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Innovation Propensity and Firm Size: Evidence from Manufacturing

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Abstract

Digitalization has enabled the networking of production facilities and the interaction of all stakeholders across the value chain. Smart factories helped reversed the decline of manufacturing and increased its total value added. The resultant Fourth Industrial Revolution (4IR) has led to an explosion of innovation reflected in the exponential growth of related patents and other forms of intellectual property rights (IPR). IPR and protection mechanisms are presumed drivers of global innovation and the interrelationship between innovation, IPR and economic growth is well-established. This paper addresses the question of propensity of manufacturing firms for specific forms of IPR across firm sizes. Using data from a large swath of German manufacturing firms, a novel model is developed to predict the probability of any given firm registering a specific form of IPR depending upon its size and innovativeness.

Keywords: Intelligent manufacturing; innovation management; intellectual property rights; SMEs.

1. Introduction

The ubiquitous use of sensors, the proliferation of distributed computing devices, the emergence of high-speed wireless communication networks, and the deployment of increasingly sophisticated machinery has transformed the way goods are manufactured. The convergence of these trends is interchangeably called Industry 4.0 or the Fourth Industrial Revolution to signal that its impact is expected to be far-reaching [1]. These blanket terms encompass a wide range of enabling technologies, including advanced cyber-physical systems, the Internet of Things (IoT), machine learning, cloud computing, and robotics [2].

The Fourth Industrial Revolution (or simply 4IR) has ushered the age of intelligent manufacturing, with its explicit promise of radically optimizing the manufacturing process via digitalization. In the "smart factory" processes and supply chains are simulated and optimized with every machine connected and monitored for added flexibility, mass customization, increased efficiency and improved quality.

A key discriminant of the 4IR, when compared to previous industrial revolutions, is that data (including data-analysis techniques and business models using such data) has become a source of new competitiveness along with technological innovations. In order to realize this competitiveness premium, manufacturers need to invest in physical networks linked with cyber networks to allow the real-time flow of information throughout their value chain. Data thus collected can be turned into information and can be acted upon quickly. In short, securing data connectivity and getting actionable insights from data are at the core of 4IR [3].

Within this context, the 4IR dramatically transforms the traditional manufacturing paradigm in which core technology is the key source of competitiveness and the making of such technology proprietary ensures an advantage over competitors in the same industry [4]. Manufacturing firms need to innovate continuously in order to stay competitive and, at the same time, they need to protect the intellectual property of their innovations in the rapidly changing industrial landscape of the 4IR [5].

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The use of formal intellectual property rights protection mechanisms has increased in importance globally over the years, due to the rise of the knowledge economy. Intellectual property (IP) is considered to be a key driver of business performance in the sense that it can convert investments in manufacturing into economic benefits [6]. The patent system is indeed credited as the crucial legal foundation on which the first industrial revolution was built, and IP is expected to have similar positive implications for innovation in the knowledge-based economy of the 4IR [7]. The patent system is already evolving to extend protection for 4IR innovations in the virtual world.

IPR as a driver of global innovation in the 4IR and the interrelationship between innovation, IPR and economic growth is already established [8]. The seminal European Patent Office 2017 report [9] shows steadily growing importance that 4IR developments have in the patent system. The report revealed that the number of 4IR patent applications at the EPO increased exponentially during the 25 years between 1991-2016, rising from around 200 in 1991 to 1,500 in 2003 and reaching about 5,500 in 2016 [9]. Impressively, the growth rate for 4IR patent applications was 54% in the last three years of the surveyed period (during which the overall growth of patent applications was barely 8%).

The increase in 4IR patent applications is driven by a limited number of applicants with significant regional concentration of inventive activity. Inventions in intelligent manufacturing technologies at the EPO have been dominated by the USA, Europe and Japan with China and Korea rapidly catching up. About 30% of the are coming from Europe. Within Europe, which accounts for about 30% of the total 4IR patent applications, Germany is the leader followed by France. Germany excels in the application domains of Vehicles and Manufacturing, while France leads in enabling technologies such as Artificial intelligence and User interfaces.

Among the top 150 4IR applicants at the EPO there are 56 European enterprises, which are primarily large companies from various industry sectors. Yet European policy interventions at the local, regional or national level routinely aim to support small and medium-sized enterprises (SME's) [10, 11].

In this broad context, the primary objective of this paper is to examine whether there are measurable differences between large manufacturing firms and small and medium-sized ones as regards their preferred form of IPR in protecting their innovations. A secondary objective is to inform appropriate policy in developing an innovation ecosystem with strong IPR protection. This is crucial since the innovation performance of manufacturing firms is severely undermined when they operate in environments with weak IPR protection [12].

The paper is organized as follows. A concise review of the methodology, including definitions and the dataset employed is presented in Section 2. This is followed, in Section 3, by an overview of the econometric model employed and the results of the regression analysis performed. An informed discussion of the results obtained is provided in Section 4. Finally, in Section 5, the conclusions of the paper are summarized along with limitations and suggestions for future research.

2. Methodology

The most inclusive European resource is the set of Community Innovation Surveys (CIS), a series of biannual surveys designed to assess the innovativeness of different sectors and regions and executed by national statistical offices in the 27 European Union member states (EU27), in the European Free Trade Agreement (EFTA) countries and in states with a candidate status for accession to the European Union. Each CIS provides analytical data broken down by countries, type of innovators, economic activities and size classes. The public data release normally takes place two and half years after the end of the survey reference period and is managed by EUROSTAT [13], which also uses CIS for its annual European Innovation Scoreboard. Published CIS data have been often used for academic research on innovation.

CIS surveys typically have a section dedicated to IPR with detailed information collected from a very large number of companies across Europe. In the context of this paper, CIS 2016 data (made available in 2019) are used to examine the effect of firm size on its innovative production as measured via the various modalities of IPR recorded.

As a matter of choice, the presentation is based on Germany with its 63,409 manufacturing firms surveyed providing a rich and representative tableau of company sizes and activities [14].

CIS surveys record innovative activities that culminate into IPR. The list of IPR recorded is detailed in Table 1 and includes six separate variables and an aggregated one. The value of each variable denotes the number of firms that engaged in just one type of IPR during the survey period. The value of the variable aggregated term "Any IPR" is not the sum of the other variables, but the number of firms that engaged in at least one type of IPR activity.

The CIS data for Germany are painstakingly compiled by clustering the manufacturing firms surveyed according to their size class and innovativeness.

Size class is determined by three categories: small (SML), medium (MED) and large-sized (LRG) firms (enterprises with less than 10 employees were not surveyed). A firm is considered to be engaged in innovation (INNO) if it introduced an innovation or had ongoing or abandoned innovation activities during the three years preceding the survey period. Otherwise, the firm is considered not have engaged in innovation (NON-INNO) in innovation.

The list of survey variables is presented in Table 2 along with an ordered set of (arbitrary) numerical values for each category or binary state.

Table 1. List of IPR in CIS 2016.

Variable	Explanation
Patent	Enterprises that applied for a patent
Trademark	Enterprises that registered a trademark
Utility model	Enterprises which applied for a utility model
Industrial design	Enterprises that registered an industrial design right
Trade secret	Enterprises which used trade secrets
Copyright	Enterprises which claimed copyright
Any IPR	Enterprises which applied for/registered/claimed any IPR

Table 2. List of survey variables.

Variables	Notes	Value
Size class:		
SML	10 to 49 employees	1
MED	50 to 249 employees	2
LRG	More than 250 employees	3
Innovative activity:		
NON-INNO	Not engaged in innovation	0
INNO	Engaged in innovation	1

Table 3. Descriptive statistics of the German manufacturing firms surveyed.

	Firms surveyed	% of total	INNO firms surveyed	% of total INNO firms	% INNO firms in class
SML	43,777	69%	28,158	63%	64%
MED	15,564	25%	12,504	28%	80%
LRG	4,068	6%	3,785	9%	93%
Total	63,409	100%	44,447	100%	70%

Table 4. Types of German manufacturing firms surveyed.

Type of Manufacturing	Firms	%
Manufacture of food products	9,162	14%
Manufacture of beverages	682	1%
Manufacture of tobacco products	29	0%
Manufacture of textiles	968	2%
Manufacture of wearing apparel	383	1%
Manufacture of leather and related products	195	0%
Manufacture of wood products except furniture	1,927	3%
Manufacture of paper and paper products	980	2%
Printing and reproduction of recorded media	2,225	4%
Manufacture of coke and refined petroleum products	68	0%
Manufacture of chemicals and chemical products	1,655	3%
Manufacture of basic pharmaceutical products	346	1%
Manufacture of rubber and plastic products	3,945	6%
Manufacture of other non-metallic mineral products	2,248	4%
Manufacture of basic metals	1,271	2%
Manufacture of metal products, except machinery	13,177	21%
Manufacture of computer, electronic and optical products	2,903	5%
Manufacture of electrical equipment	2,806	4%
Manufacture of machinery and equipment	8,021	13%
Manufacture of motor vehicles	1,391	2%
Manufacture of other transport equipment	436	1%
Manufacture of furniture	1,860	3%
Other manufacturing	3,447	5%
Repair and installation of machinery and equipment	3,284	5%
Total:	**63,409**	**100%**

In Tables 3 and 4, the descriptive statistics of the 63,409 German manufacturing firms surveyed are presented across size classes in summary form. (Percentages in the tables may not add up to 100 due to rounding.) It should also be noted that while the numbers and percentages of the Total row are summing the corresponding columns of Table 3, the bracketed figure of 70% is the *weighted average* of the % of INNO firms across each of the three size classes.

The relative ratio of SML, MED and LRG firm sizes in the total sample is approximately 12:4:1, which is fairly representable of the size distribution of German manufacturing firms [13]. On the average 70% of these firms are characterized as INNO. The relative ratio of SML, MED and LRG firm sizes in the subset of INNO firms is skewed to 7:3:1. This is due to the fact that an overwhelming 93% of the large-sized firms are INNO while the same percentage drops down to 80% for MED firms and to 64% for SML firms.

In the CIS survey, the manufacturing firms were asked if they applied or registered for protectable intellectual property rights during the three years preceding the survey period. Table 5 details the results across size classes and innovativeness for each of the IPR modalities detailed in Table 1. (Non-innovative firms *do* engage in IPR applications and registrations which are the outcome of inventive activities outside the three-year window or of accidental discoveries outside the purview of a defined innovation project.) For INNO and NON-INNO firms and across all firm sizes, the most common form of IPR is Trade secret, followed by Patent and Trademark.

Since a firm can be involved in more than one type of IPR, the sum of the values of the six distinct variables in each row exceeds the total number of firms surveyed in each case. The use of multiple forms of IPR is common in complex industry sectors such as manufacturing and typically signals innovation activities that are maturing from a single invention to the product level.

An important caveat of this analysis is that the IPR recorded in Table 5 are not exclusively related to 4IR. Yet, the analysis is relevant to 4IR as Germany is a leader in 4IR innovations, accounting for 12% of all 4IR patents filed worldwide. While in general 4IR inventions are predominantly filed in the ICT sector, in Germany such inventions are predominantly in manufacturing. This is driven primarily by Germany‘s high R&D intensity in the motor vehicles sector as well as in the equipment and machinery supporting this sector [15].

From Table 5, it can be seen that 65% of all the INNO firms engaged in innovation were involved in Any IPR application and registration activities. (The percentage varied from 90% for LRG and 75% for MED to 58% for SML innovative manufacturing firms.) In contrast, only 23% of the NON-INNO firms engaged in Any IPR activities. (The percentage varied from 71% for LRG and 40% for MED to 19% for SML non-innovative firms.)

To address the discrepancies observed across size classes for INNO and NON-INNO firms, multivariate analysis is employed.

3. Multivariate analysis and results

The objective of this paper is to study the differences in inventive activity between small, medium, and large manufacturing firms and between INNO and NON-INNO firms as evidenced by their acquisition of IPR. The independent variable, or regressor, is firm size which can only take the values SML, MED, and LRG. Separate but similar models are used for INNO and NON-INNO firms.

Table 5. Firms applying or registering for intellectual property rights.

INNO	Any IPR	Patent	Trademark	Utility model	Industrial design	Trade secret	Copyright	*INNO firms surveyed*
SML	16,240	5,125	4,168	3,912	2,169	12,510	1,815	28,158
MED	9,366	4,411	3,061	3,014	1,328	7,503	1,228	12,504
LRG	3,420	2,357	1,679	1,455	667	2,777	729	3,785
Total firms:	29,026	11,893	8,908	8,381	4,164	22,790	3,772	44,447
Out of 44,447	**65%**	**27%**	**20%**	**19%**	**9%**	**51%**	**8%**	**100%**

NON-INNO	Any IPR	Patent	Trademark	Utility model	Industrial design	Trade secret	Copyright	*NON-INNO firms surveyed*
SML	2,962	846	1,192	769	672	2,197	732	15,619
MED	1,216	452	495	433	428	870	294	3,060
LRG	201	35	37	34	70	102	5	283
Total firms:	4,379	1,333	1,724	1,236	1,170	3,169	1,031	18,962
Out of 18,962	**23%**	**7%**	**9%**	**7%**	**6%**	**17%**	**5%**	**100%**

Specifically, the models used in this study aim to estimate the probability *P(i)* of the event of a manufacturing firm in a specific size class applying or registering for a given IP form *i*.

Based on Table 1, seven dummy variables were thus created as dependent variables of the model:

- *i = 1*: Any IPR
- *i = 2*: Patent
- *i = 3*: Trademark
- *i = 4*: Utility model
- *i = 5*: Industrial design
- *i = 6*: Trade secret
- *i = 7*: Copyright

Each of the dummy variables is binary depending upon the firm reported the corresponding activity (1) or not (0).

Taking into account both the binary form of the dependent variables, the ordered categorical form of the regressor, and the nonlinear nature of their relation, only nonlinear probability models (NLPMs) were considered. Probit emerged as the most suitable tool for studies of this type [16, 17].

Probit regression is based on the assumption that the probability P(i) of IP form i being registered by a manufacturing firm can be computed as:

$$P(i) = \beta_{i0} + \beta_{i1}(size) + u_i \tag{1}$$

where the regressor variable of firm size takes the values SML, MED and LRG; the regression coefficients βi0 and βi1 need to be computed; and *ui* is a normally distributed random error term for each observation *i* [18]. Probit models are often used to report alternative metrics, such *predictive margins*, that are easier to interpret. Predictive margins are the expected probabilities of the outcome for specified values of the regressors and are better suited for problems with categorical variables [19].

The analysis in this paper thus proceeds based on the Probit model in (1) and the report of predictive margins reflecting the average adjusted predictions. Probit regression addressed INNO and NON-INNO firms separately, so as to keep these two categories of firms distinct. The analysis was performed using the STATA v16 statistical software with the statistical significance set at a two-sided p value of $\leqslant 0.05$ [20].

Table 6 reports the computed predictive margins reflecting the average adjusted predictions (and their significance) for each of the seven IP forms described previously. It should be noted that all the predictive margins computed are significant at 1%, except for Copyright values for LRG NON-INNO firms which are significant at 5%.

The upper part of Table 6 is dedicated to INNO firms and reveals that the predicted probability of LRG innovative firms applying or registering for Any IPR is almost 90% but declines to 75% and 58% for MED and SML firms respectively. The same declining trend from large to small innovative firms can be traced for all other distinct forms of IPR recorded.

In support of the observations from Table 4, Trade secret is the most common IPR applied for regardless of firm size. The probability of an innovative manufacturing firm applying for or registering for a trade secret is about 73%, 60% and 44% for LRG, MED and SML firms respectively. Patent is a close second, but the chasm between SML and LRG firms is now significant. The probability of an innovative manufacturing firm applying or registering for a patent is about 62%, 35% and 18% for LRG, MED and SML firms respectively. Trademarks and Utility models follow with Industrial designs and Copyrights being less popular choices.

As regards the spread, a LRG innovative firm is about 60% more likely to report Any IPR or Trade secret than a SML firm and 2-3 more times as likely to report Trademark, Utility model, Industrial Design or Copyright. The biggest difference is in Patents where a LRG firm is a whopping 3.5 times more likely to report a patent than a SML firm.

Turning to the lower part of Table 6, the predicted probability of LRG non-innovative firms applying or registering Any IPR is 71% but declines to about 40% and 19% for MED and SML firms respectively. The same declining trend from large to small non-innovative firms can be traced for Industrial design and Trade secret, which remains the most common IPR applied for regardless of firm size. Interestingly though, non-innovative MED firms are *more* active than either SML or LRG firms in Patent, Trademark, Utility model and Copyright, with LRG firms even lagging SML firms in Copyright.

As regards the spread, a LRG innovative firm is about 4 times more likely to report Any IPR and 6 times more likely to report Industrial design than a SML firm and 2-3 more times as likely to report Patent, Trademark, Utility model, or Trade secret. As regards Copyright, a SML non-innovative firm is 3.5 times more likely to report a patent than a LRG firm.

Table 6. Predictive margins: probability of having different types of intellectual property rights across class sizes.

	Any IPR	**Patent**	**Trademark**	**Utility model**	**Industrial design**	**Trade secret**	**Copyright**
INNO firms reporting IPR across size classes (44,447 observations):							
1 (SML)	0.577 [0.003] ***	0.182 [0.002] ***	0.148 [0.002] ***	0.139 [0.002] ***	0.077 [0.002] ***	0.444 [0.003] ***	0.064 [0.001] ***
2 (MED)	0.749 [0.004] ***	0.353 [0.004] ***	0.245 [0.004] ***	0.241 [0.004] ***	0.106 [0.003] ***	0.600 [0.004] ***	0.098 [0.003] ***
3 (LRG)	0.904 [0.005] ***	0.623 [0.008] ***	0.444 [0.008] ***	0.384 [0.008] ***	0.176 [0.006] ***	0.734 [0.007] ***	0.193 [0.006] ***
NON-INNO firms reporting IPR across size classes (18,962 observations):							
1 (SML)	0.190 [0.003] ***	0.054 [0.002] ***	0.076 [0.002] ***	0.049 [0.002] ***	0.043 [0.002] ***	0.141 [0.003] ***	0.047 [0.002] ***
2 (MED)	0.397 [0.009] ***	0.148 [0.006] ***	0.162 [0.007] ***	0.142 [0.006] ***	0.140 [0.006] ***	0.284 [0.008] ***	0.096 [0.005] ***
3 (LRG)	0.710 [0.027] ***	0.124 [0.020] ***	0.131 [0.020] ***	0.120 [0.019] ***	0.247 [0.026] ***	0.360 [0.029] ***	0.018 [0.008] **

Standard errors in brackets. * Significant at 10%; ** significant at 5%; *** significant at 1%.

4. Discussion

Despite the comprehensiveness of the CIS survey, numerous factors such as the choice of respondent within a firm, the methods of collection used, the different culture and business norms across firms, can produce noise in the data. Aggregating the data does improve the signal-to-noise ratio at the expense of reducing the ability to identify issues at the micro level. Yet, it is a limitation of the survey instruments used in CIS that there is no record of the number of filings that each individual firm had during the survey period. Only the specific type was recorded. With this broad caveat in mind, it has been demonstrated that the propensity of a firm for specific forms of IPR is indeed moderated by its size and innovativeness.

As expected, INNO manufacturing firms are more involved in inventive activities leading to protectable IPR than NON-INNO ones. Surprisingly though, NON-INNO manufacturing firms are also engaged in such activities at quite a significant level. It was noted that this could be the outcome of inventive activities outside the three-year window or of accidental discoveries outside the purview of a defined innovation project. The greater affinity of NON-INNO firms for lighter forms of IPR, and not patents, lends additional weight to this hypothesis. Another possible mediating factor could be that a number of NON-INNO firms are transitioning to the INNO category and their involvement with single IPR is a sign of their trajectory. These central trends are valid across all firm sizes, but they are differently nuanced for INNO and NON-INNO firms.

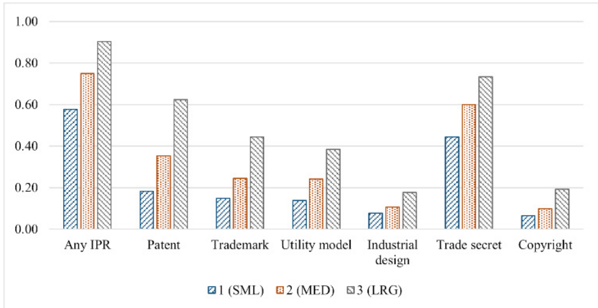

Fig. 1. Ranking of IP forms in INNO firms across size classes.

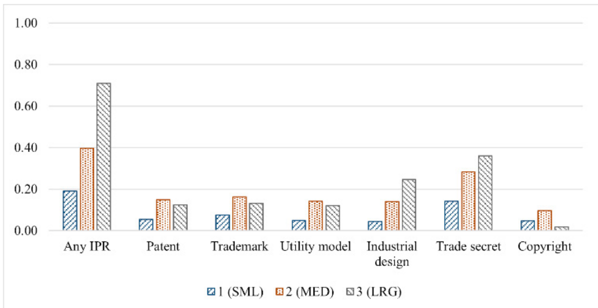

Fig. 2. Ranking of IP forms in NON-INNO firms across size classes.

For manufacturing firms in the INNO category, the probability of being involved in IPR activities rises significantly with firm size for all forms of IPR recorded. The differential is largest in Patents where a LRG firm is 3.5 times more likely to report patent activity than a SML firm.

Figures 1 and 2 capture succinctly the differences in the preferred modalities of IPR activities for INNO and NON-INNO firms across firm sizes. In all cases, the prevailing forms of IPR protection are Trade secret and Patent, which have distinct signaling and protection characteristics.

A patent grants an exclusive property right to the inventor for a limited period of time in exchange for disclosure of the innovation. A patent must reflect a technological novelty, be inventive and susceptible of industrial application. In general, patents signal a firm's innovation capabilities by showing that the firm possesses an invention or technology that is worth being protected.

Trade secret on the other hand refers to business information that is not known or readily accessible by the relevant public and has commercial value because it is secret. Trade secret protection is primarily governed by contract law, no specific novelty or originality is required, and there is no time limit.

Innovating firms often use both patents and trade secrets to protect their innovations. In Industry 4.0, patents are more likely to be used (alone or in combination with trade secrets), for product innovations. Trade secrets (often without patents) are more likely to be used for process innovations [16].

The results of this paper indicate that it is about 3 times more probable that a small innovative firm uses trade secret over patent as the IPR vehicle of choice. It is about 2 times more probable that a medium innovative firm uses trade secret over patent as the preferred form of IPR. Large innovative firms use patents *and* trade secrets (and other forms of IPR) with a high degree of complementarity [17].

Complementarity is characteristic of complex industry sectors and reflects the importance of first mover advantage resulting in high patent value. The benefits of using multiple forms of IPR become more apparent when the focus is shifted from a single invention to the product level.

5. Conclusions

The objective of this study was to enhance the body of research on the interplay between innovation, IPR and the 4IR in manufacturing with the emphasis on the firm size.

Intellectual property and innovation are intimately related. The public nature of knowledge in Industry 4.0 means that companies can only take advantage of their innovations if they are protected. Formal IPR instruments, such as patents, trademarks, utility models, industrial designs, trade secrets and copyrights, protect innovators from exploitation of their knowledge. IPR provide important incentives for innovation, reduce information asymmetry, and improve business performance [17].

Both trade secrets and patents are likely to be used when the innovation is *new to the market*. Trade secrets are preferred when the innovation is *new to the firm* and in open innovation practices. In general, the use of trade secrets for protecting innovations is higher than the use patents for most economic sectors [16].

The results of this study demonstrate that large manufacturing firms remain the dominant players in the invention, protection and commercialization of new technologies in Industry 4.0. It is apparent that the ability of many small firms to successfully engage in innovation is hampered by their lack of resources, and by their limited ability to assess risk [21, 22].

While the present study focused on German manufacturing firms, it resonates with broader studies in the field. Indeed, the fact that large firms have an innovation advantage was observed at least 30 years ago in a German study, based though on data from the U.S. Small Business Administration, which challenged the then prevailing view that SMEs are the engines of innovation and technological change [23]. The study theorized that innovation, with its high fixed costs and inherent risks, is better suited for economies of scale which only large firms can exploit.

In the context of Industry 4.0, the majority of SMEs remain technology followers [24]. There is a significant minority though of technology developers or new technology users that plays a key role in the early stages of new technological inventions and their validation.

When SMEs protect their inventions, they prefer trade secrets as they expect fewer benefits from patents compared to large firms and while they cannot afford the pressure of high litigation risk associated with patenting [25, 26].

Considering the intensiveness and rapidness of technology development in Industry 4.0, it is a valid research question whether the IPR patterns detected from CIS 2016 may have changed over time. The imminent release of the CIS 2018 data is expected to provide the requisite dataset for such an investigation.

CRediT author statement

Saltanat Akhmadi: Conceptualization, Investigation, Software, Formal Analysis, Writing– Original Draft. Mariza Tsakalerou: Methodology, Validation, Writing– Review & Editing, Supervision.

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