International Journal of Trade and Global Markets

ISSN online: 1742-755X - ISSN print: 1742-7541
https://www.inderscience.com/ijtgm

Cultural diversity as a source of regional innovation: evidence from Poland

Małgorzata Wachowska, Magdalena Homa

DOI: 10.1504/IJTGM.2023.10054225

Article History:

Received:	07 April 2020
Last revised:	12 October 2020
Accepted:	12 October 2020
Published online:	05 April 2023

Cultural diversity as a source of regional innovation: evidence from Poland

Małgorzata Wachowska*
and Magdalena Homa

Faculty of Law, Administration and Economics,
University of Wroclaw,
Pl. Uniwersytecki 1, 50-137 Wrocław, Poland
Email: malgorzata.wachowska@uwr.edu.pl
Email: magdalena.homa@uwr.edu.pl
*Corresponding author

Abstract: Using a cross-sectional dataset at the level of patent applications of Polish regions, we investigate whether greater cultural diversity in the structure of inventors increases the quality of inventions they generate. Using the number of citations received by inventions as a proxy for the quality of innovation and the Herfindahl index to measure cultural diversity in a team of inventors, we find that both the mere presence of foreigners in applications as well as greater cultural diversity in a team of inventors, significantly improves the quality of Polish technical solutions. We obtained similar results at the level of Polish regions, although in this case the positive relationship between cultural diversity and innovation was not always significant, and in the case of one voivodeship, cultural diversity even reduced the quality of inventions created there.

Keywords: cultural diversity; human migration; innovation; knowledge flows; inventors; Poland.

Reference to this paper should be made as follows: Wachowska, M. and Homa, M. (2023) 'Cultural diversity as a source of regional innovation: evidence from Poland', *Int. J. Trade and Global Markets*, Vol. 17, No. 1, pp.1–29.

Biographical notes: Małgorzata Wachowska, PhD in Economics, is employed as Assistant Professor at the Institute of Economic Sciences of the University of Wroclaw. Her scientific interests focus on issues related to the diffusion of knowledge, with particular emphasis on knowledge flows by means of international migration of human capital. She is the author and co-author the monograph as well as over 40 papers, chapters in monographs and conference proceedings, from the above mentioned area.

Magdalena Homa, PhD in Economics (applications of mathematics in economics), Assistant Professor at the University of Wroclaw in Institute of Economic Sciences. Scientific research focuses on the following topics: mathematics and insurance (actuarial) statistics, financial econometrics and mathematics. The subject of the publication includes two research areas which are a combination of financial and actuarial approaches: actuarial modelling of complex insurance products such as unit-linked insurance, participating insurance or multi-state insurance.

1 Introduction

It is believed that cultural diversity – which is generally expressed through a different language, place of upbringing, religion, traditions, lifestyle, clothing or interests – facilitates the development of innovation (Fleming, 2001; Nathan, 2014) and accelerates know-how diffusion processes (Kerr, 2008). A diverse population, namely, makes it possible to combine not only different cultures but also stocks of knowledge, viewpoints, abilities or research perspectives that are unique to them. As a consequence, diverse teams have a richer mix of ideas and therefore can be more creative (Tzeng, 2014) and effective in solving problems (Page, 2007) than homogeneous teams. Moreover, as Florida (2002) argues, organisations and cities open to diversity have more potential in attracting highly skilled workers because the most talented individuals look for places where all kinds of otherness are accepted. Thus, both enterprises and entire regions or countries that support cultural diversity can benefit twice. Firstly, because a culturally diverse group of people alone can provide a recombination of previously unrelated knowledge from around the world, and secondly, because the more diverse the population, the greater the chance that outstanding specialists will join it.

Although many studies link culturally diverse workforce and population to the level of innovation in the region, some emphasise that under certain circumstances the negative effects of cultural diversity may outweigh the benefits. As authors of these studies argue, greater diversity means often also higher costs of coordinating the diversity (Leten et al., 2007; D'Ambrosio et al., 2017). It is also a source of many misunderstandings and conflicts (Østergaard et al., 2011), which lead to lower trust and weaker communication between individuals (Alesina and La Ferrara, 2005) or hinder cooperation between them (Joshi and Jackson, 2003), and thus diversity, instead of helping will ultimately distract valuable human capital from research tasks (Pelled et al., 1999), becoming a barrier to achieving a higher level of innovation (Bassett-Jones, 2005).

Poland, like many other countries, is becoming more and more culturally diverse, which is a process mainly driven by immigration. It is estimated that in 2019 1.7% of the population were people born abroad (UN DESA, 2019), of which the largest part were citizens of Ukraine, Germany and Belarus, followed by Lithuania, Russia, Great Britain, France and the US. From Poland's perspective, therefore, the important question is whether it can draw on increased global migration flows and benefit from cultural diversity in the form of increased innovation.

In light of the above, the paper focuses on the relationship between the degree of cultural diversity in the structure of inventors and the quality of technical solutions they generate. We investigate whether in regions of Poland where inventor teams are more culturally diverse, inventions are of higher quality than in regions where inventor teams are homogeneous. In particular, we consider two main questions:

1 whether the presence of foreign inventors and their greater cultural heterogeneity in the region increases the quality of the inventions they generate

2 whether it is possible to identify a specific group or cultural groups that make a special contribution.

Since we expect that the diversity in knowledge base, resulting from, among other things, the inflow of migrants from different cultural environments, increases the organisation's

ability to absorb and generate innovation, and improves the quality of R&D activities, we formulate three hypotheses:

H1: the mere participation of a foreigner in the investor team increases the value of inventions generated;

H2: greater cultural diversity among foreigners increases the value of generated inventions;

H3: regions in which inventor teams show greater cultural diversity have a greater number of more valuable inventions than regions in which inventor teams are culturally less diverse.

We take the frequency of citation of inventions as a measure of their quality, assuming that inventions that receive a greater number of citations represent greater value. We use the Herfindahl index to measure the degree of cultural diversity in a team of inventors, which, due to data limitations, we reduce to diversity in terms of citizenship. We conduct a multiple regression analysis to examine the relationship between cultural diversity and the quality of technical solutions created and to identify the cultural group that has the greatest impact on the quality of created inventions. We obtained the data on the number of citations received by inventions from individual regions of Poland and the citizenship of their inventors as a result of our own research focused on the analysis of 991 international patent applications (PCT) filed in 2004–2011 by Polish entities located in 16 regions of Poland.

We contribute to the discussion on the role of cultural diversity in increasing innovation in two essential ways. Firstly, we provide evidence for a country further down in international innovation rankings – Poland – thus taking into account the possibility that factors that promote innovation may vary depending on the technological potential of the country. Previous studies testing the relationship between cultural diversity and innovation relate mainly to technology leaders, especially the US (Stephan and Levin, 2001; Ottaviano and Peri, 2004; Kerr, 2009; Hunt and Gauthier-Loiselle, 2010; Kerr and Lincoln, 2010; Hunt, 2011), while there are few studies that focus on other countries. There is a shortage of research, among others, on the experience of Central and Eastern European countries, i.e., Poland. This is an oversight given that migration flows in Poland have intensified after the country joined the European Union (EU) in 2004.

Secondly, we focus on the qualitative dimension of innovation, i.e., we analyse the effect of cultural diversity not so much on the number as on the quality of innovation. We are interested in whether cultural diversity among inventors increases the quality of technical solutions created, which – as it can be presumed – will be the greater the more citations those solutions receive. With the exception of a few studies (Kim et al., 2009; Oettl and Agrawal, 2008; Bosetti et al., 2015; Fassio et al., 2019; Miguelez and Noumedem Temgoua, 2017), none of which analyses the case of Poland, work that focuses on the benefits of cultural diversity is limited to testing the relationship between diversity and innovation in quantitative terms (Chellaraj et al., 2005; Wadhwa et al., 2007a, 2007b; Partridge and Furtan, 2008; Kerr and Lincoln, 2010; Niebuhr, 2010; Hunt and Gauthier-Loiselle, 2010; Hunt, 2011; Østergaard et al., 2011; Ozgen et al., 2013; Parrotta et al., 2014; Nathan, 2014; Moser et al., 2014; Gagliardi, 2015; Bratti and Conti, 2018; Bahar et al., 2019; Prithwiraj and Kim, 2019).

The rest of the paper is organises as follows. Section 2 contains a brief review of the literature from the perspective of the role of cultural diversity in raising the level of

innovation. Section 3 describes the data and the research method (including limitations) used in this study. The research results are presented in Section 4, and the main conclusions, policy implications and future research directions are presented in the last section.

2 Cultural diversity in raising the level of innovation: literature review

2.1 Cultural diversity: terminological dilemmas

Although intuitively obvious, in practice the term 'cultural diversity' or 'multiculturalism' is ambiguous. Generally, it is understood as coexistence, in a specific space, of a community of people representing different cultures; it is not clear what exactly should be understood by "culture".

Most often, culture is considered to be the knowledge or the spiritual and material heritage of individual societies that is passed down from generation to generation (Bjerke, 2004). Therefore, among the categories that describe culture, the system of professed values, faith denomination, religion, language, traditions or collective experience are indicated. The following also matter in distinguishing diverse cultures: age, gender, place of residence/upbringing, occupation or social class. In addition to these most obvious dimensions of culture, they also include kinship, common territory, nationality and appearance (Bulmer, 1996). There are also voices that an important element that distinguishes a particular cultural group from others is active participation in political life, and more precisely, the way in which the group demands its own place within the space of an individual country (Burszta, 1998). This multitude of determinants of culture, and thus of cultural diversity, is largely due to the fact that, depending on the context and as society evolves, the meaning of these terms may change (Aspinall, 2009). Therefore, in relation to various countries or human groups, the criteria for distinguishing individual cultural groups may vary or their meaning may be different.

One of the researchers who propagated the idea of making the meaning of the term „cultural diversity" dependent on the context was Jerzy Smolicz, the author of, among other things, the Core Values theory. In light of the above theory, the main components of culture are the so-called core values. These are the most important values or symbols of a given group's culture necessary for its further functioning and existence (Kennedy, 2015, pp.253–255). According to Smolich, these special values can be: religion, family traditions, family structure, patriotism or culinary customs, and these core values can be different for each cultural group. Thus, as Smolicz argues, for Greek Australians they will be language, multi-generational family pattern and belonging to the Greek Orthodox Church, while for Australians of Polish descent – Polish language and a multi-generational family pattern (Smolicz, 1991, as cited in Ratajczak, 2014, p.211).

Because of the semantic similarity, the term "cultural diversity" is often used interchangeably with the term "ethnic diversity", although in fact "ethnic diversity" has a broader meaning. In addition to culture, the basic criterion for distinguishing an ethnic group is origin (Brixy et al., 2017), which means that "culturality" is only an element that falls within a certain range of categories that define "ethnicity" (Szczecińska-Musielak, 2014). However, given that origin determines culture, the former can be in fact treated as a determinant for distinguishing not only an ethnic group but also a cultural one. These

dilemmas related to the definition of both concepts mean that researchers studying the role of diversity in innovation quite commonly use these terms interchangeably.

In this study, the literature review is based on both the papers in which "cultural diversity" and "ethnic diversity" terms are used to describe broadly understood cultural separateness. Studies which test the relationship between the influx of migrants and the innovation of host party have also been taken into account, as their authors to more or less associate cultural diversity with the presence of foreigners.

2.2 Literature review

In existing literature on diversity economics, the contribution of multiculturalism to innovation is considered from two main perspectives: either from the level of enterprise or from the level of a certain territorial unit, such as a city, region or country. Regardless of the level of aggregation adopted, generally, cultural diversity has been identified as an important factor affecting the innovation potential, with empirical evidence for territorial units being more explicit than for companies.

In relation to companies, some studies indicate that not only they do not benefit from cultural diversity, but their innovation even clearly decreases as they employ more foreigners (Bassett-Jones, 2005; Ozgen et al., 2013; Brixy et al., 2017; Awaworyi Churchill et al., 2017). Other studies do not find neither negative nor positive impact of cultural diversity on innovation (Østergaard et al., 2011; Schneider and Eckl, 2016), and still other studies suggest that cultural diversity in a team of employees is important for the company's innovation processes (Fleming, 2001; Lee and Nathan, 2010; Brunow and Stockinger, 2013; Parrotta et al., 2014; Lee, 2015; Pholphirul and Rukumnuaykit, 2017).

Contrary to this, among the analyses at the level of a city, region or country in fact there are none that would indicate a negative relationship between cultural diversity and innovation. At most, they do not find a strong positive relationship or they prove there is no relationship (neither positive nor negative). It should be stressed, however, that the majority of studies at the level of a territorial unit refer to the US, which have been winning the international race for talent for years. Therefore, it is uncertain whether it is cultural diversity *per se* or rather the influx of so-called "stars" that drives innovative results at the level of a country or a region and city.

According to literature on the US, cultural diversity increases productivity at the urban level (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% points increases the number of patents per capita by about 13% while an increase in the number of immigrants in colleges by 1% point leads to 9–18% increase in the number of patents per capita. The hypothesis of the beneficial effect of cultural diversity based on foreigners is also confirmed by Stephan and Levin (2001), who 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. (2007a) 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. Meanwhile, Kerr (2008) as well as Kerr and Lincoln (2010) find 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, commercialisation, patent licensing and publishing. However, uneducated immigrants or those who arrived in old age do not surpass natives in this regard.

This optimistic view of the world in which a mix of cultures favours innovation also emerges from research focused on other countries that occupy top positions in international rankings of innovation. 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, 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 leading in terms of technological development 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.

While for countries in high positions in international innovation rankings the cultural diversity strengthens innovation processes at the macro level, the conclusions of research focusing on other economies are no longer so clear or they provide only very indirect evidence of the positive relationship between cultural diversity and innovation (e.g., Bilan and Strielkowski, 2016; Karsidi et al., 2017; Utami et al., 2019). 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. In turn, Mayerhoffer (2019), based on the example of the Czech Republic, shows that increasing cultural diversity based the relative number foreigners increases R&D innovation, but reduces the number of non-R&D innovations. Contrary to this, Stojčić et al. (2016) argue that international movement of people positively affects innovation in Croatian counties.

Similarly ambiguous results are recorded for the group of countries made up of both highly and low developed countries. Thus, based on a sample of 9 million papers and 6 million scientists from around the world, AlShnebli et al. (2018) find that publications with a diverse cultural composition in the structure of authors are better in quality, as they receive a greater number of citations than papers with a homogeneous composition of authors. However, Barjak and Robinson (2008) show, on 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 it is not a necessary condition for success.

To sum up, it may be said that relatively unambiguous conclusions about the effects of cultural diversity can be formulated only for the US and in this case it does not matter

whether the analysis covers companies, regions or the whole country. So far as other countries are concerned, mainly due to the limited number of surveys at the level of territorial units, it is difficult to clearly define the contribution of cultural diversity to raising innovation.

3 Data and research method

In this paper, we wonder if the cultural diversity resulting from the presence of foreigners is beneficial from the perspective of the quality of inventions filed for patent protection. We investigate whether in 16 regions of Poland inventions generated by culturally diverse teams of inventors are more groundbreaking (of higher quality) than those created by homogeneous teams. In particular, we wonder if the regions of Poland where teams of inventors are more culturally heterogeneous are at the same time more innovative.

3.1 Sample

The empirical analysis has covered PCT applications from 2004 to 2011 filed by entities from Poland. By applications of entities from Poland we mean only applications that have been submitted by Polish entities with headquarters located in the territory of one of the 16 regions of Poland. The analysis did not include the so-called individual applications which, due to their culturally mixed composition of inventors, who are also applicants, made it impossible to clearly assign the patent application to a specific country. Ultimately, the research sample consisted of 991 patent applications (Table 1).

The sample of 991 patent applications includes all PCT patent applications filed in 2004–2011 by Polish organisations (full sample), but not all patent applications filed by Polish organisations operating in Poland have been included. The sample does not include patent applications filed, for example, under the national (at the Patent Office of the Republic of Poland) or regional procedure. There are several reasons for focusing only on patent applications filed under international procedure. Firstly, international inventions are considered to be more groundbreaking and have a greater potential for commercialisation than others, which makes them more likely to be cited. This stems from the fact that the international patent procedure is more expensive than national or regional one, and the more countries where the invention is protected, the higher the costs. Hence, an applicant will be interested in an "international patent" only if they themselves estimate that the economic value of the invention is high. Secondly, PCT inventions are more likely to be created with the participation of foreigners than domestic inventions. Thirdly, only PCT patent applications make it possible to determine the citizenship of inventors, and thus to identify foreigners in the research team (for details, see point 3.6 of the paper). Considering that the main aim of the paper is to shed more light on the relationship between cultural diversity of inventor teams and the "value" of the inventions created, limiting research only to the "most valuable applications" and those being most likely to be created with the participation of foreigners seems most accurate.

Table 1 Descriptive statistics of the research sample

Voivodship	*Number of applications*	*Percentage of applications in the total number of applications* (%)	*Cumulative percentage of applications* (%
Masovian	347	35.02	35.02
Lesser Poland	130	13.12	48.13
Lower Silesian	88	8.88	57.01
Greater Poland	86	8.68	65.69
Silesian	79	7.97	73.66
Pomeranian	71	7.16	80.83
Łódź	50	5.05	85.87
Subcarpathian	37	3.73	89.61
Kuyavian-Pomeranian	21	2.12	91.72
West Pomeranian	20	2.02	93.74
Lubusz	18	1.82	95.56
Lublin	15	1.51	97.07
Świętokrzyskie	15	1.51	98.59
Opole	8	0.81	99.39
Podlaskie	4	0.40	99.80
Warmian-Masurian	2	0.20	100
Polish Regions in total	*991*	*100*	

Source: Based on own research

On the basis of the date presented in Table 1, it can be concluded that voivodships in Poland differ strongly in terms of the number of PCT patent applications submitted. In general, only two regions are responsible for almost 50% of PCT applications: Mazovian Voivodship, where slightly more than 35% of applications are concentrated and Lesser Poland Voivodship, with just over 13% of applications. None of the other regions reaches even the level of 10% of applications, and as many as 9 voivodships not even 5%.

3.2 Measures of diversity

Due to the fact that the term "cultural diversity" can have many meanings (see Section 2 for more information), the attempt to quantify specific cultural groups is a kind of challenge for the researcher. Namely, it is difficult to grasp what determines cultural separateness of a given human population, and it is even more difficult to operationalise this. In this paper, we focus only on one aspect of cultural diversity: citizenship, which is widely used in literature as a proxy for cultural diversity (Wadhwa et al., 2007a, 2007b; Miguelez and Noumedem Temgoua, 2015, 2017; Noumedem Temgoua, 2018; Miguelez, 2018).

We are aware of the fact that distinguishing individual cultural groups only on the basis of citizenship, i.e., one of the many categories that describe "culture", is a certain limitation of research. There is namely a danger that the number of individual groups of inventors will be either overestimated or underestimated. It seems, however, that the risk

of error is relatively small in this case, as it can be presumed that individuals with different citizenship were also born or raised in other countries, and therefore came into contact with other customs, traditions, experiences, behaviour, mentality or religion. Additionally, in the conditions of our research, citizenship was the only aspect of "culture" that could be obtained (see Section 3.6 for more information).

With the use of citizenship, we construct two cultural diversity variables:

1 *FORINV* – The number of inventions (patent applications) with the presence of foreign inventors. A binary variable, it takes value "1" if there is at least one researcher with foreign– i.e., other than Polish – citizenship in the inventor team and value "0" if all inventors have Polish citizenship.

2 *DIVERSITY* – Cultural diversity in the inventor team, which is measured by means of the Herfindahl index (HI) (Hall and Tideman, 1967). The HI value can range from "0" to "1" and the greater its value, the greater diversity of the team, while the value of "0" means that the inventor team is homogeneous. The index takes the following form:

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

where s_{ij} is the share of the group of inventors with citizenship i ($i = 1, \ldots, 35$) in the inventor team j ($j = 1, \ldots, 991$).

Table 2 contain summary statistics for the diversity measures. The results show that the distribution of inventions in the creation of which foreigners are involved is very uneven. Virtually 50% of applications submitted with the contribution from foreign inventors originate in one region. It is Mazovian Voivodship, which accounts for 70 applications of this type, which represents 48.95% of all applications involving foreigners. It is followed by Lesser Poland and Greater Poland voivodships, each with only 13 applications. Among the Polish regions are also those which do not have any inventions generated by researchers from other countries. They are Świętokrzyskie, Opole and Warmian-Masurian voivodships.

Individual regions of Poland also differ in terms of the percentage of applications with foreign participation in the total number of their applications (Table 2). In this case, the leader in the ranking is Lubusz voivodship, where there are 33.33% of patent applications submitted with participation of foreigners and the second position is occupied by Mazovian voivodship, where the percentage of application with foreign participation is 20.17%.

The results also show that the cultural diversity of the inventor teams is small, regardless of the voivodship in which the invention is filed for patent protection (Table 2). This is evidenced by the average value of the HI index, which is ca. 0.04. This value is exceeded by 7 voivodships, among which Podlaskie voivodship comes first with the Herfindahl index value of 0.12.

3.3 The measure of innovation

The measure of quality or breakthrough of the invention used in this paper is the frequency of its citation, i.e., the number of citations received by invention. Patent citations are a recognised and often used measure of the value of an invention

(Trajtenberg, 1990; Kerr, 2009). It is also assumed that the greater number of citations received reflects the higher economic potential of the invention and shows its greater importance for the economy and science.

Table 2 Descriptive statistics of diversity measures

Voivodship	*Number of applications*	*Number of applications with the presence of foreign inventors* (FORINV)	*Percentage of applications with the presence of foreign inventors in the region's total number of applications*	*Percentage of applications with the presence of foreign inventors in the total number of applications with foreign participation*	*Cumulative percentage of applications with the presence of foreign inventors*	*HI*
Masovian	347	70	20.17%	48.95%	48.95%	0.06
Lesser Poland	130	13	10%	9.09%	58.04%	0.03
Greater Poland	86	13	15.12%	9.09%	67.13%	0.06
Pomeranian	71	11	15.49%	7.69%	74.82%	0.05
Lower Silesian	88	9	10.23%	6.29%	81.11%	0.03
Silesian	79	9	11.39%	6.29%	87.4%	0.04
Lubusz	18	6	33.33%	4.20%	91.6%	0.08
West Pomeranian	20	4	20%	2.80%	94.4%	0.05
Subcarpathian	37	3	8.11%	2.10%	96.5%	0.00
Kuyiavian-Pomeranian	21	2	9.52%	1.40%	97.9%	0.05
Łódź	50	1	2%	0.70%	98.6%	0.00
Lublin	15	1	6.67%	0.70%	99.3%	0.03
Podlaskie	4	1	25%	0.70%	100%	0.12
Świętokrzyskie	15	0	0%	0.00%		0.00
Opole	8	0	0%	0.00%		0.00
Warmian-Masurian	2	0	0%	0.00%		0.00
Polish Regions in total	*991*	*143*	*14.43%*	*100%*	-	*0.04*

Source: Based on own research

We construct an innovation variable:

INNOVATION – Number of citations excluding autocitations at the applicant's level (as of April 2019) received by an invention submitted in the years 2004–2011 for international patent protection by an entity from the region j (j = 1, …, 16).

Table 3 contains basic descriptive statistics of the quality variable for inventions in individual regions of Poland. The results suggest that inventions originating in Poland

generally represent low quality as they are rarely cited by others. On average, an invention submitted for international patent protection by a Polish entity receives 3.52 citations, while e.g., applications from Hungary receive an average of 4.53 and from the Czech Republic 5.09 citations (own calculation). What is more, as much as 25% of the total number of 991 applications did not receive a single citation.

Table 3 Basic descriptive statistics of the invention quality variable for individual voivodships

Voivodship	*Average number of citations*	*Median*	*Q1*	*Q3*	*S*	*Skewness*
Lubusz	8.00	3.50	1.00	8.00	11.14	1.91
Masovian	5.60	1.00	0.00	5.00	13.90	5.35
West Pomeranian	4.55	1.50	0.00	6.50	6.93	2.39
Opole	4.00	2.00	1.00	5.50	4.90	1.95
Warmian-Masurian	3.50	3.50	1.00	6.00	3.54	0.00
Subcarpathian	3.41	2.00	1.00	4.00	4.50	
Łódź	3.10	1.00	0.00	4.00	4.60	
Silesian	2.34	1.00	0.00	3.00	3.39	2.45
Lesser Poland	2.32	1.00	0.00	3.00	3.82	2.13
Świętokrzyskie	2.27	1.00	0.00	3.00	3.20	2.31
Kuyavian-Pomeranian	2.00	0.00	0.00	2.00	4.24	3.10
Pomeranian	1.66	1.00	0.00	3.00	2.27	1.89
Greater Poland	1.65	1.00	0.00	2.00	2.73	2.32
Lower Silesian	1.61	1.00	0.00	2.00	2.49	2.83
Lublin	1.27	0.00	0.00	3.00	1.83	1.08
Podlaskie	1.25	1.00	0.00	2.50	1.50	0.37
Polish regions in total	*3.52*	*1.00*	*0.00*	*3.00*	*0.28*	*7.68*

Source: Based on own research.

Analysing the results at the level of regions, it can be said that only in one voivodship the distribution of citations is symmetrical (Warmian-Masurian) and in all the others it is asymmetrical and characterised by right-hand asymmetry, which means that inventions with low and very low frequency of citation prevail or those which had no citations. The Lubusz voivodship stand out against the background if Polish regions with an average of 8 citations, followed by the following regions: Mazovian, West Pomeranian and Opole voivodships, which receive the number of citations above the national average, i.e., over 3.5 citations.

Table 4 contains basic descriptive statistics of the quality variable for inventions in in individual regions of Poland, including the participation of foreign researchers. On the basis of the data it contains, it may be concluded that, except for six regions of Poland, inventions created with the participation of foreigners receive a greater number of citations than those created only by Poles. In some cases, the difference between the number of citations received by an invention generated by culturally heterogeneous teams

and teams without the participation of foreigners is actually very large. For example, in Lubusz voivodship the former receive on average 14.17 citations, while inventions created without the involvement of foreigners only 4.92.

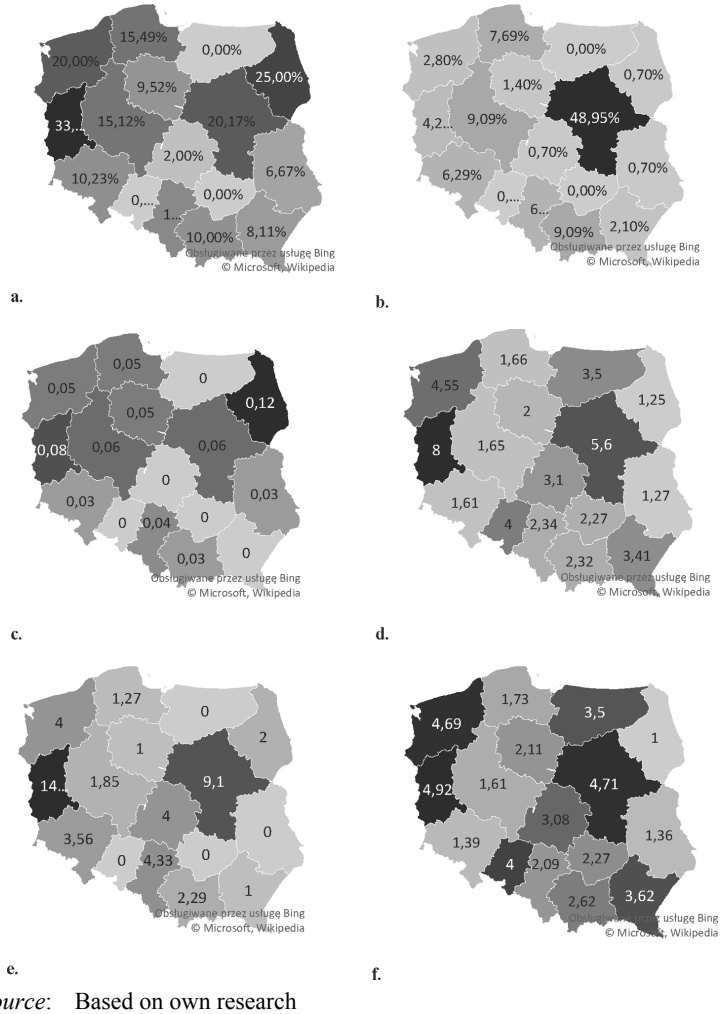
Table 4 Basic descriptive statistics of the invention quality in individual voivodships, including the participation of foreign inventors

Voivodship	*Participation of foreign inventors*	*Average number of citations*	*Median*	*Q1*	*Q3*	*S*	*Skewness*
Lower Silesian	NO (0)	1.39	1.00	0.00	2.00	2.34	3.48
	YES (1)	3.56	3.00	2.00	5.00	3.05	0.61
Kuyavian-Pomeranian	NO (0)	2.11	0.00	0.00	2.00	4.46	2.92
	YES (1)	1.00	1.00	1.00	1.00	0.00	0.00
Lublin	NO (0)	1.36	0.00	0.00	3.00	1.86	0.97
	YES (1)	0.00	0.00	0.00	0.00	0.00	0.00
Lubusz	NO (0)	4.92	3.50	1.00	6.50	6.02	2.32
	YES (1)	14.17	6.50	2.00	33.00	16.53	0.83
Łódź	NO (0)	3.08	1.00	0.00	3.00	4.65	2.12
	YES (1)	4.00	4.00	4.00	4.00	0.00	0.00
Lesser Poland	NO (0)	2.62	2.00	0.00	3.00	3.36	1.74
	YES (1)	2.29	1.00	0.00	3.00	3.88	4.56
Masovian	NO (0)	4.71	1.00	0.00	4.00	13.50	6.40
	YES (1)	9.10	3.00	1.00	9.00	14.97	2.64
Opole	NO (0)	4.00	2.00	1.00	5.50	4.90	1.95
	YES (1)	–	–	–	–	–	–
Subcarpathian	NO (0)	3.62	2.00	1.00	5.00	4.63	2.33
	YES (1)	1.00	1.00	0.00	2.00	1.00	0.00
Podlaskie	NO (0)	1.00	0.00	0.00	3.00	1.73	1.73
	YES (1)	2.00	2.00	2.00	2.00	0.00	0.00
Pomeranian	NO (0)	1.73	1.00	0.00	3.00	2.24	1.89
	YES (1)	1.27	0.00	0.00	1.00	2.53	2.33
Silesian	NO (0)	2.09	1.00	0.00	3.00	2.17	1.34
	YES (1)	4.33	2.00	0.00	2.00	8.15	2.52
Świętokrzyskie	NO (0)	2.27	1.00	0.00	3.00	3.20	2.31
Warmian-Masurian	NO (0)	3.50	3.50	1.00	6.00	3.54	0.00
Greater Poland	NO (0)	1.61	1.00	0.00	2.00	2.70	2.31
	YES (1)	1.85	1.00	0.00	2.00	3.00	2.68
West Pomeranian	NO (0)	4.69	1.50	0.00	6.00	7.52	2.40
	YES (1)	4.00	4.00	0.00	8.00	4.62	0.00

Source: Based on own research

Table 5 and Figure 1 recapitulate the most important descriptive statistics for the innovation quality variable (INNOVATION) and cultural diversity variables (FORINV, DIVERSITY). Based on the presented characteristics, it can be observed that the most frequently cited inventions do not always originate in regions with the largest number of applications (e.g., Lubusz voivodship), and the inventor team diversity does not always is largest in regions with the largest number of applications with the participation of foreigners (e.g., Podlaskie voivodship). Nevertheless, some relationships become visible that may indicate that the quality of inventions is determined by both the mere presence of foreigners in the team of inventors and their greater cultural diversity.

Figure 1 Selected descriptive statistics for polish regions: (a) percentage of application with foreign participation in the region's total number of applications; (b) percentage of applications with foreign participation in the total number of applications with foreign participation; (c) HI index by voivodship; (d) average number of citations by voivodship; (e) average number of citations for applications with the participation of foreigners by voivodship and (f) average number of citations for applications without the participation of foreigners by voivodship



Source: Based on own research

Table 5 Selected descriptive statistics of the invention quality variable and cultural diversity variables

Voivodship	*Number of applications*	*Average number of citations*	*HI*	*Participation of foreign inventors*	*Number of applications*	*Average number of citations*
Lower Silesian	88	1.61	0.03	NO (0)	79	1.39
				YES (1)	9	3.56
Kuyavian-Pomeranian	21	2.00	0.05	NO (0)	19	2.11
				YES (1)	2	1.00
Lublin	15	1.36	0.03	NO (0)	14	1.36
				YES (1)	1	0.00
Lubusz	18	8.00	0.08	NO (0)	12	4.92
				YES (1)	6	14.17
Łódź	50	3.10	0.00	NO (0)	49	3.08
				YES (1)	1	4.00
Lesser Poland	130	2.32	0.03	NO (0)	117	2.62
				YES (1)	13	2.29
Masovian	347	5.60	0.06	NO (0)	277	4.71
				YES (1)	70	9.10
Opole	8	4.00	0.00	NO (0)	8	4.00
Subcarpathian	37	3.41	0.00	NO (0)	34	3.62
				YES (1)	3	1.00
Podlaski	4	1.25	0.12	NO (0)	3	1.00
				YES (1)	1	2.00
Pomeranian	71	1.66	0.05	NO (0)	60	1.73
				YES (1)	11	1.27
Silesian	79	2.34	0.04	NO (0)	70	2.09
				YES (1)	9	4.33
Świętokrzyskie	15	2.27	0.00	NO (0)	15	2.27
Warmian-Masurian	2	3.50	0.00	NO (0)	2	3.50
Greater Poland	86	1.65	0.06	NO (0)	73	1.61
				YES (1)	13	1.85
West Pomeranian	20	4.55	0.05	NO (0)	16	4.69
				YES (1)	4	4.00

Source: Based on own research

First of all, inventions from regions with the highest percentage of applications with foreign participation tend to receive the largest number of citations (Lubusz, Mazovian, West Pomeranian voivodships). The only exception is Podlaskie voivodship, whose frequency of citation is among the lowest, despite being at the forefront of the regions with the largest number of applications with the participation of foreigners in relation to

the total number of its own applications. A similar relationship is visible between the diversity of inventor teams in individual regions measured by the HI index and the number of citations received by applications from these regions. In this regard, also Lubusz, Mazovian and West Pomeranian voivodships are at the forefront of regions with the highest HI index and the largest number of citations for inventions; the exceptions are Greater Poland and – as before – Podlaskie voivodships. Although both of these are characterised by fairly high cultural diversity of the inventor teams, they do not score highest in terms of the number of citations received.

3.4 Time period of the study

The time period of the study has been limited to years 2004–2011. The beginning of the research period coincides with the year of Poland's accession to the European Union. From the perspective of population migration movements – both from and to Poland – this is a breakthrough year. On the one hand, the opening of foreign job markets for workers from Poland caused mass migration of Poles, and on the other hand, Poland as a full member of the EU began to be perceived by foreigners as an attractive place to work and live. It can therefore be presumed that inventions filed for international patent protection from 2004 will have a higher likelihood of being developed by heterogeneous, international research teams.

The analysis was completed on year 2011, as it was considered that inventions filed after this period had a significantly lower likelihood of being cited. This stems from the fact that the dissemination of information about an invention takes time and, consequently, delays of many years are observed in patent citations, ranging from 3 to as many as 16 years (Adams et al., 2006; Adams and Clemmons, 2013; Wachowska, 2016).

We are aware that ending the analysis in 2011 is a certain limitation of the research, as the real intensification of migration flows to Poland started only in 2013–2015. This means that this study may ignore a number of important dependencies resulting from the increased number of foreigners, perhaps also among inventors. On the other hand, however, including subsequent years (i.e., after 2011) in the analysis might show a false negative relationship (or no positive one) between the presence of foreigners in the inventor team and the quality of technical solutions generated. A definitely smaller number of citations received by PCT applications filed after 2011 could suggest that greater cultural diversity does not translate into higher innovation quality. It would actually only be the result of a citation delay that occurs from the moment of filing the patent application to the moment it is cited.

3.5 Empirical strategy

In order to determine whether the mere participation of foreigners in the team of inventors on the one hand, and the greater cultural diversity of the team of researchers on the other hand, has an effect on the increase in the number of citations received by inventions created by this team, we conduct the study in two stages. First, we perform a preliminary correlation analysis with the use of the Pearson correlation coefficient[1] and consider two simple regression models (Model 1, Model 2), and then we estimate the parameters of the multiple regression model (Model 3) with the use of the ordinary least squares method (OLS). Models from 1 to 3 take the following forms:

$$INNOVATION = \alpha_0 + \alpha_1 FORINV + \varepsilon, \quad \text{(Model 1)}$$

$$INNOVATION = \alpha_0 + \alpha_1 DIVERSITY + \varepsilon, \quad \text{(Model 2)}$$

$$INNOVATION = \alpha_0 + \alpha_1 FORINV + \alpha_2 DIVERSITY + \varepsilon, \quad \text{(Model 3)}$$

where the variable INNOVATION is our measure of innovation, i.e., the number of citations received by the invention originating in the region j (j = 1, …, 16) or the whole country (if the analysis is performed at the level of entire Poland). The variable FORINV is the first of our cultural diversity variables for cultural diversity. It represents the number of patent applications originating in the region j (j = 1, …, 16) or the whole of Poland (in the analysis is performed at the level of entire country) in which at least one foreigner participated. The variable DIVERSITY is the second cultural diversity variable. It is a Herfindahl index calculated for patent applications originating in the region j (j = 1, …, 16) or the whole of Poland (if the analysis is performed at the level of entire country).

In order to determine the cultural group that is most responsible for the higher quality of inventions, we use the multiple regression method and then we employ step-wise insignificant variable elimination to determine combination of cultural groups that is optimal in terms of significance and associated with the largest probability that the invention will be frequently cited. To this end, we estimate the regression function using the ordinary least squares method (model 4):

$$INNOVATION = \alpha_0 + \alpha_1 X_1 + \cdots + \alpha_k X_k + \varepsilon, \quad \text{(Model 4)}$$

where the dependent variable INNOVATION is the number of citations received by the invention originating in the region j (j = 1, …, 16) or the whole of Poland (if the analysis is performed at the level of entire country), while the independent variable X_k is the number of foreigners in the team of inventors from the kth cultural group (k = 1, …, 35).

3.6 Data

Information regarding the frequency of citation of inventions from individual regions of Poland and its detailed characteristics, such as the cultural composition of inventors, was obtained as a result of the analysis of international patent applications (PCT). The PCT application form has been developed by the World Intellectual Property Organisation (WIPO), which also deals with the administrative handling of the applications and their collection in the PatentScope database. In many regards, the PCT form resembles questionnaires filled under the national or regional procedure. First of all, it contains basic data on the applicant, inventor and the invention itself, such as the date of submitting the patent application, the name and surname of the inventor, their place of residence on the day of submitting the patent application, the name and address of the applicant's seat, the technological field of the invention or patents citations (references to someone else's earlier publication or patent). However, unlike in all these patent applications, there is one more information included in PCT applications – the citizenship of the applicant, and until September 16, 2012 also the citizenship of the creator of the invention (see Miguelez and Fink, 2013 for details).

From the perspective of the research undertaken in this paper, the latter information is particularly useful, as it makes possible the determination of the number of inventors with

foreign citizenship mentioned in Polish 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 in terms of the information about the origin of the inventor – have their limitations. First of all, they only make it possible to determine the citizenship of the inventor, which means that when estimating the number of foreigners, long term migrants who were granted citizenship of the host country before submitting the patent application can be ignored. This means that it is not possible to accurately determine the contribution of naturalised persons, who in fact can be more effective in raising innovation than migrants who arrived later.

4 Research results

Based on the descriptive statistics presented in Section 3.3 regarding the invention quality variable and variables approximating cultural diversity, it may be concluded that the distribution of the quality of invention in the case of patent applications submitted in individual regions of Poland both with and without the participation of foreign inventors differs significantly. Importantly, in six of the voivodships under investigation the share of foreign inventors reduced the quality of inventions, while in the remaining ones an increase in innovation in the group of applications with the participation of foreign inventors was observed. Nevertheless, the question arises whether the observed change in the quality of inventions is actually affected by the presence of foreigners or these results are distorted by the place of submitting. Therefore, at the beginning the significance of the relationship between the quality of inventions and the place (voivodship) of submitting was examined. For this purpose the Pearson correlation coefficient and the Student's t-test of significance were determined and the results are presented in Table 6.

Table 6 Pearson correlation coefficients for the quality of inventions and the variable "place of submitting"

Variable	*Pearson coefficient*	*T*	*P-value*	*Significance α = 0.05*	*Significance α = 0.1*
Place of submitting – voivodship	–0.028144	–0.884987	0.376	–	–

Source: Based on own work

The high p-value obtained indicates the insignificant impact of the place of submitting on the quality of Polish inventions, which allowed us to proceed to the next stage of the study. In order to answer the question whether the participation of foreigners in the team of inventors and the greater cultural diversity of the team of researchers results in an increase in the number of citations received by Polish inventions created by this team, first of all, a relationship analysis with the use of correlation was performed (for results see Table 7).

In both cases, the obtained results (small p-values) of the correlation analysis verification conducted prove a significant linear relationship between variables under

study, which means that it is reasonable to use a simple regression to further assess the relationship. The results of the OLS estimation of regression line parameters for the total of Polish regions (Model 1 and Model 2) are presented in Tables 8 and 9.

Table 7 Pearson correlation coefficients for the quality of inventions and selected variables (for Poland)

Variable	*Pearson coefficient*	*T*	*P-value*	*Significance α = 0.05*	*Significance α = 0.1*
FORINV	0.1242743	3.93677	0.0001	+	+
DIVERSITY	0.09648580	3.047	0.002	+	+

Source: Based on own research

Table 8 Results of OLS estimation of regression line parameters in model 1 for the total of polish regions

observations used 1–991 ($n = 990$)
the number of incomplete observations ignored: 1

	Coefficient	*Standard error*	*Student's t-test*	*P-value*	
Const	3.06139	0.306649	9.983	<0.0001	***
FORINV	3.17637	0.806847	3.937	<0.0001	***

Arithmetic mean of the dependent variable	3.520202	Standard deviation of the dependent variable	8.989664
Residual sum of squares	78690.72	Residual standard error	8.924488
Coefficient of determination R^2	0.015444	Adjusted R^2	0.014448
F(1, 988)	15.49814	P-value for F-test	0.000088
Logarithm of the likelihood	−3570.659	Akaike information criterion	7145.318
Bayesian information criterion	7155.114	Hannan-Quinn information criterion	7149.043

Source: Own research

The results of the significance test of parameters in Models 1 and 2 indicate that in both regression lines the model parameters estimated are significant and their positive value suggests that both variables independently result in an increase in the frequency of citation of Polish inventions. The value of the parameter $\alpha_1 = 3.18$ in Model 1 means that patent applications with the participation of foreigners have on an average three more citations, while the parameter $\alpha_1 = 6.17$ in Model 2 means that cultural diversity increases the number of citations by as many as 6 on average. Thus, the highly cited inventions are characterised by both the presence of foreigners and the higher cultural diversity of the research team.

Table 9 Results of OLS estimation of regression line parameters in model 2 for the total of polish regions

observations used 1–991 (n = 990)
the number of incomplete observations ignored: 1

	Coefficient	*Standard error*	*Student's t-test*	*P-value*	
Const	3.24468	0.298545	10.87	<0.0001	***
DIVERSITY	6.17161	2.02547	3.047	0.0024	***

Arithmetic mean of the dependent variable	3.520202	Standard deviation of the dependent variable	8.989664
Residual sum of squares	79181.03	Residual standard error	8.952248
Coefficient of determination R^2	0.009310	Adjusted R^2	0.008307
F(1, 988)	9.284227	P-value for F-test	0.002373
Logarithm of the likelihood	−3573.734	Akaike information criterion	7151.468
Bayesian information criterion	7161.263	Hannan-Quinn information criterion	7155.192

Source: Own research

In the next stage of the analysis, the impact of the increase in cultural diversity (measured by HI) on the change in the frequency of citation in individual voivodships was assessed. Due to the small participation of foreigners in patent applications in such voivodships as: Łódź, Subcarpathian, Kuyavian-Pomeranian, West Pomeranian, Lubusz, Lublin, Świętokrzyskie, Opole, Podlaskie, Warmian-Masurian (the number of applications with the participation of foreigners in the total number of applications for all voivodships is below 5%, see Table 2), only the 6 remaining voivodships were covered by the further analysis. Pearson correlation coefficient and OLS estimator of the slope of the regression line were also used. The results regarding the correlation coefficient and the estimation of model parameters with the OLS method for the voivodships under study are presented in Tables 10 and 11, respectively.

The correlation results (Table 10) show that for all voivodships, except for Lesser Poland, the correlation between the HI index and the number of citations received is positive, although it is not always strong enough to be considered significant. The significance was confirmed in the case of two voivodships: Masovian and Lower Silesian, as evidenced by the low p-value (Table 11). The positive value of the parameters suggests that an increase in the HI index results in an increase of the frequency of citation, and thus the larger cultural diversity increases the quality of inventions filed for patent protection in the voivodships under study, except for Lesser Poland. In the case of Lesser Poland voivodship, the regression line parameter is negative, which shows that an increase in cultural diversity (measured by HI) reduces the quality of inventions.

Meanwhile, when proceeding to assessing the impact of both the presence of foreign researchers in the team of inventors and the higher cultural diversity in the structure of inventors measured by HI on the change in the frequency of citation of a patent

application, multiple regression analysis was performed (Model 3). The results are presented in Table 12.

Table 10 Pearson correlation coefficient for the invention quality and the variable DIVERSITY by voivodship

Masovian	*Lesser Poland*	*Lower Silesian*	*Greater Poland*	*Silesian*	*Pomeranian*
0.08911286	–0.02933324	0.12370665	0.08353576	0.15635258	0.10476437

Source: Based on own research

Table 11 OLS estimator of the slope of the variable DIVERSITY in model 2 with the assessment of its significance

Voiodship	*Parameter*	*P-value*	*Significance α = 0.05*	*Significance α = 0.1*
Masovian	7.58093	0.0975	–	+
Lesser Poland	−1.02319	0.7404	–	–
Lower Silesian	2.56868	0.0908	–	+
Greater Poland	1.50495	0.4472	–	–
Silesian	3.97750	0.1688	–	–
Pomeranian	1.4115	0.3846	–	–

Source: Based on own research

Table 12 Results of OLS estimation of multiple regression parameters in model 3 for the total of polish regions

observations used 1–991 ($n = 990$)
the number of incomplete observations ignored: 1

	Coefficient	*Standard error*	*Student's t-test*	*P-value*	
Const	3.06139	0.306804	9.978	<0.0001	***
FORINV	3.15851	1.27362	2.480	0.0133	**
DIVERSITY	0.0577717	3.18732	0.01813	0.9855	

Arithmetic mean of the dependent variable	3.520202	Standard deviation of the dependent variable	8.989664
Residual sum of squares	78690.70	Residual standard error	8.929006
Coefficient of determination R^2	0.015444	Adjusted R^2	0.013449
F(1, 988)	7.741394	P-value for F-test	0.000461
Logarithm of the likelihood	−3570.659	Akaike information criterion	7147.318
Bayesian information criterion	7162.011	Hannan-Quinn information criterion	7152.905

Source: Own research

It can be seen that in the system of both variables in the multiple regression model the variable DIVERSITY becomes insignificant, and this stems from the fact that it is characterised by a smaller relationship with the variable INNOVATION, and additionally it conveys the same information to a large extent (the relationship between these variables measured by the Pearson correlation coefficient equals 0.77350026 with p-value = 0.0000).

Due to the fact that cultural diversity (especially when measured by the participation of foreigners in patent applications) determines the quality of inventions, in the next stage of analysis it was attempted to answer to the question which ethnic group had the greatest impact on the quality of inventions in individual voivodships. To this end, the multiple regression method was used, and then using step-wise insignificant variable elimination the final combination of cultural groups (in individual regions) was obtained that was associated with the largest likelihood that the invention will be frequently cited. The estimation results for the total of Polish regions are presented in Table 13, while for individual voivodships in Table 14.

Table 13 Results of OLS estimation of multiple regression parameters in model 4 for the total of polish regions

observations used 1–991 (n = 990)
the number of incomplete observations ignored: 1

	Coefficient	*Standard error*	*Student's t-test*	*P-value*	
Const	3.19084	0.275947	11.56	<0.0001	***
Japan	122.109	18.4311	6.625	<0.0001	***
Belgium	29.6949	8.03038	3.698	0.0002	***
US	30.2238	7.26622	4.159	<0.0001	***
Turkey	189.046	43.0559	4.391	<0.0001	***

Arithmetic mean of the dependent variable	3.516650	Standard deviation of the dependent variable	8.985818
Residual sum of squares	73039.20	Residual standard error	8.606757
Coefficient of determination R^2	0.086296	Adjusted R^2	0.082589
F(1, 988)	23.28101	P-value for F-test	2.07e–18
Logarithm of the likelihood	−3536.836	Akaike information criterion	7083.673
Bayesian information criterion	7108.166	Hannan-Quinn information criterion	7092.986

Source: own research.

Based on the results from Table 13 regarding the OLS estimation of multiple regression, it can be said that the frequency of citation of a Polish invention increases with the presence of Americans, Japanese, Turks and Belgians. At the same time, however, analysing the estimation results for individual regions of Poland (Table 14), it can be seen that there is no main cultural group of inventors that, regardless of the place of submitting the invention, would increase its frequency of citation.

Table 14 Results of the OLS estimation of multiple regression parameters in model 4 for selected regions

MASOVIAN					
observations used 323–669 (n = 347)					
	Coefficient	*Standard error*	*Student's t-test*	*P-value*	
Const	4.90479	0.701589	6.991	<0.0001	***
Japan	242.666	39.6123	6.126	<0.0001	***
US	42.5886	12.7741	3.334	0.0009	***
Turkey	180.476	64.8351	2.784	0.0057	***

LOWER SILESIAN					
observations used 1–88 (n=88)					
	Coefficient	*Standard error*	*Student's t-test*	*P-value*	
Const	1.38536	0.255577	5.420	<0.0001	***
France	5.53757	2.10760	2.627	0.0102	**
Belgium	10.7690	5.81858	1.851	0.0677	*
Ireland	16.8439	7.03576	2.394	0.0189	**

GREATER POLAND					
observations used 886–971 (n = 85)					
	Coefficient	*Standard error*	*Student's t-test*	*P-value*	
Const	1.50463	0.283173	5.313	<0.0001	***
UK	14.5278	4.34452	3.344	0.0012	***

SILESIAN					
observations used 790–868 (n = 79)					
	Coefficient	*Standard error*	*Student's t-test*	*P-value*	
Const	2.05128	0.250805	8.179	<0.0001	***
UK	34.4231	3.34380	10.29	<0.0001	***

POMERANIAN					
observations used 719–789 (n = 71)					
	Coefficient	*Standard error*	*Student's t-test*	*P-value*	
Const	1.56323	0.260188	6.008	<0.0001	***
India	6.00931	2.16255	2.779	0.0070	***

Source: Own work

The results indicate that in the case of Masovian voivodship it is the presence of Americans, Japanese and Turks which is associated with the greatest likelihood that the invention will be cited, while in Lower Silesian voivodship it is worth taking care of the

presence of French, Belgians and Irish; in Greater Poland and Silesian voivodships, the quality of inventions is increased by the English, while in Pomeranian voivodship by the Indian. Therefore, taking into account the right combination of cultural groups that constitute the optimal cultural diversity in individual voivodships, one should expect increased frequency of citation of inventions. As for Lesser Poland voivodship, in the case of which the opposite relationship was observed, i.e., diversity is a destimulant of quality, it was not possible to indicate an ethnic group increasing the quality of inventions.

Taking into account the right combination of cultural groups constituting the optimal cultural diversity in individual voivodships, increased frequency of citation should be expected, as shown in Table 15.

The analysis of the average number of citations received by patent applications with the participation of foreigners, taking into account the optimal combination of culture groups, confirms that the inclusion of citizens of the indicated countries in the team optimises the rate of citation and thus ensures the highest quality of the invention.

Table 15 The average number of citations received, taking into account the optimal combination of cultural groups in the team of inventors

	Optimal cultural diversity Significance α = 0.05	
Voivodship	*NO*	*YES*
Masovian	9.1	43.9
Lower Silesian	3.55	5.00
Greater Poland	1.84	7.00
Silesian	4.33	25
Pomeranian	1.27	4

Source: Based on own research

5 Concluding remarks

Despite the recognised role of all kinds of diversity, including cultural one, in stimulating creativity and innovation, lively discussions on this topic continue. On the one hand, people originating in other cultures differ from the rest of the population, e.g., in terms of ideas, experiences or research perspectives, owing to which they enrich the existing knowledge stocks with elements specific for their own cultural environments. On the other hand, different perceptions of reality resulting from different cultures may become an element that divides or even causes hostility. In this case, instead of promoting innovation processes, cultural diversity will inhibit them.

The purpose of this paper has been to shed more light on these issues by providing evidence for Poland, which – like a number of other countries further down in innovation rankings – extremely rarely becomes the subject of interest for research in the field of diversity economics. First of all, we wondered if in those regions of Poland where inventor teams are more culturally diverse, inventions are of higher quality (they receive more citations) than in regions where inventor teams are homogeneous.

We find that when considered separately, both the participation of foreigners in the team of inventors and their greater cultural diversity significantly improve the quality of Polish inventions. Technical solutions developed by teams of which at least one foreigner is a member receive on average slightly over three citations more than inventions created only by Poles. Meanwhile, the larger cultural diversity of an inventor team further improves the quality of inventions, which receive on average over 6 citations more than inventions of homogeneous teams. However, if we consider the simultaneous impact of both variables on the improvement of the quality of Polish inventions, the greater cultural diversity of inventors becomes irrelevant in explaining the quality of inventions. Thus, we provide evidence for our first hypothesis (H1), in the light of which greater cultural diversity measured by the participation of a foreigner in the inventor team favours higher quality of technical solutions generated. However, we do not find evidence to support the second hypothesis (H2), according to which greater cultural diversity among foreigners in the inventor team – measured by the Herfindahl index – improves the quality of generated inventions. In other words, it is important for the quality of inventions generated in Poland that foreigners participate in research, and it does not matter that they come from different cultural backgrounds.

Our findings have also shown that generally those regions of Poland in which inventor teams are more culturally diverse, at the same time generate inventions of higher quality than regions in which research teams are more homogeneous, which has made it possible for us to positively verify our third hypothesis (H3). More detailed research on a sample of voivodships with the largest number of applications with the participation of foreigners (6 voivodships) also revealed that increased cultural diversity in the inventor team translates into an increase in the number of citations by more than 7 in the Masovian voivodship and more than 2 in the Lower Silesian voivodship. So far as Greater Poland, Silesian and Pomeranian voivodships are concerned, the relationship between an increase in diversity in the structure of inventors and the quality of inventions they generate is positive, but it is not very significant. Meanwhile, the quality of technical solutions in Lesser Poland voivodship deteriorates with an increase in cultural diversity.

The analysis conducted in this paper also showed that immigrants from different countries are not a homogeneous group and in this sense they are not always ideal substitutes for local researchers. Their contribution to increasing innovation depends on the country they come from, on the one hand, and the conditions or specifics of the host region, on the other hand. The optimal group of inventors-foreigners that ensures the highest quality of Polish inventions are citizens of Japan, Belgium, the US and Turkey. In the presence of this cultural mix, the number of citations received by an invention increases from the country average of 3.52 to as many as 19 citations.

Depending on the region of Poland, the creators of inventions of the highest quality are, however, citizens of other countries. In the case of Masovian voivodship, such an optimal cultural combination is created by citizens of Japan, the US and Turkey, in Lower Silesian voivodship – citizens of France, Belgium and Ireland, in Greater Poland and Silesian voivodships – citizens of the UK, while for Pomeranian voivodship the citizens of India are the most valuable. In all the above mentioned cases, patent applications with the participation of an optimal combination of foreigners receive a greater number of citations than other applications in which foreigners were involved. This is particularly evident in Masovian and Silesian regions, where the average number of citations increases from 9.1 to 43.9 and from 4.33 to 25, respectively.

In general, we interpret our results as evidence that highly skilled migrants and the resulting cultural diversity of the population contribute to raising the level of innovation of in host regions. Our conclusions are therefore consistent with the literature evidence, especially in studies focused on the countries occupying high positions in international innovation rankings. Moreover, our results – like findings by Mayerhoffer (2019) for the Czech Republic and Stojcić (2016) for Croatia – suggest that the positive effects of the influx of migrants can be felt not only in the most technologically advanced countries in the world that at the same time have greater potential in attracting talent, but also in countries further down in innovation rankings.

Despite its limitations (see point 3.2, 3.4 and 3.6 for more), this paper may provide some suggestions to public authorities. First of all, decision-makers could allocate funds for increasing Poland's potential to attract outstanding specialists from abroad, as well as to promote cultural diversity in organisations whose activities are based on R&D. However, the financial support for the mobility of highly qualified employees should be limited to a certain proportion of foreigners per research team so as to take into account the fact that only an appropriate combination of inventors from Poland and abroad as well as an appropriate combination of countries of origin of the foreigners themselves increase the creativity of research teams. Moreover, supporting activities aimed at attracting highly skilled foreigners should be approached individually, depending on the region of Poland, so as to take into account its specifics and compatibility with the foreigners' specific culture.

The results of our analyses may be useful from the perspective of future research, which could be extended by more measures of cultural diversity. In this paper, both measures of cultural diversity:

1 the presence of a foreigner in the patent application

2 the diversity of an inventor team measured by the Herfindahl index, were based on citizenship.

Since, in fact, cultural differences result not only from different citizenship, but they can be the result of a number of other conditions, this fact should be taken into account. In relation to inventors, such a determinant of "culture" could be e.g., the university in which they were educated or the country where the university was located. The it could turn out that the cultural diversity of many inventor teams is greater than one based only on citizenship. This is because some Poles are educated abroad and having returned to their home country, they bring to the research a kind of "foreign element", "foreign academic culture". Undoubtedly, such a perspective on cultural diversity would give more space to formulate conclusions.

References

Adams, J.D. and Clemmons, J.R. (2013) 'How rapidly does science leak out? A study of the diffusion of fundamental ideas', *Journal of Human Capital*, Vol. 7, No. 3, pp.191–229.

Adams, J.D., Clemmons, J.R. and Stephan, P.E. (2006) *How Rapidly Does Science Leak Out?*, NBER WP, No. 11997.

Alesina, A. and La Ferrara, E. (2005) 'Ethnic diversity and economic performance', *Journal of Economic Literature*, Vol. 43, No. 3, pp.762–800.

AlShnebli, B.K., Rahwan, T. and Woon, W.L. (2018) 'The preeminence of ethnic diversity in scientific collaboration', *Nature Communications*, Vol. 9, No. 1, pp.1–10.

Aspinall, P. (2009) 'The future of ethnicity classifications', *Journal of Ethnic and Migration Studies*, Vol. 35, No. 9, pp.1417–1435.

Audretsch, D., Dohse, D. and Niebuhr, A. (2010) 'Cultural diversity and entrepreneurship: a regional analysis for Germany', *The Annals of Regional Science*, Vol. 45, No. 1, pp.45–85.

Awaworyi Churchill, S., Valenzuela, M.R. and Sablah, W. (2017) 'Ethnic diversity and firm performance: evidence from China's materials and industrial sectors', *Empirical Economics*, Vol. 53, No. 4, pp.1711–1731.

Bahar, D., Choudhury, P. and Rapoport, H. (2019) *Migrant Inventors and the Technological Advantage of Nations*, Harvard Business School, WP, No. 19-119.

Barjak, F. and Robinson, S. (2008) 'International collaboration, mobility and team diversity in the life sciences: impact on research performance', *Social Geography*, Vol. 3, No. 1, pp.23–36.

Bassett-Jones, N. (2005) 'The paradox of diversity management, creativity and innovation', *Creativity and Innovation Management*, Vol. 14, No. 2, pp.169–175.

Bilan, Y. and Strielkowski, W. (2016) 'Migration in post-transition economies: immigration surplus in visegrad group countries', *International Journal of Trade and Global Markets*, Vol. 9, No. 2, pp.182–196.

Bjerke, B. (2004) *Kultura a Style Przywództwa. Zarządzanie w Warunkach Globalizacji*, Oficyna Ekonomiczna Grupa Wolters Kluwer, Kraków.

Bosetti, V., Cattaneo, C. and Verdolini, E. (2015) 'Migration of skilled workers and innovation: a European perspective', *Journal of International Economics*, Vol. 96, No. 2, pp.311–322.

Bratti, M. and Conti, C. (2018) 'The effect of immigration on innovation in Italy', *Regional Studies*, Vol. 52, No. 7, pp.934–947.

Brixy, U., Brunow, S. and D'Ambrosio, A. (2017) *Ethnic Diversity in Start-Ups and Its Impact on Innovation*, IAB DP, Nos. 25/2017.

Brunow, S. and Stockinger, B. (2013) *Establishment's and Regions Cultural Diversity as a Source of Innovation: Evidence From Germany* NORFACE DP, No. 2013-22.

Bulmer, S. (1996) 'The ethnic group question in the 1991 census of population', in Coleman, D. and Salt, J. (Eds.: *Ethnicity in the 1991 Census of Population*, HMSO, London.

Burszta, W. (1998) *Antropologia kultury: tematy, teorie, interpretacje*, Wydawnictwo Zysk i S-ka, Poznań.

Chellaraj, G., Maskus, K.E. and Mattoo, A. (2005) *The Contribution of Skilled Immigration and International Graduate Students to U.S. Innovation*, World Bank Policy Research, WP, No (3588).

D'Ambrosio, A., Gabriele, R., Schiavone, F. and Villasalero, M. (2017) 'The role of openness in explaining innovation performance in a regional context', *Journal of Technology Transfer*, Vol. 42, No. 2, pp.389–408.

Fassio, C., Montobbio, F. and Venturini, A. (2019) 'Skilled migration and innovation in European industries', *Research Policy*, Vol. 48, No. 3, pp.706–718.

Fleming, L. (2001) 'Recombinant uncertainty in technological search', *Management Science*, Vol. 47, No. 1, pp.117–132.

Florida, R. (2002) *The Rise of the Creative Class*, Basic Books, New York.

Gagliardi, L. (2015) 'Does skilled migration foster innovative performance? Evidence from British local areas', *Paper in Regional Science*, Vol. 94, No. 4, pp.773–794.

Hall, M. and Tideman, N. (1967) 'Measures of concentration', *Journal of the American Statistical Association*, Vol. 62, No. 317, pp.162–168.

Hunt, J. (2011) 'Which immigrants are most innovative and entrepreneurial? distinctions by entry visa', *Journal of Labor Economics*, Vol. 29, No. 3, pp.417–457.

Hunt, J. and Gauthier-Loiselle, M. (2010) 'How much does immigration boost innovation?', *American Economic Journal: Macroeconomics*, Vol. 2, No. 3, pp.31–56.

Joshi, A. and Jackson, S.J. (2003) 'Managing workforce diversity to enhance cooperation in organizations', in West M., Tjosvold, D. and Smith, K (Eds.): *International Handbook of Organizational Teamwork and Cooperative Working*, John Willey & Sons, Ltd, Chichester, pp.277–296.

Karsidi, R., Sutarno, Agung Prabowo, M. and Trinugroho, I. (2017) 'The importance of synergy and organisation culture to accelerate university in the global environment: a case study', *International Journal of Trade and Global Markets*, Vol. 10, No. 4, pp.314–321.

Kennedy, S. (2015) 'Selective multiculturalism? symbols of ethnic identity and core values theory', *Journal of Educational and Social Research*, Vol. 5, No. 1, pp.249–260.

Kerr, W. (2008) 'Ethnic scientific communities and international technology diffusion', *Review of Economics and Statistics*, Vol. 90, No. 3, pp.518–537.

Kerr, W. and Lincoln, W.F. (2010) 'The supply side of innovation: H-1B visa reforms, and U.S. ethnic invention', *Journal of Labor Economics*, Vol. 28, No. 3, pp.473–508.

Kerr, W.R. (2009) *Breakthrough Inventions and Migrating Clusters of Innovation*, Harvard Business School, WP, No. 10-020.

Kim, J., Lee, S.J. and Marschke, G. (2009) 'International knowledge flows. evidence from an inventor-firm matched data set', in Freeman, R.B. and Goroff, D.L. (Eds.): *Science and Engineering Careers in the United States: An Analysis of Markets and Employment*, University of Chicago Press, Chicago, pp.321–348.

Lee, N. (2015) 'Migrant and ethnic diversity, cities and innovation: firm effects or city effects?', *Journal of Economic Geography*, Vol. 15, No. 4, pp.769–796.

Lee, N. and Nathan, M. (2010) 'Knowledge workers, cultural diversity and innovation: evidence from London', *International Journal of Knowledge-Based Development*, Vol. 1, Nos. 1–2, pp.53–78.

Leten, B., Belderbos, R. and Van Looy, B. (2007) 'Technology diversification, coherence and performance of firms', *Journal of Product Innovation Management*, Vol. 24, No. 6, pp.567–579.

Mayerhoffer, M. (2019) 'Cultural diversity and innovation: the case of the Czech Republic in comparison to the EU', *Proceedings of the 7th International Conference Innovation Management, Entrepreneurship and Sustainability*, University of Economics, Prague, pp.578–588.

Miguelez, E. (2018) 'Inventor diasporas and the internationalization of technology', *The World Bank Economic Review*, Vol. 32, No. 1, pp.41–63.

Miguelez, E. and Fink, C. (2013) *Measuring the International Mobility of Inventors: A New Database*, WIPO WP, No. 8.

Miguelez, E. and Noumedem Temgoua, C. (2015) 'Highly skilled migration and knowledge diffusion: a gravity model approach', *Paper Presented at the EU – SPRI Conference*, 10–12 June, Helsinki. Finland.

Miguelez, E. and Noumedem Temgoua, C. (2017) *Immigration Externalities, Knowledge Flows and Brain Gain*, Cahiers du GREThA, No. 2017-07.

Moser, P., Voena, A. and Waldinger, F. (2014) 'German jewish émigrés and US invention', *American Economic* Review, Vol. 104, No. 10, pp.3222–3255.

Nathan, M. (2014) 'Same difference? Minority ethnic inventors', diversity and innovation in the UK', *Journal of Economic Geography*, Vol. 15, No. 1, pp.129–168.

Niebuhr, A. (2010) 'Migration and innovation: does cultural diversity matter for regional R & D activity?', *Papers in Regional Science*, Vol. 89, No. 3, pp.563–585.

Noumedem Temgoua, C. (2018) *Highly-Skilled Migration: Knowledge Spillovers and Regional Performances*, Economies and Finances, Université de Bordeaux, Bordeaux.

Oettl, A. and Agrawal, A. (2008) 'International labor mobility and knowledge flow externalities', *Journal of International Business Studies*, Vol. 39, No. 8, pp.1242–1260.

Østergaard, C.R., Timmermans, B. and Kristinsson, K. (2011) 'Does a different view create something new? The effect of employee diversity on innovation', *Research Policy*, Vol. 40, No. 3, pp.500–509.

Ottaviano, G.I.P. and Peri, G. (2004) *Cities and Cultures*, FEEM WP, No. 92.04.

Ozgen, C., Nijkamp, P. and Poot, J. (2011) *Immigration and Innovation in European Regions*, IZA DP, No. (5676).

Ozgen, C., Nijkamp, P. and Poot, J. (2013) *Measuring Cultural Diversity and Its Impact on Innovation: Longitudinal Evidence from Dutch Firms*, IZA DP, No (7129).

Page, S. (2007) *The Difference: How the Power of Diversity Creates Better Groups, Firms, Schools, and Societies*, Princeton University Press, Princeton.

Parrotta, P., Pozzoli, D. and Pytlikova, M. (2014) 'The nexus between labor diversity and firm's innovation', *Journal of Population Economics*, Vol. 7, No. 2, pp.303–364.

Partridge, J. and Furtan, W.H. (2008) 'Increasing Canada's international competitiveness: is there a link between skilled immigrants and innovation?', *Paper Presented at the 2008 Annual Meeting,* pp.27–29 July, Orlando, Florida 6504, American Agricultural Economics Association (New Name 2008: Agricultural and Applied Economics Association).

Pelled, L.H., Eisenhardt, K. and Xin, K. (1999) 'Exploring the black box: an analysis of work group diversity, conflict, and performance', *Administrative Science Quarterly*, Vol. 44, No. 1, pp.1–28.

Pholphirul, P. and Rukumnuaykit, P. (2017) 'Does immigration always promote innovation? Evidence from Thai manufacturers', *Journal of International Migration and Integration*, Vol. 18, No. 1, pp.291–318.

Prithwiraj, Ch. and Kim, D.Y. (2019) 'The ethnic migrant inventor effect: codification and recombination of knowledge across borders', *Strategic Management Journal*, Vol. 40, No. 2, pp.203–229.

Ratajczak, M. (2014) 'Podróż ku międzykulturowości', *Kultura – Historia – Globalizacja*, Vol. 15, pp.209–220.

Schneider, J. and Eckl, V. (2016) *The Difference Makes a Difference; Team Diversity and Innovative Capacity: OECD: Developing Novel Approaches to Measure Human Capital and Innovation*, [online] https://www.oecd.org/sti/015%20-%20SKY_Schneider_Eckl_201607025.pdf (Accessed 3 July, 2019)

Stephan, P.E. and Levin, S.G. (2001) 'Exceptional contributions to US science by the foreign-born and foreign-educated', *Population Research and Policy Review*, Vol. 20, Nos. 1–2, pp.59–79.

Szczecińska-Musielak, E. (2014) 'Przejawy etniczności we współczesnym świecie. zarys problematyki', *Kultura – Media – Teologia*, Vol. 19, pp.78–92.

Trajtenberg, M. (1990) 'A penny for your quotes: patent citations and the value of innovations', *RAND Journal of Economics*, Vol. 21, No. 1, pp.172–187.

Tzeng, Ch-H. (2014) 'A review of contemporary innovation literature. A schumpeterian perspective', *Innovation*, Vol. 11, No. 3, pp.373–394.

United Nations, Department of Economic, and Social Affairs, Population Division (2019) *International Migrant Stock 2019* (United Nations database, POP/DB/MIG/Stock/Rev. 2019).

Utami, W., Sulianti, K.T.D., Paramu, H. and Slamin (2019) 'Expatriate career development: self efficacy, multicultural personality, collective efficacy, and individual expatriate performance', *International Journal of Trade and Global Markets*, Vol. 12, No. 2, pp.187–198.

Wachowska, M. (2016) 'Lags between academic science and inventiveness in Poland', *Forum Scientiae Oeconomia*, Vol. 4, No. 3, pp.81–91.

Wadhwa, V., Gereffi, G., Rissing, B. and Saxenian, A. (2007a) *Education, Entrepreneurship and Immigration: America's New Immigrant Entrepreneurs, Part II (June 11 2007)* [online]. Ewing Marion Kauffman Foundation, https://ssrn.com/abstract=991327 or http://dx.doi.org/10.2139/ssrn.991327 (Accessed on February 2020).

Wadhwa, V., Jasso, G., Rissing, B., Gereffi, G. and Freeman, R. (2007b) *Intellectual Property, The Immigration Backlog, and Reverse Brain-Drain*, American's new immigrant entrepreneurs, Part III, Ewing Marion Kauffman Foundation.

Note

[1]The Pearson correlation coefficient (rxy) takes values from the range [–1,1]. The significance of the correlation coefficient has been verified using the Student's t-test of significance, with the test statistic taking the following form: $T=|rxy|\sqrt{n}–2$ $\sqrt{1}–rxy2\sim t\alpha 2$, $n–1$. If the empirical value of the statistic exceeds its theoretical value then there is a basis for rejecting the null hypothesis, which means the correlation is significant.