Issues Inside the Field of Economics of Innovation: Definitions, Data Sources, Estimation Procedures and Comparability of Results

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Abstract

Innovation economics requires an interdisciplinary approach and at least knowledge in economics and history. A historiographical approach to data representativeness is necessary to perform literature review without producing errors when comparing studies with datasets lacking small companies. Knowledge in econometrics is necessary to assess the possibility to compare results from two innovation papers. An identification strategy is necessary for comprehension because the definitions of innovators are most of the time rather incomparable. Some papers recognize only successful innovators in terms of delivering the product new to the market. In other papers, innovators are companies, which imitated their competitors or trained staff recently. These issues are dependent on the understanding of the definition of the term innovation. Comparison of innovation economics research results or using them in an argument is not possible without complex understanding of data (representativeness), methods (set of control variables) and other limits of dependent variables.

Keywords: Innovation economics, identification strategy, innovation, innovation activities.

Introduction

The analysis of innovation activities in a defined economy requires a rich theoretical background and places relatively high demands on the researcher. This paper aims to review the issues and problems researches face and mistakes they do when analysing innovation activities of firms, industries and national economies.

This paper brings together theoretical contributions of theories dealing with endogenous growth theory and perspectives from scholars who have contributed to the empirical testing in the field of innovation activities, international competition, business strategies, and generally, economics of technological and social change.

The aim is to broaden the understanding in the field of innovation economics. The methods respect traditional economic historical approaches. The aims are traditional in the sense of their practical scientific contribution to the field of economics of innovation. Initially, definitions and theories are discussed to contribute to a better understanding of the so-called "i-terms" (innovation, imitation, invention) and their definitions, i.e., to promote their dynamic and simultaneous relationship.

This understanding of the terms allows us to proceed to the second aim, which is a review of the recently used econometric methods, innovation datasets, and their results. As mentioned above, there are many ways innovation can be understood, many ways innovation process is estimated, and many issues with data sets. That is why interpreting and comparing the results must be done with caution.

The firm-level strategies and microeconomic principles are an essential part of the Schumpeterian based growth theories. I want to pay tribute to one of the most influential economists and historians, Josef Alois Schumpeter, whose theories and thought experiments, however imperfect, are a source of inspiration for many scholars around the world. In the academic competition-innovation debate nothing is resolved yet (Gilbert 2006).

This paper aspires to show that to analyse hypotheses about a firm's market survival conditions, potential competitors, the process of creative destruction, dynamic efficiency, and the never-ending debate about competition and innovation, an interdisciplinary approach and knowledge of at least in economics and history are required.

Materials and Methods

Literature review is a main technique; a direct comparison of Scopus indexed papers follows to show specific problems and issues. To show differences, issues and problems, highest cited original articles in the fields of Business, Management and Accounting and the fields of Economics, Econometrics and Finance are analysed. The selection is based on the title of the article and the use of the word innovation. In the first stage, five articles regardless their publication year are selected, then Scopus indexed original articles from authors experience and general innovation literature are used to complement the analysis of highly cited literature. For the analysis of definitions, terms innovation and innovator are searched for and their definitions are described. For the analysis of the methods, an estimation method is described. For the dataset limitations, representativeness of the data is described.

Table 1: Summary statistics for CIS waves in the Czech manufacturing industry

Variable	**Obs.**	**Mean**	**Std. Dev.**	**Min**	**Max**
Innovator (new to the market)	42663	0.16	0.36	0	1
Innovator (new to the firm)	42663	0.28	0.45	0	1
Total R&D expenditures	42387	11616.37	146349.80	0	1.51E+07
Number of employees	34913	259.99	1205.67	1	81662

Source: Czech Statistical Office (2016)

For the case study, Czech Community Innovation Survey (CIS) datasets (2001, 2003, 2005, 2006, 2008, 2010, 2012 and 2014) were used for the analysis. The firm level innovation data and financial statements were not joined because CZSO no longer provides the opportunity to join data. Case study is aimed at the decision and intensity of innovators (Table 1). Estimation strategy of innovation process is similar to the one used by Castellacci (2009) and Crepon, Duguet and Mairesse (1998), however due to the data unavailiabilty (assets, material and energy costs are no longer provided by CZSO) only two frist equations were used (Table 2).

Table 2: Estimation porocedure of innovation porcess – innovation intensity

Heckman procedure	$r_{it}^{*}\begin{cases} \mathbf{1}\ \boldsymbol{if}\ \boldsymbol{r_{it}} = (\boldsymbol{X_{1it}\beta_1} + \boldsymbol{\rho_i} + \boldsymbol{\varepsilon_{it_1}}) > \mathbf{0} \\ \mathbf{0}\ \boldsymbol{otherwise}\ (\boldsymbol{r_{it}} \leq \mathbf{0}) \end{cases}$ $\boldsymbol{k_{it}^{*}} = \ln(\boldsymbol{k_{it}})\,|(\boldsymbol{r_{it}} > \mathbf{0}) = \boldsymbol{X_{2it}\beta_2} + \boldsymbol{\rho_i} + \boldsymbol{\varepsilon_{it_2}}\ \boldsymbol{with}\ \boldsymbol{Df}(\boldsymbol{k_{it}}) = (\mathbf{0}, \infty)$

Source: Based on Castellacci (2009) and Crepon, Duguet and Mairesse (1998)

Where Xnitβn‘s (with n = 1, 2, 3, and 4) are vectors of explanatory variables and ε_itn‘s (with n = 1, 2, 3, and 4) are random-error terms. The error terms are assumed to be independent of the exogenous variables. The vector of parameters to be estimated is denoted βn (with n = 1, 2, 3, and 4). The first equation (rit*) accounts for selection bias. The probability of a firm i to engage in continuous R&D in a year t is specified as a probit model, i.e. P(rit*>0) = Φ(X1itβ1), where rit* equals 1 if firm i is an innovator and reports R&D expenditures.

The second linear equation (ki*) describes innovation input, which relates the log of internal and external R&D expenditures (without machinery expenditures) to the number of employees in a firm i, conditional of being a process innovator and doing R&D. The $\boldsymbol{\rho}$i represents fixed effects. In both equations there are potential determinants (Xnitβn‘s); such as, a firm’s size, foreign ownership, being part of a group of companies etc.

Results

There is much confusion when economists talk about innovation. The same term is used identically as an "act" and also as an "end product". For example, the term innovation is identically used as the act of innovating (the whole innovation process) and also as an end product (an invention). A consensus on a clear differentiation of the terms has clearly been an issue in economics and the social sciences from the very beginning (Brozen 1951) to the present (Godin 2008). With all the "i" terms, a pejorative meaning is perceived throughout history. Innovation meant, for example, changing to socialism (Godin 2012).

In the economics of innovation, a dynamic environment (Schumpeterian tradition) is expected and there is no universal definition of the term innovation, although many scientists (see examples in Baregheh et al. 2009) define it as a complex process. It encompasses all the activities associated with the act of innovating from the beginning to the end. Therefore, we must define the beginning and end of the process.

Typically, (Schmookler 1966), the initial phase is characterised by (1) a generation of ideas through (2) experiments and problem-solving methods. The final phase is characterised by (3) the implementation of ideas and (4) its market and society diffusion. From another point of view, we can speak of (1) basic research activities, followed by (2) applied and experimental research in the initial innovation input phase. In the output phase, we observe (3) piloting and prototyping, followed by (4) commercialization, and changes to the market and in the society. (Greenhalgh and Rogers 2009).

There are countless interactions between economic agents in every phase of the innovation process. Mostly we observe the firms' reaction (imitation, cooperation, innovation, etc.) and their adaptation (mergers, exits, court battles, etc.) to new market conditions. But there are also customers and governments, and we can track the impact of an innovation internationally, i.e., on a global scale. The demand side, governments, and global tendencies are all important sources of information. This extraction of desires is a valuable innovation factor in every phase of the innovation process.

A lot of dynamic factors and simultaneous processes are linked with the act of innovating. We are not able to track and observe all the outcomes of economic agent interactions and not even all outcomes of the innovation process. There are abandoned innovations, defence and military R&D projects, and simply all the secrets and strategic non-declaration in the financial statements and surveys.

Two interesting simultaneous processes are the full act of invention and imitation. They also have dual meanings, as does the term innovation. We observe an act of inventing/imitating and a final invention/imitation. As one can imagine, there are many possible intersections between all the "i" terms.

The act of inventing is typical of the initial (1) phase of the act of innovating, i.e., we observe creativity and the generation of ideas. But the complete process of inventing, the act and the outcome, can result in a prototype (phase 2, and 3), or an innovative outcome (4) which is an invention. To put it another way, the outcome of the act of inventing, a new law of physics, or the invention of a new chemical element, is a basic research outcome (2), i.e., not the end-product of the innovation process.

The imitation term has, again, a dual form. The act of imitating is sometimes mistakenly equated with an act of exact copying. Although these terms are related, the act of imitating can be, and usually is, a far richer act than making copies. We again can place the act of imitating in the initial phase (1) of the act of innovating, but the relationship of these two terms is more complicated. We are, in most cases, inspired, however pejoratively it may sound, by the current state of technology and scientific knowledge. Imitating usually, but not universally, follows the act of inventing and sometimes outcomes emerge as a by-product of that activity, with luck, or simply by the process of trial and error, i.e., haphazardly trying possible solutions and discarding those that are in error until one works. Therefore, the act of imitating can result in a new basic research outcome (2), a new and better prototype (3), or a new in the world market invention (4). Once more, the outcome of the act of imitating can be a similar thing, without any inventive effort, a copy, which is not the outcome of the innovation process.

The terms imitation and innovation are very close to each other and sometimes we are not able to distinguish between them. To distinguish between those two terms, a measure of novelty is introduced. We speak about imitation when there is a zero level of novelty. Novelty is broadly used in patent law. It is a level of originality and industrial usability that can be compared “objectively” to the current scientific knowledge and state of technologies. This objective manner is a patent office arbitrary routine which has its limitations. But it is a method used to assess an innovation by an impartial spectator.

Such a routine requires educated guesses, and multiple specialists involved. But only time will tell, if an innovation is useful and successfully introduced to the market. In time, after the innovation is introduced to the market, we can distinguish between incremental and radical innovations, i.e., how influential an innovation was on the market. We can also observe how a firm views its innovation impact on the market in retrospect and what type it was.

According to the Oslo manual (OECD 2005) and the Frascati manual (OECD 2002), four types of innovation are recognized. Product, process, organizational, and marketing innovation are viewed by firms as new-to-the-firm, new-to-the-local market, and finally the world's first introduction to the global market. Such typology is a useful simplification. However, as we’ve shown, the field of innovation is not black and white, and a firm, an institution, even a government is not exactly a trustworthy reviewer and reporter of its financial and innovation activities.

In the literature, both approaches are used and we observe innovation to be the act of innovating (the whole innovation process) and the end-product (just the invention). Most cited paper by Teece (1986) describes innovation and innovators in the sense of the “end-product”. “…innovators - those firms which are first to commercialize a new product or process in the market” (Teece 1986, p. 285) “The analysis so far assumes that the firm has developed an innovation for which a market exists…” (Teece 1986, p. 301). Second

(Powell, Koput, and Smith-Doerr 1996), third (Moore, and Benbasat 1991), fourth (DiMasi, Hansen, and Grabowski 2003) and fifth most highly cited paper (Audretsch and Feldman 1996) do not define innovation or the term innovator. It is only assumed indirectly by the subject of analysis, for example in Audretsch and Feldman (1996) inventions are counted and the "end-product" definition of innovation is thus assumed.

The R&D (Research and Development) functions were popularized in Mansfield (1965) as a mix of (1) research expenditures (as the R&D input) and (2) number of important inventions (as the R&D output) and by the definition, innovation was considered to be the "end product" of an innovator or a company that was first to introduce a new product to the market.

In the CDM literature, named after researchers Crépon, Duguet and Mairesse (1998), the definition of innovation reflects the whole innovation process. This analysis of the complex definition of innovation process is reflected for example in Castellacci (2011), Classen et al. (2014), Doran and O'Leary (2011), and Hashi and Stojcic (2013). Innovators are described directly by self-reporting in CDM models. First CDM model suggested that the innovating firms were those which answered 'yes' to at least one of the following eight questions in the innovation survey: "…did you performe in the five last years (between January 1st of 1986 and December 31 of 1990) an innovation of the following type: (i) product improvement; (ii) new product for the market; (iii) product imitation (i.e., new for the firm but not for the market); (iv) technological breakthrough; (v) process improvement; (vi) packaging innovation (explicitly excluded from i, ii and iii in the questionnaire); (vii) organizational innovation linked to the introduction of technological change and (viii) marketing innovation. " (Crépon, Duguet and Mairesse 1998, p. 141) This approach suggests that imitation is a part of innovation, because in the above citation there is the option iii) innovation new for the firm but not for the market.

Similarly, Doran and O'leary (2011, p. 203) state: "Innovating firms are defined as those introducing products that are either new to them or new to the market." but the distinction here is not five last years but only three years. Classen et al. (2014, p. 602) are even more restrictive and account only for one year and they are using R&D expenditures instead of self-reporting variables "innovators including only firms with a positive innovation expenditure in 2006" and explaining innovation expenditures as "internal and external R&D or the acquisition of external resources to realize innovation projects" Classen et al. (2014, p. 597).

Hashi and Stojcic (2013, p. 358) define an innovator as a company that "invested in intramural or extramural activities in R&D, purchased new machinery, equipment and software, purchased or licensed patents, know-how and similar forms of knowledge from other organisations, engaged in training of staff for development of new or significantly improved products or processes, and activities for the market introduction of new or significantly improved goods and services." and similarly Castellacci (2011, p. 643) defines an innovator as a firm that "Engaged in R&D: a dummy variable that indicates whether a firm has carried out R&D activities in each period." The positive value of total

R&D expenditures is another way of identifying companies as innovators in a broader sense (f. e. including imitators and companies with abandoned innovation projects).

Problems with estimation

Highly cited papers by Teece (1986), Moore and Benbasat (1991) are rather theoretical and no econometric method is employed. Powell, Koput, and Smith-Doerr (1996) use indexes and fixed effects panel estimation to specific innovation issues but the innovation stage is not clearly distinguished. Cross-sectional approach is used in DiMasi, Hansen, and Grabowski (2003) to estimate innovation drug development costs using differences ($\chi 2$ testing) in phases of drug validation process. Audretsch and Feldman (1996) use Gini coefficient and ordinary least square estimation of cross-sectional data. Advanced econometrics is not used in top cited articles. It was probably because Mansfield (1964) encountered several estimation issues like endogeneity bias in the ordinary least square (OLS) estimation back in the 1960s. He was also concerned about R&D knowledge function because the data was hard to collect and the analysis depended on the firm true reporting of its financial indicators and research expenditures.

It took about thirty years for present approaches like the original CDM model to solve complicated maximum likelihood estimates, mainly due to computer computational capacity. The CDM models became popular because they gave researchers a more efficient way to estimate innovation activities and make the most of Community Innovation Surveys (CIS). However, the limitations of the Cobb-Douglas linear production function and reporting problems have remained and researchers have to be careful and perhaps not too optimistic in the empirical findings of their production function models.

In reviewed models (Crépon, Duguet and Mairesse 1998; Castellacci 2011; Classen et al. 2014; Doran and O'leary 2011; Hashi and Stojčić 2013), advanced econometrics and CDM models are introduced. The problem is that there are in general two estimation methods, one with four equations like in original CDM model and one with five equations with bivariate PROBIT in the third stage (as observed in Classen et al. 2014). Another distinction is the utilization of cross-sectional data like in Hashi and Stojčić (2013) and panel estimation procedure like in Castellacci (2011). The interpretation of results is appropriate but it is hard to compare the results of these studies because the identification strategy of explanatory variables and instruments is also different. The substantively larger problem is data credibility and representativeness.

Problems with representativeness of small companies

Papers by Teece (1986), Moore and Benbasat (1991) are rather theoretical and no database is directly used for analysis. Powell, Koput, and Smith-Doerr (1996) use own data and there are issues with under representativeness of companies which are not publicly traded and summary statistics of the number of employees or assets are missing and also, we do not know how many micro sized companies (less than 10 employees) are in the data sample. Randomly selected companies are included in the analysis of DiMasi, Hansen, and Grabowski (2003) but the direct data representativeness in terms of number of smaller companies is not provided. In Audretsch and Feldman (1996) the sample is from the Small Business Administration's Innovation Data Base, but again no summary statistics or data representativeness in terms of number of smaller companies is not provided. It can be expected that small companies are under-represented because in the previous research of one of the authors (Acs and Audretsch 1988) small companies were those with 500 and less employees.

Case study

The coefficients seem to be quite similar and the differences between new-to-the-market innovators and new-to-the-firm innovators are not substantial in decision stage (Models 1 and 3, Table 3). This is because the selection bias is to some extent suppressed. But we can observe on average lower market orientation coefficients in new-to-the-firm innovators. World markets orientation is a highly important factor of being a new-to-the-market innovator. The R&D intensity of new-to-the-market innovators is substantially dependent on the industry sector. Aggregate sector differences are not observable in case of new-to-the-firm innovators.

The problem of fixed effects estimation is that we observe only a limited within variation (Models 2 and 4, Table 3). There is a problem with datasets consisting of 4 and more CIS datasets. The questions are changed or discontinued and the ability to create complete model with interesting variables allowing for random effect estimation of R&D expenditures intensity is very limited. Another problem is the lack of willingness of statistical offices to provide data. In case of Czech Republic, the financial data are modified to some extent (around one standard deviation).

(Table 3 about here)

Conclusion

It is the hard to answer the hypotheses about a firm's market survival conditions, potential competitors, the process of creative destruction, dynamic efficiency, and the never-ending debate about competition and innovation. In this paper is shown that such analysis requires interdisciplinary approach and knowledge at least in economics and history. Historiographical approach to data credibility and representativeness is necessary to describe when performing literature review of the original research articles. Knowledge in statistics is necessary to assess the possibility of comparing results from two innovation papers.

An identification strategy is necessary to analyse because the definition of innovators is most of the time incomparable. In some papers, only successful innovators in terms of delivering products new to the market are recognized. In other papers, innovators are defined as companies that imitated their competitors or trained staff recently. These issues are dependent on the understanding of the definition of innovation, since there are at least two group of researchers who consider innovation to be described in terms of "marketized end-product new to the market" and in terms of positive R&D/innovation expenditures.

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Table 3: Innovation intensity – Czech industry 2001-2014

8 CIS Waves 2001-2014	**(1) Innovator (0/1) df/dx (New market)**	**(2) Log of R&D expenditures per employee**	**(3) Innovator (0/1) df/dx (New firm)**	**(4) Log of R&D expenditures per employee**
	PROBIT RE	**OLS FE**	**PROBIT RE**	**OLS FE**
Log of employees	0.259***	-0.594***	0.286***	-0.465***
	(0.02)	(0.20)	(0.01)	(0.13)
Being part of a group	0.353***		0.472***	
	(0.04)		(0.04)	
Foreign company	-0.200***	0.331*	-0.273***	0.202
	(0.04)	(0.18)	(0.04)	(0.14)
Manufacturing	0.780***	1.321***	0.832***	0.299
	(0.06)	(0.36)	(0.05)	(0.39)
Services	0.507***	1.060**	0.526***	0.627
	(0.07)	(0.52)	(0.05)	(0.55)
National markets	0.755***		0.472***	
	(0.06)		(0.04)	
European markets	0.715***		0.575***	
	(0.06)		(0.04)	
World markets	0.771***		0.578***	
	(0.07)		(0.05)	
Linear trend	0.065***	0.004	0.055***	0.003
	(0.01)	(0.02)	(0.01)	(0.01)
Lack of personnel	0.327***		0.488***	
	(0.04)		(0.03)	
Lack of information	0.096**		0.066*	
	(0.04)		(0.04)	
Prior innovation	-0.253***		-0.297***	
	(0.04)		(0.03)	
Cooperation		0.264**		0.264**
		(0.11)		(0.11)
Funding – local GOV		0.264		0.221
		(0.26)		(0.17)
Funding – central GOV		0.474***		0.443***
		(0.11)		(0.10)
Funding – EU		0.135		0.177*
		(0.13)		(0.10)
Funding – UE FP		0.042		0.108
		(0.15)		(0.10)
Log of R&D expenditures per employee				
Constant	-133.757***	-2.294	-114.682***	-0.049
	(13.05)	(39.27)	(11.32)	(26.30)
Observations	23802	3378	24289	5399
Adjusted R^2	n/a	4.28 %	n/a	3.52 %

Robust Standard errors (bootstrapping) in parentheses, * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$
Source: Author

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Process innovation prevails with the highest shares of innovators in 12 out of 34 countries â€“ including Canada (48%) and Ireland (41.6%). Product innovation appears in second place, prevailing in ten high-income countries as the type of innovation that was implemented by most firms. This was, for example, observed in Germany, where 49.5% of the manufacturing firms were product innovators.Â There are a few basic indicators3 on innovation that are often used along with the indicators on the share of innovators. In turn, innovations may appear not only as a result of scien-tific research. Here we define science policy as a government policy aimed at the funding, conduct and dissemination of scientific research. Innovation policy is a government policy fostering the use of research and development to produce new and competitive products and processes. In terms of instruments, science and innovation policy are interconnected. There are of course matters of pure science policy like grant funding of fundamen-tal research or the organization of scientific work. At the same time, the problem of cooperation