production of the intermediate good and R&D activity, which means that it does not change in time.

In equilibrium, individuals are indifferent between working in the sector producing the intermediate good and in the R&D sector. The second structural equation of the model is based on this fact and is known as the research arbitrage equation. Taking into account that Schumpeterian growth models recognise innovation and creative destruction as the only triggers of economic growth, all variables in the model remain unchanged in the period between two consecutive innovations. If we assume that in the period between $t=0$ and current *t* a total of *k* innovations were realised, the wage rate can be marked as ω_k, and the net present value of the post-innovation monopoly profit (rent) that will be achieved by the next ((*k*+*1*)-th) innovator as V_{k+1}.

In the course of the short time interval *dt* between two consecutive innovations (k-th and ($k+1$)-th), every individual has two options at their disposal. The first is to engage their own available labour unit in the time unit for the production of the intermediate good and to gain earnings of $\omega_k dt$. An alternative is that the available labour unit in the unit of time is used for the needs of the R&D sector, where with probability of λdt it will generate the following (($k+1$)-th) innovation and gain right on post-innovation the monopoly rent V_{k+1}, but with the risk that no innovation occurs and no rent is gained. In the equilibrium state every individual will be indifferent between engaging in the production of the intermediate good and in R&D activities. Formalisation of this condition leads us to the research arbitrage equation:

$$\omega_k dt = \lambda dt V_{k+1}, \tag{3}$$

i.e.:

$$\omega_k = \lambda V_{k+1}. \tag{4}$$

Starting from equation (4), Aghion et al. (2013) implicitly assume that the next innovator will not be the individual that generated the last k-th innovation, since post-innovation rent for that individual, if they become the next innovator, increases from V_k to V_{k+1}, while in the case of any other individual it increases from zero to V_{k+1}. According to equation (4), if all outsiders are individuals indifferent between the production of intermediate goods and R&D activities, then the k-th innovator (insider) will strictly prefer production of the intermediate good.

The net present value of post-innovation monopoly profit (V_{k+1}) is determined by the Bellman equation. If we assume that the ($k+1$)-th is the last generated innovation and that the monopoly producer of the intermediate good collects at every moment a post-innovation monopoly profit to the amount of π_{k+1}, the total profit that will be realised in the short period of time *dt* amounts to $\pi_{k+1}dt$. In addition, if we assume that no next ($k+2$)-th innovation will happen, the existing monopoly producer of the intermediate good (($k+1$)-th innovator) will collect profit infinitely, i.e., the net present value of the post-innovation monopoly profit will be:

$$V_{k+1} = \int_0^{\infty} \frac{\pi_{k+1}}{e^{rt}} dt = \frac{\pi_{k+1}}{r}, \tag{5}$$

taking into account that equilibrium interest rate r is equal to time preference rate ρ (exponential growth rate). From equation (5) it is concluded that:

$$V_{k+1} r = \pi_{k+1}, \tag{6}$$

so the net present value of profit V_{k+1} can be reformulated as:

$$V_{k+1} = \pi_{k+1} dt + (1 - rdt) \times V_{k+1}. \tag{7}$$

If the unreal assumption that no next ($k+2$)-th innovation will occur is abandoned, at the end of the very short time period dt the monopoly producer of the intermediate good will either be pushed out of the market by means of creative destruction (with probability of $\lambda z_t dt$) or will retain the monopoly position and V_{k+1} (with probability of $1\text{-}\lambda z_t dt$). Accordingly, the net present value of the post-innovation rent can be presented by the Bellman equation:

$$V_{k+1} = \pi_{k+1} dt + (1 - rdt) \begin{bmatrix} \lambda z_t dt \times 0 \\ (1 - \lambda z_t dt) \times V_{k+1} \end{bmatrix}. \tag{8}$$

Based on equation (8), it is observed that in the case of ultimately certain creative destruction ($\lambda z_t dt=1;\ 1\text{-}\lambda z_t dt=0$) the net present value of the post-innovation profit of the ($k+1$)-th innovator is equal to the profit at the initial moment of time ($t=0$) when the ($k+1$)-th innovation is generated. If preservation of the monopoly position is certain ($\lambda z_t dt=0;\ 1\text{-}\lambda z_t dt=1$), the net present value of the post-innovation profit of the ($k+1$)-th innovator is formalised through equation (7). In all remaining cases, the net present value can be formulated as:

$$V_{k+1} = \pi_{k+1} dt + V_{k+1} - \lambda z_t dt V_{k+1} - rdt V_{k+1} + \lambda z_t r dt^2 V_{k+1}. \tag{9}$$

If both sides of equation (9) are divided by dt, under condition that $dt \to 0$ and that $r=\rho$, the following is obtained:

$$\frac{V_{k+1}}{dt} = \pi_{k+1} + \frac{V_{k+1}}{dt} - \lambda z_t V_{k+1} - \rho V_{k+1}, \tag{10}$$

i.e.:

$$V_{k+1} = \frac{\pi_{k+1}}{\rho + \lambda z_t}. \tag{11}$$

Based on equation (11), it is noticeable that the net present value of the post-innovation monopoly rent is equal to the quotient of the post-innovation monopoly profit which the ($k+1$)-th innovator realises in the unit of time and risk-adjusted rate of time preference, where the possibility of creative destruction appears as a risk with probability of λz_t in the unit of time.

If we assume that by moment t a total of k innovations has been generated, solving the model goes to finding the equilibrium value of post-innovation monopoly profit (π_k), the equilibrium quantity of work consumed by R&D activities (z_t), and the equilibrium expected economic growth rate ($E(g_t)$). Taking into account that the productivity (quality) of the intermediate good increases by γ times with every new innovation, the productivity of the latest k-th intermediate good will amount to $A_k=\gamma^k$. Starting from the earlier-introduced assumption that the final good is produced under perfect competition conditions, the profit maximisation of the final good producers requires that the monopoly producer of the intermediate good formulates the price of input at the level of its marginal product, which formally requires equality of input prices and the first derivative of production function (1):

$$p_k(y) = \alpha A_k y_t^{\alpha-1}. \tag{12}$$

This relation actually presents the inverse demand function faced by the monopoly producer of the intermediate good. He also tends to maximise its post-innovation monopoly profit, taking into account the condition formalised by equation (12):

$$\pi_k = \max_y \left\{ p_k(y) y_t - \omega_k y_t \right\}. \tag{13}$$

Taking into account that the inverse demand function faced by a monopoly producer of the intermediate good is known (equation 12), equations of total and marginal revenue can be simply formulated as:

$$p_k(y)y_t = \alpha A_k y_t^{\alpha}, \tag{14}$$

$$\frac{d\left(p_k(y)y_t\right)}{dy_t} = \alpha^2 A_k y_t^{\alpha-1}. \tag{15}$$

The condition for the profit maximisation of the monopoly producer of the intermediate good is the equality of its marginal cost (ω_k) and marginal revenue (equation 15):

$$\omega_k = \alpha^2 A_k y_t^{\alpha-1}, \tag{16}$$

which can also be written as:

$$y_t^{\alpha-1} = \frac{\omega_k}{\alpha^2 A_k}. \tag{17}$$

Placing equation (17) in equation (12) gives that the equilibrium prices of the intermediate good are equal to the amount of wage rate (marginal cost) increased by constant margin:

$$p_k(y) = \frac{\omega_k}{\alpha}. \tag{18}$$

Bearing in mind this fact, the equilibrium post-innovation profit of the monopoly producer can be simply expressed by placing equation (18) in the profit equation:

$$\pi_k = p_k(y)y_t - \omega_k y_t, \tag{19}$$

giving:

$$\pi_k = \frac{1-\alpha}{\alpha}\omega_k y_t. \tag{20}$$

This last relationship indicates that equilibrium post-innovation monopoly profit is equal to the product of constant (1-α)/α and labour costs.

The next step in solving the model is deriving the equilibrium amount of labour consumed in the R&D sector. Placing equations (11) and (20) in the research arbitrage equation (4), the following is obtained:

$$\omega_k = \frac{\lambda \frac{1-\alpha}{\alpha} \omega_{k+1} y_t}{\rho + \lambda z_t}, \tag{21}$$

which can also be written as:

$$\frac{\lambda \frac{1-\alpha}{\alpha} \omega_{k+1} y_t}{\omega_k} = \rho + \lambda z_t \, . \tag{22}$$

From equations (16) and (2) the following is obtained:

$$\omega_{k+1} = \alpha^2 A_{k+1} y^{\alpha-1} = \alpha^2 \gamma A_k y^{\alpha-1} = \gamma \omega_k \, , \tag{23}$$

$$y_t = L_t - z_t \, , \tag{24}$$

placement of which in equations (22) and further calculation will give the equilibrium amount of labour consumed by R&D activities:

$$z_t = \frac{\frac{1-\alpha}{\alpha} \gamma L - \frac{\rho}{\lambda}}{1 + \frac{1-\alpha}{\alpha} \gamma} \, . \tag{25}$$

Equation (25) indicates that the equilibrium amount of labour consumed by R&D activities is a growing function of λ, γ, and L, and at the same time a decreasing function of α and ρ.

Finally, once the equilibrium amount of labour consumed by R&D activities is established, it is simple to determine the equilibrium expected economic growth rate. If it is known that $\lambda z_t dt$ is the probability of realising a new innovation in the short time period *dt*, and that each innovation is followed by increased production of the final good by γ times, production of the final good at moment $t+dt$ can be formulated as:

$$Y_{t+dt} = \gamma^{\lambda z_t dt} Y_t \,. \tag{26}$$

Applying logarithm to equation (26), the following is obtained:

$$\ln\left(Y_{t+dt}\right) = \lambda z_t dt \ln\left(\gamma\right) + \ln\left(Y_t\right). \tag{27}$$

Deducting $ln(Y_t)$ from both sides of equation (27), the following is obtained:

$$\ln\left(Y_{t+dt}\right) - \ln\left(Y_t\right) = \lambda z_t dt \ln\left(\gamma\right), \tag{28}$$

which, after being divided by *dt* with the condition that $dt \to 0$, gives the equilibrium expected continual economic growth rate:

$$E\left(g_t\right) = \lim_{dt \to 0} \frac{\ln\left(Y_{t+dt}\right) - \ln\left(Y_t\right)}{dt} = \lambda z_t \ln\left(\gamma\right). \tag{29}$$

From equation (29) it can be concluded that the equilibrium expected economic growth rate is directly correlated with the probability of innovation (creative destruction) in unit of time λz_t. This basic model formalises the mechanism by which innovation and creative destruction influence: (1) the equilibrium price of the intermediate good ($p_k(y)$), (2) the equilibrium wage rate (ω_k), (3) the equilibrium post-innovation monopoly profit (π_k), and finally (4) the equilibrium expected economic growth rate ($E(g_t)$).

Formalisation of Acemoglu et al's (2006) basic idea that productivity in technologically underdeveloped economies is dominated by imitation and adoption of frontier technology and in technologically developed countries by innovation can be most easily achieved by shifting from continuous to discrete time (Aghion et al. 2013, p.21). It was assumed that A_t, $\tilde{A}_t$, μ_n and μ_m respectively denote current average productivity in the observed country, current frontier productivity, the fraction of sectors that innovate and the fraction of sectors that imitate. If we understand innovation, according to the presented model, as multiplying productivity by factor γ, and imitation as simple convergence towards frontier productivity, an increase in productivity between two successive periods can be presented as:

$$A_{t+1} - A_t = \mu_n(\gamma - 1)A_t + \mu_m(\tilde{A}_t - A_t), \tag{30}$$

i.e.:

$$g_t = \frac{A_{t+1} - A_t}{A_t} = \mu_n(\gamma - 1) + \mu_m(a_t^{-1} - 1), \tag{31}$$

where $a_t = A_t / \tilde{A}_t$, and g_t stands for the productivity growth rate between two consecutive time periods. Equation (31) indicates that the closer the country is to the technology frontier (a_t closer to one), the more dependent on innovation and policies that stimulate its productivity growth it is; and, vice versa, the further the country is from the technology frontier (a_t closer to zero), the more dependent its productivity growth is on imitation and imitation-enhancing policies.

3.2. Analytical framework and data

As mentioned earlier in the paper, the empirical research in this study is based on the analytical framework developed and applied by Acemoglu et al. (2006, p.41) and on their claim, reflecting the essence of this research, that: "Our analysis also implies that barriers to competition should have limited costs (or even benefits) when countries are far from the world technology frontier but should become much more costly near the frontier". We classified all countries in the sample into low-barrier and high-barrier countries and then estimated the effects of convergence to productivity growth in both groups. The specification of the first panel two-way error component regression model we used is as follows:

$$YC_{it} = \alpha_1 HBPPTF_{it-1} + \alpha_2 LBPPTF_{it-1} + \mu_i + \lambda_t + \nu_{it}. \tag{32}$$

In this regression *YC*, *HBPPTF,* and *LBPPTF* respectively present productivity growth rate in country *i* between *t-1* and *t* and the interaction terms of high-barrier (HBP) and low barrier (LBP) dummies with proximity to frontier measures (PTF) in country *i* on date *t-1*. Dummy variables *HBP* and *LBP* take unit values in the case of high-barrier and low-barrier countries, respectively, and zero in other cases. Regressor *PTF* measures how close productivity in the observed country is to the frontier productivity level (productivity level in the most productive country). Interaction terms (*HBPPTF* and *LBPPTF*) stand for proximity to frontier measures separately for high-barrier and low-barrier countries. It is very important to emphasise that the focus of this research is not disclosing different determinants of productivity growth and estimating the character and intensity of their influence, but checking the empirical consistency of Acemoglu et al's (2006) theory. To this end, we are predominantly interested in the sign of coefficients α_1 and α_2 and in their significance and mutual relationship, rather than in their values. If the observed theory is compatible with the empirical data, both estimates should be statistically significant and negative, while α_1 should be higher in absolute terms. Such a finding would indicate that gradual convergence towards the technological frontier slows down productivity growth more vigorously in countries with high barriers to competition.

The second panel two-way error component regression model comprises proximity to frontier measures (PTF) in country *i* at date *t-1*, average barriers to competition (BP) in country *i* between *t-1* and *t*, and the interaction term between them (BP*PTF).

$$YC_{it} = \alpha_3 PTF_{it-1} + \alpha_4 BP_{it} + \alpha_5 \left(BP_{it} * PTF_{it-1} \right) + \mu_i + \lambda_t + \nu_{it} \tag{33}$$

According to Acemoglu et al. (2006), this research was conducted with and without controlling for education effect. Regression models that included the education variable were estimated on a sample of 128 countries (Table 2A – Appendix), while the remaining equations were estimated on a sample of 144 countries (Table 1A – Appendix), which was determined by data availability. In the case of the model without education, the sample covers the period from 2004 to 2016 and is divided into three sub-periods of four years each (2004–2008, 2008–2012, 2012–2016). When the panel data sample was devised, every four-year period was treated as one time observation. In other words the basic panel data sample, if the education effect is not controlled for, is composed of 432 observations (N=144, T=3).

The panel data sample that controls for the influence of education covers the period 2005–2015 and is divided into two five-year sub-periods (2005–2010, 2010–2015), where each sub-period stands for one time observation. The reason for dividing the time dimension of the sample into two five-year periods rather than three four-year periods, as is the case without education variable, can be found in the fact that education statistics (the so-called Barro-Lee series) are published in five-year intervals (1950, 1955,..., 2005, 2010). Therefore, the basic panel data sample with the education variable included in the models comprises a total of 256 observations (N=128, T=2).

The dependent variable (YC) in both regression models is average annual growth rate of GDP per worker in four-year periods (without education) and in five-year periods (with education), expressed in percentages. According to Djankov et al. (2002), barriers to competition represent the average number of procedures necessary to open a business in a four-year period (without education) or five-year period (with education). Classification of countries into high-barrier and low-barrier countries was based on whether the average value of barriers to competition was lower than the median barrier value of 8 (low-barrier), or was higher or equal (high-barrier). Proximity to frontier measures (PTF) were expressed in percentages and constructed as the ratio of the country's GDP per worker to the GDP per worker in Luxembourg (constant 2011 PPP $), both calculated at the beginning of each period (first year of the period). The control variable for education stands for the average years of education completed among people older than 25 at the beginning of each five-year period (in 2005 and in 2010). Data on GDP per person employed and number of start-up procedures to register a business was downloaded from the World Development Indicators database (World Bank), while data on average years of education completed among people over age 25 was sourced from the Education Statistics database (World Bank).

4. RESULTS AND DISCUSSION

The first step in econometric modelling is the estimation of two-way fixed effects error component models (Least Squares Dummy Variables (LSDV), Tables 1 and 2) and elimination of influential observations applying DFITS (Welsch and Kuh 1977) and Cook's Distance (Cook 1977) statistics.[1] The results of testing the normal distribution of the error term, obtained by applying several statistical tests (D'Agostino, Belanger, and D'Agostino 1990 with and without correction developed by Royston 1991; Shapiro and Wilk 1965 based on Royston 1982, 1992, 1993b; Shapiro and Francia 1972 based on Royston 1983, 1993a; Jarque and Bera 1980, 1987), robustly indicate that the error term is

[1] All results that are not presented in this paper are available on request from the authors.

normally distributed in all LSDV error component models estimated on reduced samples (without influential points). Application of different heteroscedasticity and serial correlation tests (Breusch and Pagan 1979/ Cook and Weisberg 1983; Koenker 1981; Wooldridge 2013; Szroeter 1978; Greene 2003, p.324; Cumby and Huizinga 1992) indicate their presence in all LSDV models. Although cross-sectional dependencies are not much of a problem in micro panels (few years and large number of cross-sections), they are tested in any case. In LSDV models with education, application of Friedman (1937) and Pesaran (2004) CD tests, relevant in panel data models with small T and large N, indicate that there is no cross-section dependence (correlation) in residuals. In the case of the LSDV models without education, application of the mentioned cross-section dependence tests is not possible (because of the calculation problem caused by elimination of influential observation), due to which heteroscedasticity, serial-correlation- consistent and spatial-correlation-consistent Driscoll and Kraay (1998) standard errors are also estimated for precautionary reasons. Heteroscedasticity and serial correlation robust F-statistics indicate that individual and time dummy variables are statistically significant at the 1% significance level in all LSDV models. At the same time, application of Breusch and Pagan (1980) and Honda (1985) tests indicates the significance of individual effects and the insignificance of time unobservable effects in all model specifications. Since robust F-tests indicate the significance of fixed individual and time effects and LM tests disclose the significance of individual stochastic effects (but not time stochastic effects), the next testing phase pertains to application of the autocorrelation and heteroscedasticity robust Hausman test (Arellano 1993) in order to distinguish between two-way mixed error component models (with random individual and fixed time effects) and two-way fixed-effects error component models (with fixed individual and time effects). Based on the obtained results the zero hypothesis is sovereignly rejected at the 1% significance level, which implies that there is correlation between the regressors and stochastic individual effects, due to which the fixed effects models with heteroscedasticity and autocorrelation robust standard errors are finally estimated. In order to check the robustness of the findings the same models are estimated in the form of Prais-Winsten (PW) regressions with panel-corrected standard errors (PCSE) and by applying feasible generalised least squares (FGLS) methods both with common and panel-specific AR(1) coefficients. Estimation using these techniques is possible only in the case of the model without education, on the complete sample of 432 observations, because elimination of influential observations and too small time dimensions in models with education generate calculation problems.

Finally, as Acemoglu et al. (2006) point out, variables that contain proximity to the frontier (HBPPTF, LBPPTF, PTF, and BPPTF) are correlated with the lags of the dependent variable, implying that the strict exogeneity assumption has to be violated (Wooldridge 2002, p.255). This is the basic reason why models are also estimated applying the two-step efficient generalised method of moments (GMM), which generates estimates efficient for arbitrary heteroscedasticity and autocorrelation and statistics robust to heteroscedasticity and autocorrelation, whereby instrumental variables are created through the observation ordinal number method and two groups method. Testing of underidentification, weak identification, and over-identifying restrictions is implemented by applying Kleibergen and Paap (2006) rk LM statistics, the Kleibergen and Paap (2006) Wald rk F statistic (with Stock and Yogo 2002, TSLS critical values), and the Hansen (1982) J statistic, respectively, which are valid when the i.i.d. assumption is violated. In the case of GMM estimations of model (32), with and without education (Table1), the mentioned tests indicate that instruments are exogenous at the 10% significance level, and equations are identified at the 1% significance level without weak identification problems. GMM estimations of model (33), with and without education (Table2), give results that point to models identification at the 1% significance level and instruments exogeneity at the 10% level. It is important to draw attention to the fact that the null hypothesis of weak identification in the case of model (33) without education is rejected at the 5% level only when weak instruments are defined as variables that potentially cause: 1) 10% or more asymptotic bias relative to OLS estimators, and 2) 20% or more test size of a 5% Wald test for endogenous regressors. Also, if model (33) with education is in question the week identification null hypothesis is rejected at the 5% level only when weak instruments are understood as variables that potentially cause 25% or more Wald test size, if the true rejection rate is 5%. Bearing in mind these weak instruments test results, it is necessary to be somewhat cautious when discussing them. Because of the potential existence of a weak instruments problem, in addition to the aforementioned tests the Anderson and Rubin (1949) Wald test and Stock and Wright (2000) SLM tests, which are robust to weak instruments, were conducted. In both versions (with and without education) of model (33), these tests convincingly confirm the significance of all endogenous regressors.

Finally, as obtained on the basis of LSDV estimation results, estimating FGLS, PW, and GMM equations robustly confirms the significance of cross-section and time dummies in both versions (with and without education) of both models (32 and 33).

Table 1. Estimation results of regression (32)

		LSDV	FGLS (1)	FGLS (2)	PW (PCSE) (1)	PW (PCSE) (2)	GMM	LSDV	GMM
HBPPTF (α_1)		-0.514	-0.542	-0.575	-0.570	-0.604	-1.544	-0.555	-1.135
		(0.121)*	(0.035)*	(0.025)*	(0.107)*	(0.108)*	(0.347)*	(0.147)*	(0.280)*
		[0.099]*						[0.127]*	
		{0.130}***							
LBPPTF (α_2)		-0.196	-0.202	-0.231	-0.229	-0.247	-0.785	-0.298	-0.545
		(0.063)*	(0.025)*	(0.017)*	(0.088)*	(0.087)*	(0.200)*	(0.110)*	(0.153)*
		[0.052]*						[0.095]*	
		{0.090}							
p-equality		0.0001	0.0000	0.0000	0.0004	0.0002	0.0013	0.0343	0.0051
Education		NO	NO	NO	NO	NO	NO	YES	YES
No. of obs.		399	432	432	432	432	432	232	256
R^2		0.76	-	-	0.72	0.74	0.47	0.88	0.73
Endogeneity test (p)	Both						0.0002		0.0006
	HBPPTF						0.0035		0.0077
	LBPPTF						0.0002		0.0037

Source: Authors' calculation

Notes: Values in parentheses, brackets, and braces are Rogers (1993), Newey and West (1987) and Driscoll and Kraay (1998) standard errors. The labels (1) and (2) respectively represents common and panel specific AR(1) coefficients. Also, asterisks *, ** and *** denote significance at the 1%, 5%, and 10% significance level.

The estimation results of model (32) (Table 1) show that all α_1 and α_2 coefficients are negative and highly significant at the 1% level, except in case of using the Driscoll-Kraay standard errors in model without education, where α_1 is significant at the 10% level and α_2 is insignificant. Estimators obtained by all methods reveal that the absolute value of α_1 is significantly higher than the absolute value of α_2, which implies a considerably faster decline of productivity growth rate in countries with high barriers to competition as they converge to the frontier. Also, testing the null hypothesis of equality of α_1 and α_2 parameters (lower part of Table 1) produces convincing results that the parameters are significantly different. It is important to emphasise that these findings are completely consistent with the tested theory.

Table 2. Estimation results of regression (33)

		LSDV	FGLS (1)	FGLS (2)	PW (PCSE) (1)	PW (PCSE) (2)	GMM	LSDV	GMM
PTF (α_3)		–0.238	–0.259	–0.298	–0.303	–0.333	–1.271	–0.362	–0.404
		(0.061)*	(0.018)*	(0.014)*	(0.079)*	(0.081)*	(0.268)*	(0.066)*	(0.229)***
		[0.056]*						[0.082]*	
		{0.108}							
BP (α_4)		0.531	0.617	0.663	0.597	0.637	1.150	0.350	0.533
		(0.141)*	(0.024)*	(0.030)*	(0.135)*	(0.136)*	(0.241)*	(0.135)**	(0.236)**
		[0.123]*						(0.166)**	
		{0.019}*							
BPPTF (α_5)		–0.026	–0.031	–0.034	–0.029	–0.031	–0.073	–0.017	–0.042
		(0.006)*	(0.001)*	(0.001)*	(0.006)*	(0.006)*	(0.015)*	(0.006)*	(0.015)*
		[0.006]*						[0.007]**	
		{0.001}*							
Education		NO	NO	NO	NO	NO	NO	YES	YES
No. of obs.		393	432	432	432	432	432	230	256
R^2		0.78	-	-	0.72	0.74	0.30	0.89	0.73
Endogeneity test (p)	Both						0.0000		0.0156
	PTF						0.0003		0.7608
	BPPTF						0.0005		0.0065

Source: Authors' calculation
Notes: Values in parentheses, brackets, and braces are Rogers (1993), Newey and West (1987) and Driscoll and Kraay (1998) standard errors. The labels (1) and (2) respectively represents common and panel specific AR(1) coefficients. Also, asterisks *, ** and *** denote significance at the 1%, 5%, and 10% significance level.

Obtained estimates for model (33) (Table 2) indicate negative and statistically significant α_3 and α_5 parameters, mostly at the 1% significance level. In addition, the results also point to positive α_4 parameters that are statistically significant, predominantly at the 1% significance level. Model (33) implies a PTF effect on productivity growth equal to $\alpha_3 + \alpha_5$*BP. Estimations of parameters α_3 and α_5 definitely confirm the finding related to model (32) that productivity growth diminishes as countries move towards the frontier, and this effect is much stronger in countries with high barriers to competition. The second important fact pertains to the effect that BP has on productivity growth, which is equal to $\alpha_4 + \alpha_5$*PTF. On the basis of the presented results it is clear that this effect is a declining function of PTF and always positive (regardless of the PTF value; i.e., regardless of the degree of countries' technological and economic development). In that sense, it is important to point out that when countries are moving towards the frontier, productivity growth decreases because of two effects: 1) the main effect that PTF has on productivity growth that is quantified by α_3, and 2) the additional effect that PTF has on BP's multiplicator which is measured by α_5. The results of positive BP influence on productivity growth for both underdeveloped and advanced countries are not consistent with the examined theory. This finding is in direct conflict with Acemoglu et al's (2006, p.38) attitude that non-competitive arrangements, which are appropriate for relatively underdeveloped nations because they can improve their convergence to the frontier, are not beneficial for more advanced economies. It means that barriers to entry are more harmful to productivity growth closer to the frontier; i.e., they become much more costly for advanced countries. Likewise, Aghion et al. (2013 p.23) formulate the prediction, based on the observed theory, that: "High entry barriers become increasingly detrimental to growth as the country approaches the frontier", which is not proved by the results of this study. The findings presented in this paper show that countries with high barriers to competition lose their productivity growth more rapidly was they approach the world technology frontier, but this does not mean that barriers have a negative impact on growth, and these two findings should not be confused. Namely, the faster atrophying of high-barrier countries' growth as they converge to the frontier is a direct consequence of the fact that reduction of growth rate is a function of barrier values, which has already been shown using the PTF multiplicator equation ($\alpha_3 + \alpha_5 * BP$). In other words, according to these findings, as countries with high barriers to competition become increasingly developed, productivity growth is quickly reduced, but they also still have a higher growth rate.

If the claim that underdeveloped countries' productivity growth is predominantly influenced by imitation and advanced economies' productivity growth is predominantly the consequence of innovation is accepted as true, the results of this study indicate that barriers to competition enhance both innovation and imitation.

5. CONCLUSION

Econometric analysis of two panel data sets comprising 128 and 144 countries (with and without controls for education), respectively covering the periods 2005–2015 and 2004–2016, generates the clear and robust result that countries with high barriers to competition realise notably larger productivity growth decline than low-barrier countries as they approach the technology frontier, which is the corollary of the diminishing influence of barriers to competition on productivity growth. From the perspective of this result, the growth theory empirically checked in this study is unquestionable. This conclusion is forcefully confirmed by the estimation results of both model specifications used. The second important finding is that barriers to competition have a positive impact on productivity growth, which is contrary to the tested theory. Although productivity growth declines more rapidly in countries with high barriers than in countries with low barriers, when they approach the frontier it is still larger. Bearing in mind these results, we conclude that the observed theory is not completely consistent with empirical data. Finding that barriers to competition enhance productivity growth can be explained by Romer (1990)'s product variety model, which implies detrimental effect of competition to innovation and growth, i.e. competition reduces post-innovation rents and discourages innovation and growth. Another possible explanation could be the inverted-U relationship between competition and innovation confirmed by Aghion, Bloom, Blundell, Griffith and Howitt (2005), under the assumption that these panel data sets include countries that are in the downward-sloping part. However, an explanation of the decreasing influence of barriers to competition on productivity growth is outside the scope of this research and cannot be derived from its results, but could be an intriguing topic for future research.

REFERENCES

Acemoglu, D., Aghion, P. & Zilibotti, F. (2006). Distance to Frontier, Selection, and Economic Growth. *Journal of the European Economic Association*, 4 (1), pp. 37–74. doi: 10.1162/154247606776014677

Aghion, P. & Howitt, P. (1992). A Model of Growth Through Creative Destruction. *Econometrica*, 60 (2), pp. 323–351. doi: 10.2307/2951599

Aghion, P., Akcigit, U. & Howitt, P. (2013). *What Do We Learn From Schumpeterian Growth Theory?* NBER Working Paper 18824, Cambridge, MA 02138: National Bureau of Economic Research.

Aghion, P., Bloom, N., Blundell, R., Griffith, R. & Howitt, P. (2005). Competition and Innovation: An Inverted-U Relationship. *Quarterly Journal of Economics*, 120 (2), pp. 701–728. doi: 10.1093/qje/120.2.701

Anderson, W.T. & Rubin, H. (1949). Estimation of the Parameters of a Single Equation in a Complete System of Stochastic Equations. *Annals of Mathematical Statistics*, 20 (1), pp. 46–63. doi:10.1214/aoms/1177730090

Arellano, M. (1993). On the testing of correlated effects with panel data. *Journal of Econometrics*, 59 (1–2), pp. 87–97. doi: 10.1016/0304-4076(93)90040-c

Barro, J.R. & Sala-i-Martin, X. (1997). Technological Diffusion, Convergence, and Growth. *Journal of Economic Growth*, 2, pp. 1–26.

Breusch, T.S. & Pagan, R.A. (1979). A simple test for heteroscedasticity and random coefficient variation. *Econometrica*, 47 (5), pp. 1287–1294. doi: 10.2307/1911963

Breusch, T.S. & Pagan R.A. (1980). The Lagrange Multiplier Test and its Applications to Model Specification in Econometrics. *Review of Economic Studies*, 47 (1), pp. 239–253. doi: 10.2307/2297111

Cook, D.R. (1977). Detection of Influential Observation in Linear Regression. *Technometrics*, 19 (1), pp. 15–18. doi: 10.2307/1268249

Cook, D.R. & Weisberg, S. (1983). Diagnostics for Heteroscedasticity in Regression. *Biometrika*, 70 (1), pp. 1–10. doi: 10.2307/2335938

Cumby, E.R. & Huizinga, J. (1992). Testing the Autocorrelation Structure of Disturbances in Ordinary Least Squares and Instrumental Variables Regressions. *Econometrica*, 60 (1), pp. 185–195. doi: 10.2307/2951684

D'Agostino, B. R., Belanger, A., D'Agostino and Jr., B.R. (1990). A Suggestion for Using Powerful and Informative Tests of Normality. *American Statistician*, 44 (4), pp. 316–321. doi: 10.1080/00031305.1990.10475751

Djankov, S., La Porta, R., Lopez-de-Silanes, F. & Shleifer, A. (2002). The Regulation of Entry. *Quarterly Journal of Economics*, 117 (1), pp. 1–37.

Driscoll, C.J. & Kraay, C.A. (1998). Consistent Covariance Matrix Estimation with Spatially Dependent Panel Data. *Review of Economics and Statistics*, 80 (4), pp. 549–560. doi: 10.1162/0034653985578

Friedman, M. (1937). The Use of Ranks to Avoid the Assumption of Normality Implicit in the Analysis of Variance. *Journal of the American Statistical Association*, 32 (200), pp. 675–701. doi:10.1080/01621459.1937.10503522

Galor, O. & Tsiddon, D. (1997). Technological Progress, Mobility, and Economic Growth. *American Economic Review*, 87 (3), pp. 363–382.

Gerschenkron, A. (1962). *Economic Backwardness in Historical Perspective*. Harvard University Press.

Greene, H.W. (2003). *Econometric Analysis. 5th ed*. New York: Prentice-Hall.

Hansen, P.L. (1982). Large Sample Properties of Generalized Method of Moments Estimators. *Econometrica*, 50 (4), pp. 1029–1054. doi: 10.2307/1912775

Hassler, J. & Rodríguez Mora, V.J. (2000). Intelligence, Social Mobility, and Growth. *American Economic Review*, 90 (4), pp. 888–908. doi: 10.1257/aer.90.4.888

Honda, Y. (1985). Testing the Error Components Model with Non-Normal Disturbances. *Review of Economic Studies*, 52 (4), pp. 681–690. doi: 10.2307/2297739

Howitt, P. (2000). Endogenous Growth and Cross-Country Income Differences. *American Economic Review*, 90 (4), pp. 829–846. doi: 10.1257/aer.90.4.829

Howitt, P. & Mayer-Foulkes, D. (2005). R&D, Implementation, and Stagnation: A Schumpeterian Theory of Convergence Clubs. *Journal of Money, Credit and Banking*, 37 (1), pp. 147–177. doi: 10.1353/mcb.2005.0006

Jarque, M.C. & Bera, K.A. (1980). Efficient Tests for Normality, Homoscedasticity and Serial Independence of Regression Residuals. *Economics Letters*, 6 (3), pp. 255–259. doi: 10.1016/0165-1765(80)90024-5

Jarque, M.C. & Bera, K.A. (1987). A Test for Normality of Observations and Regression Residuals. *International Statistical Review*, 55 (2), pp. 163–172. doi: 10.2307/1403192

Kleibergen, F. & Paap, R. (2006). Generalized reduced rank tests using the singular value decomposition. *Journal of Econometrics*, 133 (1), pp. 97–126. doi:10.1016/j.jeconom.2005.02.011

Koenker, R. (1981). A note on studentising a test for heteroscedasticity. *Journal of Econometrics*, 17 (1), pp. 107–112. doi: 10.1016/0304-4076(81)90062-2

Nelson, R. & Phelps, S.E. (1966). Investment in Humans, Technological Diffusion, and Economic Growth. *American Economic Review*, 56 (1/2), pp. 69–75.

Newey, K.W. & West, D.K. (1987). A Simple, Positive Semi-Definite, Heteroscedasticity and Autocorrelation Consistent Covariance Matrix. *Econometrica*, 55 (3), pp. 703–708. doi: 10.2307/1913610

Pesaran, M.H. (2004). *General diagnostic tests for cross-section dependence in panels*. CWPE Working Paper 35/04. Cambridge, UK: University of Cambridge.

Rogers, H.W. (1993). sg17: Regression standard errors in clustered samples. *Stata Technical Bulletin,* 13, pp. 19–23.

Romer, M.P. (1990). Endogenous Technological Change. *Journal of Political Economy*, 98 (5), pp. S71–S102.

Royston, P. (1982). An Extension of Shapiro and Wilk's W Test for Normality to Large Samples. *Journal of the Royal Statistical Society. Series C (Applied Statistics)*, 31 (2), pp. 115–124. doi: 10.2307/2347973

Royston, P. (1983). A Simple Method for Evaluating the Shapiro-Francia W' Test of Non-Normality. *Journal of the Royal Statistical Society. Series D (The Statistician)*, 32 (3), pp. 297–300. doi: 10.2307/2987935

Royston, P. (1991). sg3.5: Comment on sg3.4 and an improved D'Agostino test. *Stata Technical Bulletin,* 3, pp. 23–24.

Royston, P. (1992). Approximating the Shapiro–Wilk W-test for non-normality. *Statistics and Computing*, 2 (3), pp. 117–119. doi: 10.1007/bf01891203

Royston, P. (1993a). A pocket-calculator algorithm for the Shapiro–Francia test for non-normality: An application to medicine. *Statistics in Medicine*, 12 (2), pp. 181–184. doi: 10.1002/sim.4780120209

Royston, P. (1993b). A Toolkit for Testing for Non-Normality in Complete and Censored Samples. *Journal of the Royal Statistical Society. Series D (The Statistician)*, 42 (1), pp. 37–43. doi: 10.2307/2348109

Shapiro, S.S. & Francia, S.R. (1972). An Approximate Analysis of Variance Test for Normality. *Journal of the American Statistical Association*, 67 (337), pp. 215–216. doi: 10.2307/2284728

Shapiro, S.S. & Wilk, B.M. (1965). An Analysis of Variance Test for Normality (Complete Samples). *Biometrika*, 52 (3/4), pp. 591–611. doi: 10.1093/biomet/52.3-4.591

Stock, H.J. & Wright, H.J. (2000). GMM with Weak Identification. *Econometrica*, 68 (5), pp. 1055–1096. doi: 10.1111/1468-0262.00151

Stock, H.J. & Yogo, M. (2002). Testing for Weak Instruments in Linear IV Regression. NBER Technical Working Paper 284, Cambridge, MA 02138: National Bureau of Economic Research.

Szroeter, J. (1978). A Class of Parametric Tests for Heteroscedasticity in Linear Econometric Models. *Econometrica*, 46 (6), pp. 1311–1327. doi: 10.2307/1913831

Welsch, R. E. & Kuh, E. (1977). *Linear Regression Diagnostics*. (MIT and NBER Computer Research Center Working Paper 923–77), Cambridge, MA 02139: Massachusetts Institute of Technology and National Bureau of Economic Research Computer Research Center.

Wooldridge, M.J. (2002). *Econometric Analysis of Cross-Section and Panel Data*. Cambridge MA, London, UK: The MIT Press.

Wooldridge, M.J. (2013). *Introductory Econometrics: A Modern Approach. 5th ed*. Mason, OH, USA: South-Western.

Zeira, J. (1998). Workers, Machines, and Economic Growth. *Quarterly Journal of Economics*, 113 (4), pp. 1091–1117. doi: 10.1162/003355398555847

Received: March 9, 2018
Accepted: June 25, 2018

APPENDIX

Table 1A. Countries in the panel data sample (models without education effect)

Afghanistan	Lao PDR
Albania	Latvia
Algeria	Lebanon
Angola	Lesotho
Argentina	Lithuania
Armenia	Macedonia, FYR
Australia	Madagascar
Austria	Malawi
Azerbaijan	Malaysia
Bangladesh	Maldives
Belarus	Mali
Belgium	Mauritania
Benin	Mauritius
Bhutan	Mexico
Bolivia	Moldova
Bosnia and Herzegovina	Mongolia
Botswana	Morocco
Brazil	Mozambique
Bulgaria	Namibia
Burkina Faso	Nepal
Burundi	Netherlands
Cambodia	New Zealand
Cameroon	Nicaragua
Canada	Niger
Central African Republic	Nigeria
Chad	Norway
Chile	Pakistan
China	Panama
Colombia	Papua New Guinea
Congo, Dem. Rep.	Paraguay
Congo, Rep.	Peru
Costa Rica	Philippines
Cote d'Ivoire	Poland
Croatia	Portugal
Czech Republic	Romania
Denmark	Russian Federation
Dominican Republic	Rwanda

Ecuador	Samoa
Egypt, Arab Rep.	Sao Tome and Principe
El Salvador	Senegal
Eritrea	Serbia
Estonia	Sierra Leone
Ethiopia	Singapore
Fiji	Slovak Republic
Finland	Slovenia
France	Solomon Islands
Georgia	South Africa
Germany	Spain
Ghana	Sri Lanka
Greece	Sudan
Guatemala	Sweden
Guinea	Switzerland
Guyana	Tanzania
Haiti	Thailand
Honduras	Timor-Leste
Hong Kong SAR, China	Togo
Hungary	Tonga
Iceland	Tunisia
India	Turkey
Indonesia	Uganda
Iran, Islamic Rep.	Ukraine
Iraq	United Kingdom
Ireland	United States
Israel	Uruguay
Italy	Uzbekistan
Jamaica	Vanuatu
Japan	Venezuela, RB
Jordan	Vietnam
Kazakhstan	West Bank and Gaza
Kenya	Yemen, Rep.
Korea, Rep.	Zambia
Kyrgyz Republic	Zimbabwe

Table 2A. Countries in the panel data sample (models with education effect)

Afghanistan	Lao PDR
Albania	Latvia
Algeria	Lesotho
Argentina	Lithuania
Armenia	Malawi
Australia	Malaysia
Austria	Maldives
Bangladesh	Mali
Belgium	Mauritania
Belize	Mauritius
Benin	Mexico
Bolivia	Moldova
Botswana	Mongolia
Brazil	Morocco
Bulgaria	Mozambique
Burundi	Namibia
Cambodia	Nepal
Cameroon	Netherlands
Canada	New Zealand
Central African Republic	Nicaragua
Chile	Niger
China	Norway
Colombia	Pakistan
Congo, Dem. Rep.	Panama
Congo, Rep.	Papua New Guinea
Costa Rica	Paraguay
Cote d'Ivoire	Peru
Croatia	Philippines
Czech Republic	Poland
Denmark	Portugal
Dominican Republic	Romania
Ecuador	Russian Federation

Egypt, Arab Rep.	Rwanda
El Salvador	Senegal
Estonia	Serbia
Fiji	Sierra Leone
Finland	Singapore
France	Slovak Republic
Gabon	Slovenia
Gambia, The	South Africa
Germany	Spain
Ghana	Sri Lanka
Greece	Sudan
Guatemala	Swaziland
Guyana	Sweden
Haiti	Switzerland
Honduras	Tajikistan
Hong Kong SAR, China	Tanzania
Hungary	Thailand
Iceland	Togo
India	Tonga
Indonesia	Trinidad and Tobago
Iran, Islamic Rep.	Tunisia
Iraq	Turkey
Ireland	Uganda
Israel	Ukraine
Italy	United Kingdom
Jamaica	United States
Japan	Uruguay
Jordan	Venezuela, RB
Kazakhstan	Vietnam
Kenya	Yemen, Rep.
Korea, Rep.	Zambia
Kyrgyz Republic	Zimbabwe