European Research Studies Journal
Volume XXIII, Issue 4, 2020

pp. 1157-1176

The Role of Ethnic Diversity in Stimulating Innovation Processes: Comparative Analysis of Poland, the Czech Republic and Hungary

Submitted 23/08/20, 1st revision 29/09/20, 2nd revision 20/10/20, accepted 06/11/20

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Abstract:

Purpose: *Since existing literature suggests that ethnic diversity is one of the key elements that shape the dynamics of innovation, we examine whether inventions generated by ethnically diverse teams in the Czech Republic, Poland and Hungary are more valuable than those created by homogenous teams of native researchers.*
Design/Methodology/Approach: *Using the OLS method, we estimate the parameters of the regression model in order to examine the relationship between ethnic diversity and the quality of technical solutions created as well as to determine which ethnic group and which combination of these groups (for each country) has the greatest impact on the quality of inventions. We take the frequency of citation as a measure of the quality of inventions, and the degree of ethnic diversity in the inventor team is measured using the Herfindahl index.*
Findings: *Based on a cross-sectional data set being a sample of 2518 international patent applications (PCT) from 2004-2012, we have observed that both the mere presence of foreigners as well as greater ethnic diversity in the inventor team significantly increase the quality of technical solutions in Poland and Hungary, and moderately in the Czech Republic. Our study has also revealed that of all ethnic groups, Americans have the greatest impact on the citation of inventions, and it is the case in all three countries covered by the study. The optimal combination of individual groups, however, is different for each of these three countries: in Poland, the highest quality of inventions is related to the presence of citizens of the US, Belgium, Japan and Turkey, in Hungary – the US and Israel, and in the Czech Republic – the US, Germany and Canada.*
Practical Implications*: The research results can be used by decision makers in Poland, the Czech Republic and Hungary when shaping the countries' migration and innovation policies.*
Originality/Value*: Original research.*

Keywords: *Ethnic diversity, migration, innovation, knowledge flows, inventors, patents.*

JEL classifications: *C31, F22, J15, O15, O31.*

Paper type: *Research article.*

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1. Introduction

Creating a favorable environment for innovation processes is becoming one of the major challenges of modern economies. Innovations, in particular breakthrough technical solutions, determine the competitive success of companies and are a key factor for the well-being and long-term growth of countries and regions. The literature indicates that one of the sources of innovation is broadly conceived diversity. A diverse population or team of employees makes it possible to combine not only different cultures, religions, gender or age, but also different stocks of knowledge, ideas, skills, experiences and research perspectives, often very unique for specific cultural environments. The diversity makes a group of people more creative, open to non-standard ideas, have greater absorption capacity, and thus being able to solve emerging problems more effectively. It is also an impulse for creative exchange of ideas between actors, which makes organizations as well as entire regions or countries more innovative.

In recent years, it is especially the role of ethnic diversity in stimulating innovation that has become the subject of lively discussion. This is largely due to the evidently increased global population flows as well as the ethnic structure of immigrants evolving towards greater diversity in terms of country of origin. Also, the experience of the United States of America, in which the influence of foreign cultures on innovation is simply striking, affects the intensification of research in this area. The fact that the US benefits from the circulation of international and diverse knowledge prompts other countries to join the international "race" for talent. At the same time, both countries belonging to the technological leaders as well as those located further in international innovation rankings compete for the most valuable human capital.

Unfortunately, cultural diversity also has a dark side. It can be a source of many misunderstandings and conflicts (Østergaard *et al*., 2011), lead to lower trust and poorer communication between individuals (Alesina and La Ferrara, 2005), which hinders cooperation (Joshi and Jackson 2003) and eventually pulls precious human capital away from research tasks (Pelled *et al*., 1999) as well as leads to fewer solutions with less economic potential (Alesina and La Ferrara, 2005). Consequently, instead of helping, the diversity becomes a barrier to achieving a higher level of innovation (Basset-Jones, 2005; Noja and Cristea, 2018)).

Given that ethnic diversity can have both positive and negative effects, the final contribution of diversity to innovation may depend on the context. However, many countries seem to disregard this fact, failing to see that factors that promote innovation may vary depending on the country's innovation level. As a result, they forcefully implement solutions that work in the most innovative countries but are not necessarily adapted to the conditions of less innovative economies.

The subject of this paper is the impact of ethnic diversity among employees on innovation performance of countries that do not belong to the top innovators in the

world. More specifically, the aim of the article is to indicate the relationship between ethnic diversity among inventors and the economic potential of inventions they generate that are filed for patent protection by entities from Poland, the Czech Republic and Hungary: the three most populous countries of Central and Eastern Europe that joined the EU in 2004. We mainly wonder whether the presence of foreigners and their greater ethnic heterogeneity increases the quality of these inventions and whether it is possible to identify specific ethnic groups or combinations of these groups that make a particular contribution in this regard.

We use citation frequency as a measure of the quality of inventions. By doing this we assume that more groundbreaking inventions, with greater commercial potential, will be more likely to be cited by others. To measure the degree of diversity in a research team in terms of ethnicity, which we have reduced to diversity in terms of citizenship due to limited data, we have used the Herfindahl index. On a sample of 2518 international patent applications, in the first stage of the study we conduct a simple linear regression analysis and a classical correlation analysis to examine the relationship between ethnic diversity and the level of innovation of technical solutions created, then, using multiple regression, we determine which ethnic group and which combination of these groups (for each country) has the greatest impact on the innovation potential of inventions. In order to obtain the number of citations and the data on detailed characteristics of the inventions, e.g. the ethnic composition of the inventor team, we have conducted our own research focused on an analysis of international patent applications (PCT) filed in 2004-2014 by entities from Poland, the Czech Republic and Hungary.

We contribute to the discussion on the role of ethnic diversity in increasing innovation in a few ways. First, we provide evidence for the countries that are further in international innovation rankings – Poland, the Czech Republic and Hungary – thus taking into account the possibility that factors promoting innovation may vary depending on the technological potential of the country. Previous studies examining the relationship between ethnic diversity and innovation relate mainly to the US while there are few studies focusing on other countries, especially those not being innovation leaders. There is a lack of studies, among others, regarding the experience of Central and Eastern European countries, i.e., Poland, the Czech Republic and Hungary. This is a certain oversight given that migration intensified in these countries after they had joined the European Union in 2004. Moreover, they note – especially Poland – an increasing inflow of highly qualified immigrants (OECD, 2017).

Second, we focus on the qualitative dimension of innovation, i.e. we analyze the impact of ethnic diversity not so much on the quantity as the quality of innovations. We are interested in whether ethnic diversity among inventors increases the quality of technical solutions created which – as can be presumed – will be the greater, the more citations these solutions receive. Studies focused on the benefits of the ethnic diversity of an inventor community tend to be limited to examining the relationship between

diversity and innovation as measured by the number of patent applications (Niebuhr, 2010; Parrota *et al*., 2014; Nathan, 2014; Bahar *et al*., 2019; Noja, 2018).

Third, we consider not only the number of different ethnic groups but also optimal ethnicity combinations leading to higher quality inventions. This is a rarely used approach in existing literature. The majority of studies linking ethnic diversity with innovation do not go beyond indicating a specific national group that contributes most to increasing innovation while they do not seek the optimal combination of different ethnic groups that are responsible for the greatest success under certain conditions.

The rest of the paper is organized as follows. Section 2 contains a brief review of the literature from the perspective of the role of ethnic diversity in raising the level of innovation. Section 3 describes the data and the method used in this work. The results of the study are presented in Section 4, and the main conclusions, policy implications and directions of future research in the final section.

2. Ethnic Diversity and Innovation: A Literature Review

Research into the contribution of ethnic diversity to innovation seeks answers to three key questions. Firstly, whether areas (e.g., countries, regions, urban agglomerations) that are more ethnically diverse are also more innovative, e.g. whether they have more patents. Secondly, whether teams of employees that are more ethnically diverse are more innovative than homogeneous teams, created only by native employees, e.g. whether they generate more inventions. Finally, whether companies that employ more ethnically diverse teams of employees are more innovative.

Three research approaches are related to these three questions. The first, which identifies the effects of diversity at the state, region, or city level, is the most indirect. In this case it is *de facto* only presumed that immigrants, by leading to greater ethnic diversity in each geographical area, contribute to greater innovation. Studies in this literature current infer the contribution of ethnic diversity to innovation from positive relationship between the number of immigrants in the population and the number of either patent applications or non-technical innovations. In fact, there is no certainty whether it is ethnic diversity *per* se or rather the influx of so-called „stars" or other factors that drive the region's innovative results. This uncertainty is magnified by the fact that the vast majority of studies representing this approach focus on geographic areas that, due to their high level of prosperity and innovation, have at the same time huge potential for attracting talents.

In absolute terms, the United States of America, Germany, Switzerland, and the United Kingdom have the greatest potential for attracting talent (Miguelez and Fink, 2013). In the light of research representing the first approach, these are also countries that significantly benefit from the inflow of highly skilled migrants and the resulting ethnic diversity. According to literature, ethnic diversity increases productivity at the urban level in the US (Ottaviano and Peri, 2004) and is conducive to more patents in

American cities rich in breakthrough technologies (Kerr, 2009). It is also conducive to patents at the national level. As Hunt and Gauthier-Loiselle (2010) report, an increase in the number of immigrant scientists and engineers in the US by 0.45 percentage points increases the number of patents per capita by about 13% while an increase in the number of immigrants in colleges by one percentage point leads to 9-18% increase in the number of patents per capita.

Similar benefits at the level of geographic area are achieved by Germany, another leader both in technology and in attracting the most valuable human capital from abroad. Niebuhr (2010), for example, notes that highly qualified foreign employees contribute to the increase in regional productivity of R&D sectors in Germany. Moreover, the benefits of this diversity outweigh the negative effects associated with the inflow of foreigners. In turn, Audretsch *et al*. (2010) observe that German regions with a high degree of cultural diversity are ideal grounds for technology-oriented start-ups. Meanwhile, in the case of the UK, which is also listed among countries providing a favorable environment for talented individuals, Nathan (2014) finds that increasing the ethnic diversity of inventors by about one standard deviation in a city such as Bristol may be worth up to about 40 additional patents in total. This positive impact is especially evident in the population of East Asian inventors.

Studies conducted on a larger group of countries also provide evidence of a positive relationship between immigration and innovation at the macro level. Ozgen *et al.* (2011) observe that regions of Western Europe with a higher proportion of foreign-born residents have more patent applications per capita. Bosetti *et al.* (2012), in turn, argue that skilled migrants contribute to the creation of more inventions filed for patent protection in 20 European countries. Bahar *et al.* (2018), based on a sample of 135 countries, argue that migrants, by creating networks that facilitate interaction between nations, stimulate patenting in host countries. Importantly, this also applies to countries that do not have the initial conditions and are not endowed in the factors associated with the production of technology. Bahar *et al.* (2019), meanwhile, prove that a twofold increase in the number of foreign inventors is associated with a 25 to 50% increase in the probability of patenting certain technologies in host countries.

While for countries high in international innovation rankings the ethnic diversity resulting from the inflow of skilled migrants strengthens innovation processes at the area level, the conclusions of studies focusing on other economies are no longer so clear (Marcu *et al.,* 2018). Bratti and Conti (2018) point out that the proportion of immigrants in Italy does not translate into either technical innovations (patents) or any other innovations. Contrary to this, Stojčić *et al.* (2016) argue that international movement of people positively affects innovation in Croatian counties.

The results of studies in the second approach also mostly support the commonly formulated hypothesis in the light of which ethnic diversity facilitates activities related to knowledge transfer and innovation process. It should be noted, however, that these studies, similarly to those discussed previously, mostly focus on highly innovative

countries, including in particular the US, which generally does not give certainty that ethnic diversity is important for innovation under all conditions.

In their pioneering work, Stephan and Levin (2001) believe that those born abroad are a source of strength and vitality for American science as they are more than proportionately represented among the 250 most-cited authors, authors of highly cited patents, and individuals selected for the National Academy of Sciences and the National Academy of Engineering. Wadhwa *et al.* (2007) come to similar conclusions and state that the percentage of foreigners living in the US who participated in PCT patent applications filed from the US increased from 7.3% in 1998 to 24.2% in 2006, with immigrants born in China, India, Canada and the UK making a particularly strong contribution to the US inventive output. Kerr (2008) as well as Kerr and Lincoln (2010), also using the example of the US, note that – given the number of patent applications – foreign employees are more innovative than natives. Hunt (2011) confirmed these findings, observing that immigrants who entered the US on a student visa or temporary worker visa in their youth have an advantage over US citizens as to patenting, commercialization, patent licensing and publishing. However, uneducated immigrants or those who arrived in old age do not surpass natives in this regard.

Apart from the sole experience of the US, evidence from other studies is mixed. Based on a sample of 9 million articles and 6 million scientists from around the world, AlShebli *et al.* (2018) observe that publications with diverse ethnic composition in the structure of authors are better in quality, as they are more often cited by others. However, Barjak and Robinson (2008) show, on a sample of many different countries, that the most successful academic research teams in natural sciences have a moderate level of cultural diversity, which suggests that ethnic diversity is not a necessary condition for success.

Of the three approaches in examining the impact of ethnic diversity, by far the most difficult – as Ozgen *et al.* (2013) suggest – is the last one, in which the effects of diversity are identified at the organizational level. In practice, namely, "it attempts to empirically identify localized spillover benefits of foreign workers who mostly only represent a small minority of the employees" (Ozgen *et al.*, 2013). Perhaps this is why the empirical evidence from these studies is very mixed: from extremely negative, where a higher percentage of foreigners among the employees of an organization clearly reduces its innovation (Baset-Jones, 2005; Ozgen *et al.*, 2013; Brixy *et al.*, 2017; Awaworyi Churchill and Valenzuela, 2018), to claims that ethnic diversity does not translate into significant benefits in this regard (Østergaard *et al.*, 2011; Schneider and Eckl, 2016), to optimistic voices suggesting that ethnic diversity in a team of employees is important (Fleming, 2001; Brunow and Stockinger, 2013; Parrota *et al.*, 2014; Lee, 2015; Pholphirul and Rukumnuaykit, 2017) for the company's innovation processes.

To sum up, it can be said that the results of studies largely depend on the level of their aggregation as well as on the country of focus. Generally, the higher the level of

aggregation of a study, the greater the chance that a positive relationship between ethnic diversity and innovation will be revealed. The likelihood of detecting positive externalities in ethnic diversity is also greater for the US than for other countries. In principle, all studies in which authors indicate that ethnic diversity either has no significant impact on innovation (Barjak and Robinson, 2008; Østergaard *et al*., 2011; Schneider and Eckl, 2016; Bratti and Conti 2018) or even reduces innovative performance (Baset-Jones, 2005; Ozgen *et al.*, 2013; Brixy *et al.*, 2017) relate to other countries, such as Denmark, the Netherlands, Italy or Germany.

3. Data and Research Method

3.1 Research Sample

In the paper, we wonder if the presence of foreigners is beneficial from the perspective of the quality of inventions filed for patent protection by the host countries. We examine whether inventions generated by ethnically diverse teams of inventors are more groundbreaking, have greater innovation potential than those created by homogenous teams.

The empirical analysis has covered international patent applications (PCT) from 2004-2012 filed by entities from three Central and Eastern European countries: Poland, the Czech Republic and Hungary. However, by applications of entities from Poland, the Czech Republic and Hungary we understand only applications that have been submitted by Polish, Czech and Hungarian entities with headquarters located in Poland, the Czech Republic and Hungary, respectively. The so-called individual applications have been excluded from the analysis because the mixed ethnic structure of their inventors who are also applicants makes it impossible to clearly assign the patent application to a specific country.

Ultimately, the research sample consisted of 2518 patent applications, of which 992 belonged to Polish, 808 to Czech and 718 to Hungarian entities. Of the total number of 2518 applications, 420 represented ethnically mixed inventor teams, accounting for 16.68%, with the largest percentage of inventions generated by ethnically heterogeneous teams being in the Czech Republic (18.56%), then Hungary (17.41%) and Poland (14.62%).

3.2 Measurement

The measure of quality or breakthrough of an invention used in this paper is the frequency of its citation, i.e., the number of citations (excluding auto-citations at the applicant's level) the invention received by April 2019. Patent citations are a recognized and often used measure of the value of an invention (Trajtenberg, 1990). It is also assumed that the greater number of citations reflects the higher economic potential of the invention and proves its greater importance for the economy and science.

The Herfindahl index (HI) was used to measure the degree of ethnic diversity of an inventor team, and more specifically its diversity based on citizenship. Its value may vary from 0 to 1, and the higher it is, the greater the diversity of the team, while the value of 0 means the inventor team is homogeneous. We calculate HI as:

$$HI = 1 - \sum_{i=1}^{N} s_{ij}^2 ,$$

where s_{ij} is the share of the group of inventors with citizenship i (i = 1, …, N) in the team of inventors j.

To investigate whether diverse teams of researchers increase the quality of inventions created, we conduct the study in two stages. First, we perform a preliminary interdependence analysis using the Pearson correlation coefficient, and then using the method of ordinary least squares (OLS) we estimate the parameters of the linear regression function:

$$Y = \alpha_0 + \alpha_1 X + \varepsilon ,$$

where the dependent variable (Y) is the quality of inventions (the number of citations received by the invention), while the independent variable (X) is ethnic diversity (the Herfindahl diversity index).

In order to determine the ethnic group most responsible for the quality of inventions, we use the multiple linear regression method and then employ step-wise insignificant variable elimination to determine the optimal combination of ethnic groups (in individual countries) in terms of significance, which is associated with the highest probability that the invention will be frequently cited. To this end, we use the method of ordinary least squares to estimate the regression function:

$$Y = \alpha_0 + \alpha_1 X_1 + \cdots + \alpha_n X_n + \varepsilon ,$$

where the dependent variable (Y) is the quality of inventions (the number of citations received by an invention), while the independent variable X_i is the number of foreigners in the inventor team from the *i*th ethnic group.

The time range of the study is 2004-2012. The beginning of the research period is the year of accession of the three countries covered by the study (Poland, the Czech Republic and Hungary) to the European Union. We stopped the analysis on year 2012, recognizing that inventions submitted after that time were significantly less likely to be cited. This is due to the fact that the dissemination of information about an invention takes time and, consequently, many years of delays in patent citations are observed, ranging from 3 to as many as 16 years (Adams *et al*., 2006; Adams and Clemmons, 2013; Wachowska, 2016).

3.3 Data Sources

Information regarding the frequency of citation of Polish, Czech and Hungarian inventions, and their detailed characteristics, such as ethnic composition of inventors, was obtained as the result of an analysis of international patent applications (PCT). The PCT application form has been developed by the World Intellectual Property Organization (WIPO), which also deals with the administrative handling of applications and their collection in the PatentScope database. In many respects, the PCT form resembles questionnaires filled under the national or regional procedures. First of all, it contains basic data about the applicant, inventor and invention itself, such as the date of filing the patent application, name and surname of the inventor, their place of residence on the day of filing the patent application, name and place of the applicant's seat, field of technology of the invention and patent citations (references to someone else's prior publication or patent). However, unlike all these patent applications, PCT applications contain one more information – the nationality (more precisely, the citizenship) of the applicant, and until September 16, 2012 also that of the invention's author.

From the perspective of the research undertaken in this paper, the latter information is particularly useful because it allows us to determine the number of inventors of foreign ethnic origin mentioned in Polish, Czech and Hungarian PCT patent applications and thus their contribution to improving the quality of inventions.

Despite their many advantages, such as the high precision and reliability of the information disclosed, the PCT patent data – mainly as regards the information on the inventor's ethnic origin – have their limitations. First of all, they allow us to determine only the inventor's citizenship, which means that when estimating the number of foreigners, long term migrants who obtained citizenship of the host country before filing the patent application may be lost. This means that it is not possible to accurately determine the contribution of naturalized persons who in fact can be more effective in increasing innovation than migrants who arrived later.

Additionally, due to changes in the US patent law introduced on January 16, 2012 as a result of the Leahy-Smith America Invents Act (AIA), only part of PCT applications filed after September 16, 2012 registers the citizenship of the authors of inventions (for details, see Miguelez and Fink, 2013), hence the nationality of the inventors can be inferred only from the ethnic origin of their surnames, which for obvious reasons is subject to great uncertainty. Due to the fact that the time scope of this study was limited to 2004-2012, the citizenship of inventors in the years 2004-2011 was identified on the basis of unambiguous information provided in patent documents, while in 2012 applications that lacked such unambiguous information were omitted[3].

[3] *In the vast majority of cases, applications from 2012 contained information about the citizenship of the inventor.*

4. Study Results

4.1 Citation of Inventions

In general, the inventions of all three countries covered by the analysis (Poland, the Czech Republic, Hungary) represent a small economic value, at least when measured by the number of citations received, with Czech Republic performing the best in this list, and Poland the worst (Table 1). Moreover, in all these countries the distribution of citations is asymmetric and skewed to the right, which means that inventions with a small or very small number of citations or those that did not have any citations prevail (Figure 1). Poland performs worst in this respect again, as the percentage of inventions without citations exceeds 35% while the ratio for the Czech Republic and Hungary is just over 22%. The mean and median values also confirmed these differences (Table 1).

When considering separately inventions created only by teams of native researchers and teams with (any) foreign inventors, it can be seen that in each of the countries studied the inventions of the native ones are much less frequently cited than inventions created with the participation of foreigners (Table 2, Figure 2). This disproportion is particularly evident in Hungary, where technical solutions created only by natives received on average less than 4 citations, while those generated by ethnically diverse teams on average more than 7.5. The obtained results indicate that the participation of foreign inventors increases the quality of generated technical solutions and does so significantly.

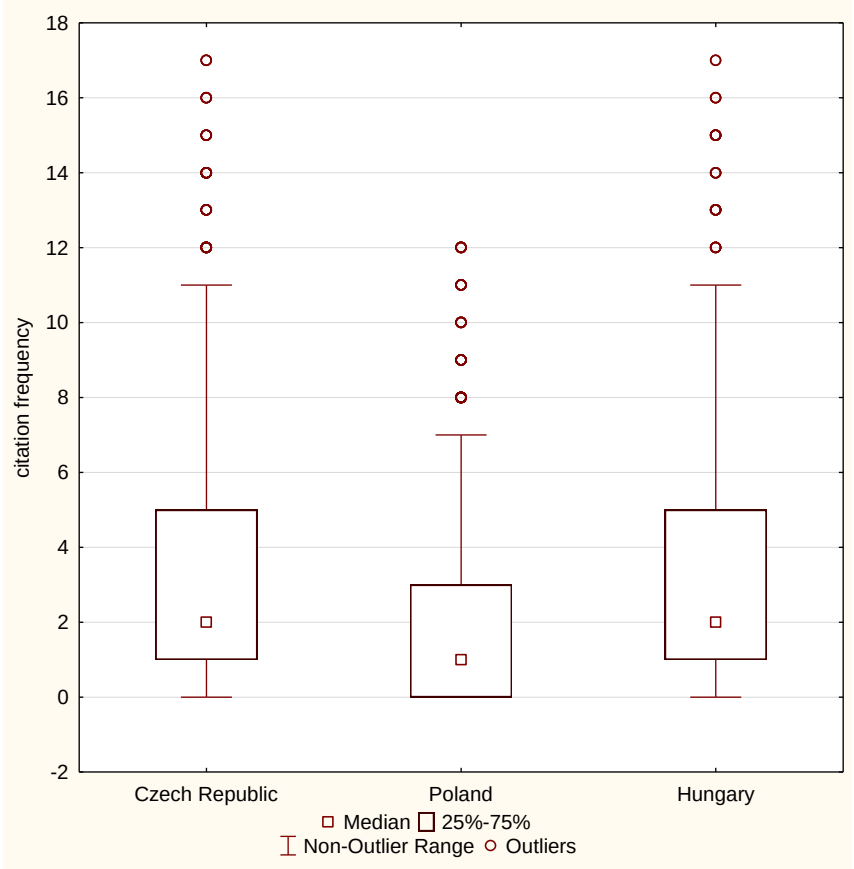
Table 1. *Basic descriptive statistics of the invention quality variable in individual countries*

Country	Mean	Median	Q1	Q3	S	skewness
the Czech Republic	5,0941	2	1	5	0,3576	6,9188
Poland	3,5232	1	0	3	0,2851	7,6789
Hungary	4,5348	2	1	5	0,3141	7,4279

Source: *Authors' own research.*

This is also confirmed by the results of the correlation analysis for the number of citations shown in Table 3. The obtained values of correlation coefficients between citations and the country in which the invention is filed are low, which proves that the impact of this country on the quality of inventions filed is non-significant. At the same time, however, when considering the participation of foreign inventors, the obtained p values (less than 0.05) indicate that there are grounds for rejecting the null hypothesis about the lack of non-significant correlation in favor of the alternative hypothesis: the correlation is significant. Therefore, the mere fact of foreign presence in the creative process increases the number of citations, which means that it is thus an important factor for the quality of an invention.

Figure 1. *Distribution of citations by country of submission*



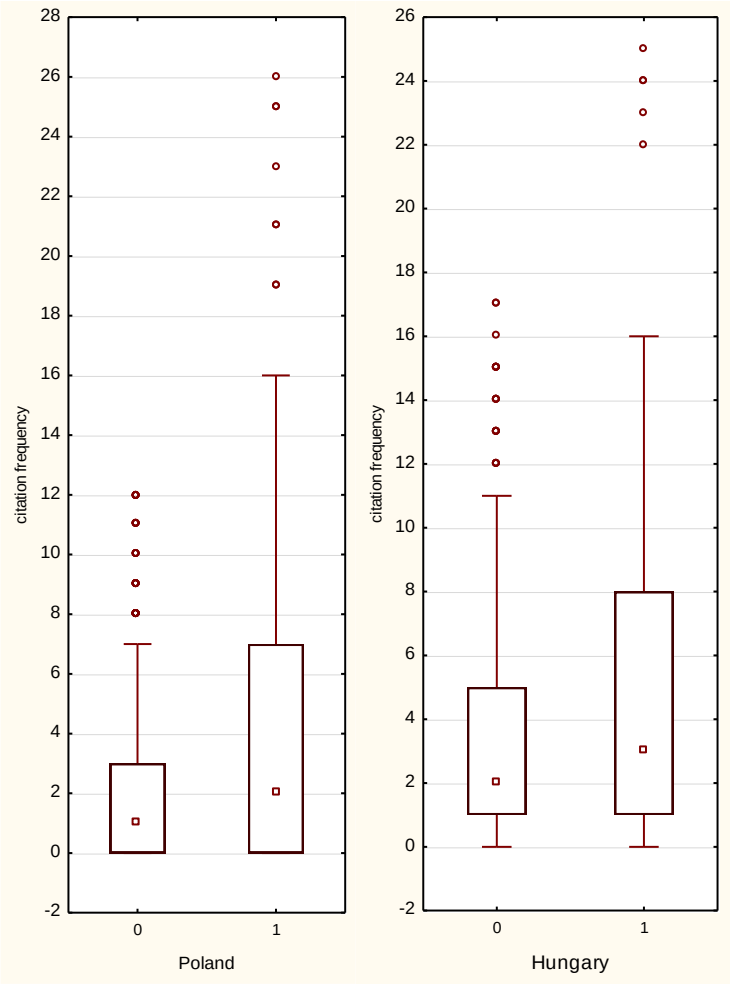
Source: *Authors' own research.*

Table 2. *Basic descriptive statistics of invention quality variable in individual countries, taking into account the participation of foreign inventors*

Country	Participation of foreigners in inventor team	Mean	Median	Q_1	Q_3	S	skewness
the Czech Republic	NO (0)	4,6657	2	1	5	0,3847	8,0592
	YES (1)	6,9733	3	1	8	0,9164	3,6287
Poland	NO (0)	3,0614	1	0	3	0,2868	9,4690
	YES (1)	6,2207	2	0	7	0,9731	3,3902
Hungary	NO (0)	3,8954	2	1	5	0,2351	4,2055
	YES (1)	7,5680	3	1	8	1,3911	5,3635

Source: *Authors' own research.*

Figure 2. *Distribution of citations by country of submission, taking into account the participation of foreign inventors*



Source: *Authors' own research.*

Table 3. *Pearson correlation coefficients for patent quality with selected variables*

Variable	Pearson coefficient	T(n-2)	p-value	Significance $\alpha = 0{,}05$	Significance $\alpha = 0{,}1$
Native	-0,0260	-1,30696	0,191	-	-
Patent with participation of foreign inventors	0,1246	6,298801	0,00000	+	+

Source: *Authors' own research.*

4.2 Ethnic Diversity and the Quality of Inventions

In the light of previous results, it can be said that the very participation of foreigners among inventors increases citation frequency and thus positively affects the quality of the invention. However, another important question is whether greater ethnic diversity results in receiving more citations.

Table 4. *Average HI in 2004-2012*

country	measure	2004	2005	2006	2007	2008	2009	2010	2011	2012	2004-2012
the Czech Republic	mean	0,2605	0,3265	0,3042	0,2545	0,3961	0,3208	0,3727	0,2983	0,2169	0,3230
	median	0,2775	0,3750	0,3750	0,2449	0,4444	0,4444	0,4097	0,3750	0,2598	0,3750
Poland	mean	0,3661	0,4081	0,3181	0,3000	0,3479	0,4141	0,2575	0,3160	0,1624	0,3091
	median	0,4375	0,4444	0,3750	0,5000	0,4444	0,4444	0,2449	0,4444	0,0000	0,4200
Hungary	mean	0,3522	0,3377	0,2533	0,2158	0,3151	0,2850	0,2531	0,2809	0,1699	0,2765
	median	0,4444	0,3750	0,3750	0,1700	0,3750	0,3750	0,2449	0,3099	0,0000	0,3750

Source: *Authors' own research.*

To resolve this, the index $HI_j, where\ j = 1,2,\dots,2518$ was calculated for all patent applications and the change in parameters of the location of its distribution in individual countries was examined, taking into account the year of filing the invention (Table 4). On the basis of the results obtained it can be said that in all the countries the HI index is not characterized by a clear tendency to change over time, which means that there is no clear trend to increase the ethnic diversity of inventors over the period considered. The average HI index level of around 0.3 indicates that ethnic diversity should be considered moderate regardless of the country in which the invention is filed.

In order to further verify the hypothesis: *ethnic diversity is conducive to greater citation frequency*; therefore, correlation analysis should be performed. Due to the lack of tendency to change over time, the classical Pearson correlation coefficient and a test of the correlation significance were used, and the results are presented in Table 5.

Table 5. *Verification of the significance of the correlation between HI and citation frequency*

Variable	Pearson coefficient	T(n-2)	Significance $\alpha = 0{,}05$	Significance $\alpha = 0{,}1$
the Czech Republic	0,06239750	1,77493	-	+
Poland	0,09697867	3,06581	+	+
Hungary	0,15369500	4,16205	+	+

Source: *Authors' own research.*

The results of the verification of hypotheses presented in Table 5 indicate a significant relationship between ethnic diversity and citation frequency in the case of inventions in Poland and Hungary, while in the Czech Republic at the significance level of 0.05 this relationship should considered insignificant. It means, therefore, that the highly cited inventions in Poland and Hungary are characterized by higher ethnic diversity and it is this diversity that increases their citation frequency. It is worth noting that by increasing the significance level, i.e., increasing the deductive fallacy, it can be said that also in the Czech Republic ethnic diversity plays an important role and increases citation of inventions, albeit to a lesser extent. Simple regression analysis was used to assess the impact of the increase in ethnic diversity on the change in the level of citation. The results of the estimation of the parameters of the model with the use of the method of ordinary least squares (OLS) for the countries studied are presented in Table 6.

The results of the OLS estimation show that in the case of Poland and Hungary the low p value gives grounds for rejecting the null hypothesis in the Student's t-test of significance of parameters (regardless of the level of significance), which means that ethnic diversity affects the quality of inventions. The positive value of parameters in both cases suggests that an increase in the HI index results in an increase in citation, and therefore greater ethnic diversity increases innovation potential of inventions. Meanwhile, in the case of the Czech Republic the simple regression parameter at the significance level $\alpha = 0{,}05$ is not significant; however, increasing the level of accepted error to $\alpha = 0{,}1$ allows us to conclude about the significant impact of ethnic diversity on citation, nevertheless this impact is the smallest, which is confirmed by the correlation analysis results.

Table 6. *OLS estimator of the slope of the HI variable with significance estimation*

Variable	the Czech Republic	Poland	Hungary
Slope of HI	0,000404952	0,000615032	0,000918607
t-Student	1,775	3,066	4,162
p value	0,0763	0,0022	3,54e-05
Significance $\alpha = 0{,}05$	-	+	+
Significance $\alpha = 0{,}1$	+	+	+

Source: *Authors' own research.*

4.3 Ethnic Groups with the Highest Innovation Potential

Because ethnic diversity determines the innovation potential of inventions, the next stage of the analysis attempts to answer the question which ethnic group has the greatest impact in this regard. For this purpose, the multiple regression method was used, and then, using step-wise insignificant variable elimination, the final combination of ethnic groups (in individual countries) was obtained, associated with the highest probability that the invention would often be cited (Table 7).

Based on the results from Table 7 regarding the OLS estimation of multiple regression, it can be said that the presence of Americans significantly ($value\ p \leq 0{,}05$) increases citation in all countries covered by the study. Therefore, based on this, Americans, responsible for highly cited inventions, should be indicated as the main ethnic group of inventors important for increasing citation in all the countries studied. Changes in the distribution of the citation frequency that results from the presence of Americans in the team of inventors are illustrated in Figure 3.

Table 7. *Results of the OLS estimation of multiple regression after the step-wise elimination of insignificant variables*

THE CZECH REPUBLIC

Model 1: OLS estimation, units of observation 1-808

	coefficient	standard error	t-Student	p value	
const	4,62932	0,354006	13,08	1,43e-035	***
USA	**37,0286**	**6,07837**	**6,092**	**1,73e-09**	*******
CANADA	42,3707	9,80488	4,321	1,74e-05	***
GERMANY	7,02561	2,29146	3,066	0,0022	***

POLAND

Model 2: OLS estimation, units of observation 1-992

	coefficient	standard error	t-Student	p value	
const	3,19783	0,275662	11,60	2,93e-029	***
USA	**30,2096**	**7,26244**	**4,160**	**3,46e-05**	*******
BELGIUM	29,6769	8,02619	3,698	0,0002	***
JAPAN	122,080	18,4215	6,627	5,63e-011	***
TURKEY	189,011	43,0336	4,392	1,24e-05	***

HUNGARY

Model 3: OLS estimation, units of observation 1-718

	coefficient	standard error	t-Student	p value	
const	3,82037	0,299669	12,75	1,09e-033	***
USA	**5,58674**	**2,20959**	**2,528**	**0,0117**	******
ISRAEL	23,7229	2,17986	10,88	1,25e-025	***

Source: *Authors' own research.*

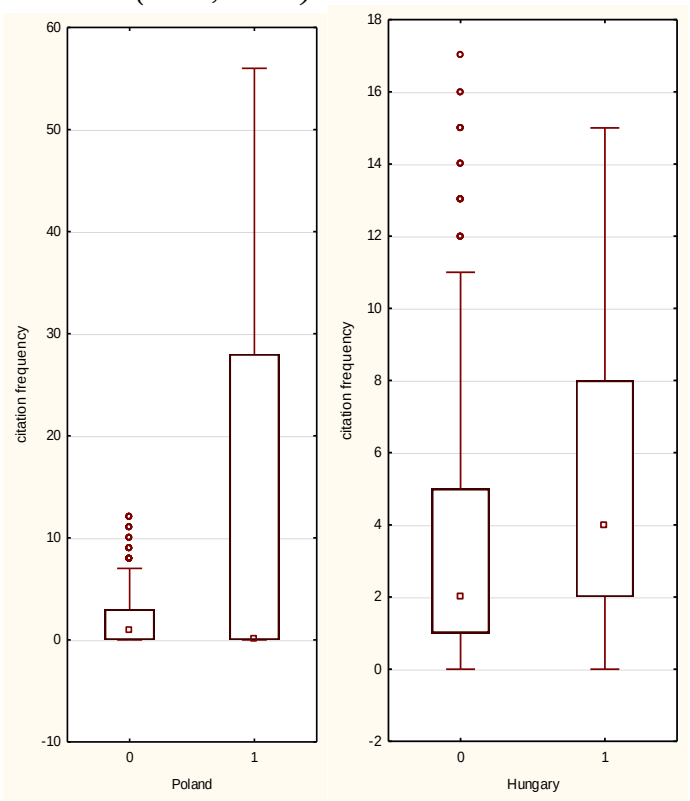
In addition, the results of multiple regression (Table 7) indicate that, depending on the country in which the invention is filed, Americans form the optimal combination with various ethnic groups, none of which is the same. And so, in the case of the Czech Republic, the higher probability that the invention will be cited is related to the additional presence of Germans and Canadians, in Poland – Japanese, Turks and Belgians, while in Hungary they are Israeli citizens. Therefore, considering the right combination of ethnic groups constituting optimal ethnic diversity in each country, basic descriptive statistics of citation were examined to determine whether it could actually be assumed that increased citation frequency was observed. The results are shown in Table 8.

Table 7. *Basic descriptive statistics of citation taking into account the optimal combination of ethnic groups*

Country	Presence of Americans	Presence of citizens from optimal ethnic groups indicated for the given country	Mean	Median	Q1	Q3	S	Skewness
the Czech Republic	NO	NO	4,9210	2	1	5	0,3438	7,3519
	YES	NO	12,3148	7	2	14	2,1643	2,5554
	YES	YES	17,6364	4	2	19	7,7615	1,9958
Poland	NO	NO	3,4380	1	0	3	0,2774	8,1029
	YES	NO	14,0000	0	0	28	9,0574	1,4399
	YES	YES	19,6190	5	1	37	5,2461	0,9592
Hungary	NO	NO	4,1327	2	1	5	0,2280	3,7865
	YES	NO	11,9153	7	2	11	2,7693	3,9337
	YES	YES	13,1563	4	2	8	4,9066	3,2308

Source: *Authors' own research.*

Figure 3. *Change in the distribution of citations taking into account the presence of Americans (0-NO; 1-YES)*



Source: *Authors' own research.*

The conducted analysis of the basic parameters of citation frequency distribution confirms that ethnic diversity determines the innovation potential of inventions; however, the presence of specific ethnic groups that affect the increase in citation is important. In the considered case, including the indicated ethnic groups in the inventor team optimizes the citation frequency and thus ensures the highest quality and potential of the invention.

5. Concluding Remarks

Since 1990, when migration became a truly global phenomenon (Massey, 1990, p. 61; Massey, 2003, p. 5-6), not only an increase in the number of people moving around the world has been observed but also changes in the structure of the migrant population. They have become increasingly diverse in terms of their country of origin, education, skills, gender, and age.

Poland, the Czech Republic, and Hungary, although they continue to be countries that rather send than receive migrants, also experience increased inflows of increasingly diverse foreigners. At the same time, these are countries located in further positions in international innovation rankings (Cornell University, 2018) which therefore strive to actively work to reduce the distance that separates them from the most innovative economies in the world.

As it is pointed out in literature that ethnic diversity is conducive to innovation, it becomes an important question for Poland, the Czech Republic and Hungary whether they can take advantage of the dormant potential in human capital from abroad. This paper answers this question to some extent. In the paper, we reflect on the role internationally mobile inventors play in increasing the innovation of their host countries. More precisely, whether in Poland, the Czech Republic and Hungary ethnically diverse teams of inventors create inventions of higher quality (with a greater number of citations) than homogeneous teams of native researchers.

We find that in all three countries covered by the analysis, the mere participation of foreigners in the inventor team increases citation frequency and thus positively affects the quality of inventions. This is demonstrated by the results of both the analysis of correlation and the average number of citations, which in the case of heterogeneous teams ranges from 6.22 to 7.57, and in the case of homogeneous teams from 3.06 to 4.66. Not only the presence itself but also the greater degree of ethnic diversity among inventors translate into higher innovation potential of technical solutions created, with this effect being in this case more visible in Poland and Hungary than in the Czech Republic.

Our findings have also shown that the contribution of immigrants from individual ethnic groups to increasing innovation varies and it is not without meaning which country the inventor comes from. The creators of the most important inventions, and in all three countries, are US citizens. The number of citations of inventions generated

with their participation rises to over 11, 12 and 14 in Hungary, the Czech Republic and Poland, respectively.

However, it is not so much the Americans themselves who ensure the highest quality and potential of the invention as rather certain ethnic combinations of inventors with the participation of Americans, unique for each of the host countries studied. Namely, in addition to US citizens, such an optimal combination consists of citizens of Belgium, Japan, Turkey in the case of Poland, citizens of Israel in Hungary, and inventors from Canada and Germany in the Czech Republic. If the optimal combinations of ethnic groups occur, the number of citations further rises to 13, 17 and 19 in Hungary, the Czech Republic and Poland, respectively.

In general, we interpret our results as evidence that highly skilled migrants, by facilitating knowledge flows between nations and the recombination of previously unrelated ideas, contribute to raising the level of innovation of their host countries. Moreover, the positive effects of the influx of migrants and the resulting ethnic diversity may be felt not only in the most innovative economies in the world but also in those less innovative, which have a smaller potential for attracting talent.

This paper can provide several suggestions to public authorities. Given that the innovation efficiency of Polish, Hungarian and Czech immigrant-inventors is clearly higher than that of the natives, the decision-makers could commit funds to increase the potential of these countries for attracting talent as well as to promote ethnic diversity in organizations whose activities are based on knowledge.

The results of the analysis undertaken in this paper may be useful from the perspective of future studies, which could be extended to a larger number of countries not belonging to the group of technology leaders. From the perspective of Poland, the Czech Republic and Hungary, a comparison with other Central and Eastern European countries might be interesting. Future analyzes could also include examining which migration paths are most beneficial from the perspective of the innovation results of the host countries, e.g. admitting foreign citizens to science and technology faculties and facilitating them to stay in the country after graduation; or attracting more scientists and engineers from abroad.

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