The Impact of Product and Process Innovations on Productivity: A Review of Empirical Studies

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Abstract

This article draws attention to insufficient research interest in the empirical assessments of the impact of product and process innovations (PPI) on economic performance. The analysis of the relevant studies for 2000–2022 found significant international and intersectoral differentiation of the considered linkages between innovation and productivity. It revealed limitations for the meaningful interpretation of the array of results accumulated in the literature. The author emphasizes the importance of an integrated multi-perspective approach to assessing the possible impact of PPI on various aspects of enterprise and industry performance when planning public innovation policy. For example, minor product innovations can make a tangible positive contribution to a company's sales growth, but have no impact on labor productivity at all. The impact of a radical resource-saving process innovation will look doubtful if it is evaluated only on a short time interval. The author concludes that it is expedient to revise established views on industrial technological innovations and develop new approaches to their measurement.

Keywords: product innovation; process innovation; innovation statistics; productivity

Paper type: Research Article

Citation: Domnich Ye. (2022) The Impact of Product and Process Innovations on Productivity: A Review of Empirical Studies. *Foresight and STI Governance*, 16(3), 68–82. DOI: 10.17323/2500-2597.2022.3.68.82

Introduction

Product and process innovations (PPI)[1] directly affect productivity and other economic parameters. Process innovation reduces costs and often leads to product innovation in design and materials, while launching new products frequently requires upgrading or designing entirely new production equipment. Companies able to closely integrate PPI tend to be successful in improving their performance and launching new product lines, while the positive feedback starts a cyclical process (Reichstein, Salter, 2006; Hullova et al., 2016; Homburg et al., 2019; Ehls et al., 2020; Malek et al., 2020). According to the innovation-driven growth theory, individual PPI effects combined with the complementary impact underlie economic growth.

At the same time PPI effects and the relationship between them remain empirically understudied (Damanpour, Gopalakrishnan, 2001; Damanpour, 2010; Ballot et al., 2015; Hullova et al., 2016) and largely escape researchers' attention. A probable cause is their secondary, concomitant nature in relevant studies. Publications directly focused on innovations' complementarity tend not to consider PPI in detail. Reviews on the topic are either outdated, or not entirely relevant (Hall, 2011; Mohnen, Hall, 2013; Teplykh, 2016). Meanwhile the need to classify and structure the latest research findings on the individual and complementary impacts of PPI on productivity is becoming increasingly urgent.

This paper summarizes the results of the theoretical discussion on PPI's contribution to productivity, including measuring its elasticity. It analyzes the international and intersectoral differentiation of the relevant effects and the robustness of their econometric estimates. The role of PPI in the business cycle is discussed, along with other production factors.

Theoretical Generalizations and Hypotheses

The impact of PPI on performance can be positive or negative. A positive effect has several interpretations, equal in terms of their explanatory power. Innovations improve the efficiency of resource use, promote the application of new technologies and help weaker firms overcome the technological gap (Hall, 2011; Crespi, Zuniga, 2012). They promote the emergence of new sectors of the economy, facilitate changes in the production and specialization structure, increase the share of knowledge-intensive activities (Alvarez et al., 2015), and ultimately create sustainable competitive advantages (Hall, 2011).

A negative impact of innovation on productivity (not infrequently observed in reality) cannot be unequivocally interpreted either. It may be due to training lags (Mohnen, Hall, 2013) or disruptions in the product life cycle (Roper et al., 2008). In some cases, introducing new products interrupts the production rhythm and diverts resources from more profitable (liquid) commodity items. Innovation products may be initially produced inefficiently with negative implications for performance. Each company has a certain market power and operates in an inelastic section of the demand curve, so when process innovations improve its production efficiency, the revenue (sales) performance declines (Mohnen, Hall, 2013). Thus, the first working hypothesis can be formulated as follows:

H1: The number of statistically significant negative coefficients of PPI's impact on productivity in a representative sample of studies based on representative samples of firms will be similar for the both innovation types.

There is an opinion that less developed countries are primarily focused on gradual, minor innovations, which is why, unlike developed economies, they are mostly interested in process innovations (Cassoni, Ramada-Sarasola, 2012; Crespi, Zuniga, 2012). At the same time, the concepts of high-tech and low-tech industries' innovations are being developed in the framework of management theory (Keupp et al., 2012; Hullova et al., 2016).

High-technology industries need access to skilled labor and developed capital markets, which contributes to their (industries) being concentrated in relatively more developed countries. Product and process technologies in such sectors tend to change rapidly, which means they must be adequately synchronized with one another (Lager, Storm, 2013). Low-technology industries mainly consume and ship raw and other materials rather than finished products and components, and do not require significant amounts of expensive equipment (Frishammar et al., 2012). Innovations related to technological and business processes play a key role in their development. This is how the term "process industries" has emerged, which refers to mining, food, metal, and woodworking production. These mostly tend to be located in developing and transitional economies. Hence two other working hypotheses:

H2: PPI in high-tech industries and advanced economies make more or less the same impact on productivity and are sensitive to intangible production factors such as research and development (R&D) expenditures, patents and licenses, qualifications and skills, etc.

[1] Product innovations are defined as products (services) introduced to the market which are new or markedly improved in terms of their properties or intended uses. Such innovations imply significant improvements in technical parameters, components and materials, firmware, usability, or other functional characteristics (OECD, 2018). In their turn, process innovations are considered to be new or significantly modernized production (delivery) methods, including radical changes in techniques, equipment, and/or software (OECD, 2018). Together, PPI make up a pool of technological innovations.

H3: Process innovation plays a key role in increasing the productivity in low-tech industries and developing economies, and is sensitive to capital investment and the application of new equipment.

The phenomenon of innovations' complementarity, including PPI, deserves special consideration; studying this area goes back to Joseph Schumpeter's works (Schumpeter, 1934). Radical innovation implies not just applying PPI, but also changing the delivery system and localizing production and maintenance services. Organizations possessing valuable and rare additional assets typically tend to profit from various forms of innovation (Teece, 1986). The study (Abernathy, Utterback, 1978) is usually seen as the starting point of the complementary PPI development theory, which proposed a three-stage model of the industry life cycle. The first two stages comprise the sequential introduction of radical PPI, followed at the third phase of incremental innovations of both types. Theoreticians count up to seven types of complementarity between PPI, depending on the depth, order, and impact area (Hullova et al., 2016; Sjodin et al., 2020; Verganti et al., 2020).

Empirical studies distinguish between the two main complementarity types (Ballot et al., 2015). The first is *complementarities-in-use*, which implies that the development and application of product innovations requires introducing process innovations and vice versa. In this case the feedback between innovations of two or more types is evaluated. The second type is *complementarities-in-performance*, associated with the synergy from combining different kinds of innovations. Studying this phenomenon involves measuring the new economic value created for the company, usually in terms of productivity. The first complementarity type is not necessarily accompanied by the second. Firms may not know which combinations of innovations would work, and frequently simply imitate other players (Damanpour, 2010; Stephan et al., 2019; Pollok et al., 2019; Leo, 2020).

For the purposes of this paper, only complementarities-in-performance studies are of interest. These can be broken down into two groups: some stated assessing this effect as their main goal, while others do assess it but do not discuss in detail. The first group is less relevant to us as it generally does not focus on PPI but also covers non-technological (organizational and marketing) innovations. A common finding of such studies is that technological innovations (or all PPI) are more likely to increase firms' productivity and can do it to a greater extent when combined with non-technological ones, and vice versa. This was demonstrated on the basis of German data for in 2002-2004 (Schmidt, Rammer, 2007), British for 2002-2004 (Battisti, Stoneman, 2010), Italian for 2002-2004 (Evangelista, Vezzani, 2010), Dutch for 2000-2006 (Polder et al., 2010), Czech, Spanish, French, Italian, Portuguese, and Slovenian for 2002-2004, (Evangelista, Vezzani, 2011), Norwegian for 1999-2004 (Sapprasert, Clausen, 2012), Spanish for 2006 (Hervas-Olivier et al., 2012), and Irish for 2004-2006 (Doran, 2012).

A notable exception is the work (Ballot et al., 2015) which assessed not only PPI complementarity in the performance of British and French firms in 2002-2004, but also its differentiation by sectors of the economy, and how it was affected by various factors including non-technological innovation. The authors show that in both countries, complementarity was achieved only by small and medium-sized enterprises which did not apply any organizational innovations. It was not observed in low-tech sectors either, though in France, in the presence of organizational innovations, the PPI effects even interchanged. In high-tech sectors complementarity was only noted for British firms not engaged in organizational innovation.

Thus, PPI complementarities-in-performance turn out to be significantly differentiated geographically, which implies the need to obtain and compare detailed econometric estimates of the combined and individual impact of each of the two innovation types on productivity. Studies in the second group seem to be more useful for this purpose, with complex measurements carried out but not discussed in detail.

Based on the above, a fourth hypothesis can be suggested:

H4: On the basis of previous research, a statistically significant complementarity effect of PPI can only be positive.

Innovation is not the only productivity factor. It is customary to include qualifications, staff training costs, R&D expenditures, patenting, the use of information and communication technologies (ICT), and a number of other factors in the production function of a modern enterprise. Obviously, a significant part of them, while not being equal to innovation, are related to it, which allows us to suggest a fifth hypothesis:

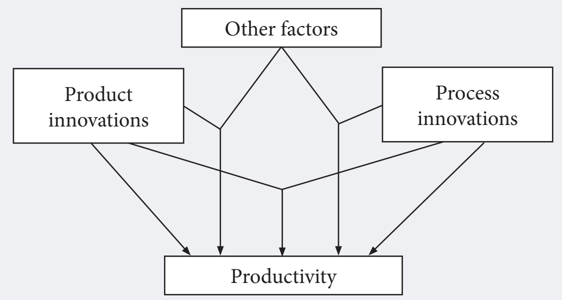
H5: The estimates of PPI's impact on productivity will be the lower with more factors included in the correlation equation.

The overall scheme of the relationship under consideration is shown in Figure 1.

Testing the Hypotheses

The variety of assessments of PPI's impact on productivity is logically due, among other things, to different ways of measuring innovation and the relationships between its effects. The best metric for output of innovative products is their cost. However, firstly, this is only applicable to product innovations, and secondly, it greatly reduces the sample of enterprises (Lööf et al., 2003; Janz et al., 2004; Criscuolo,

Figure 1. **Economic links analysed in the study**



Source: author.

2009; Wadho, Chaudhry, 2018). Binary variables (1 if the company did apply innovations of a particular type, and 0 if it did not) are less accurate (Hall, 2011), but allow one to use large samples of enterprises and estimate the complementary PPI effects on productivity (1 if the firm applied both innovation types, and 0 if not). Accordingly, in line with the stated goals and proposed hypotheses, the range of empirical studies under consideration should be limited to those using binary PPI indicators.

The search for relevant studies indexed in the academic publications databases eLibrary.ru, WoS, Scopus, ScienceDirect, JSTOR, Google Scholar, and ResearchGate for 2000-2022 revealed 26 studies published in 2004-2021. (Table 1) containing quantitative estimates of individual or combined impact of PPI on productivity. In most of them the authors did not focus on the impact under consideration, i.e., the analytical potential of their results is limited.

First of all, the possible value range of individual and complementary PPI effects is of interest. The combined effect (expressed in additional productivity gains of companies that applied both innovation types under consideration) as a rule tends to be statistically significant and have positive values (no negative values have been identified). The complementarity estimates in the studies under consideration lie in the range between 0.136 and 7.535, the individual impact of product innovations ranges between -4.148 and 3.750, and of process ones between -0.102 to 7.020. The most common interval for the three above indicators in all surveyed countries was between 0 and 1. In certain regional/industry segments, values significantly above module 1 have been recorded.

A statistically significant negative impact of product innovation was noted in two studies based on Chilean data (Alvarez et al., 2015; Santi, Santoleri, 2017). For process innovation, it was also reported in two papers based on Brazilian (Goedhuys, 2007) and Central and Eastern European (CEE) material (Hashi, Stojcic, 2013). A number of publications identified practically no differences in PPI's impact (Arvanitis, 2006; Chudnovsky et al., 2006; Griffith et al., 2006; Siedschlag et al., 2010; García-Pozo et al., 2018; Peters et al., 2018; Morris, 2018). Several papers clearly highlight the impact of either product (Musolesi, Huiban, 2010; Goedhuys, Veugelers, 2012; Acosta et al., 2015; Baumann, Kritikos, 2016) or process innovations (Vakhitova, Pavlenko, 2010; Alvarez et al., 2015; Martin, Nguyen Thi, 2015; Lin et al., 2016; Santi, Santoleri, 2017; Edeh, Acedo, 2021). In other studies, PPI's impact varies depending on the study object (sample), and econometric techniques applied (Mairesse, Robin, 2008; Masso, Vahter, 2008; Hall et al., 2009).

The high complementarity of PPI's impact was noted in several studies, for example, a study on British and French manufacturing companies in 2002-2004 (Ballot et al., 2015): the combined effect (elasticity of productivity to innovation) was estimated at 0.8-0.9. The service sector's performance in Eastern Europe, Central Asia, Latin America, and the Caribbean in 2002-2016 increased by 1.5 times (Morris, 2018). Complementarity was particularly strong (6-7.5 times) among Taiwanese original equipment manufacturers[2] in 2004-2006 (Lin et al., 2016).

Thus, the first and fourth hypotheses of our study are confirmed.

The impact of PPI on productivity, measured using the same methodology within the same time interval, significantly varies depending on the economic environment. First of all, there are discrepancies between countries. In a study of four countries' manufacturing industries in 1998-2000 (Griffith et al., 2006) a statistically significant positive impact of product innovation on productivity was found in Spain and the UK, a tangible combined effect of PPI was recorded in France, and a very small one in Germany. The spatial differentiation of technological innovation's contribution to productivity was also observed in the service sector. For example, in 2006-2008 PPI's effect reached significant positive values for British and German service companies, while in Ireland such firms steadily increased their productivity by applying only process innovations (Peters et al., 2018). The roles of both innovation types also significantly differ between large regional country groups: PPI's impact, including the combined one, on productivity in Latin America and the Caribbean in 2002-2016 was 3-4 times higher than the relevant figures for Eastern European (including Russia) and Central Asian countries (Morris, 2018).

[2] Original equipment manufacturers are firms that make parts and equipment that can be sold by other manufacturers under a different brand name.

The differentiation of PPI impact by industry is much higher than by country. In the Brazilian manufacturing industry, technological innovations did not significantly affect the growth of sales in 2000-2002 except for the high-tech sector, where process innovations had a pronounced negative impact (Goedhuys, 2007). PPI impact on labor productivity in the French service sector in 2002-2004 was four times higher, while the cumulative effect was 1.5 times higher than in the manufacturing industry (Miresse, Robin, 2008). Similarly, in Ireland in 2004-2008 the tertiary sector companies were 2-2.5 times ahead of manufacturing ones in terms of the parameters in question (Siedschlag et al., 2010). In Chile in 2005-2008, product innovations made a strong negative impact, while process innovation, on the contrary, positively affected performance in the industry. At the same time, in the service sector their contribution was generally negligible. The exception was knowledge-intensive business services, where the role of process innovation turned out to be significantly positive (Alvarez et al., 2015).

The dominant innovation type appears to be unrelated to the previous development path, as evidenced by the studies of large country samples comprising developed and transition economies. The results of the 2004 European enterprise survey showed that process innovations, developed both in-house and in partnership with other players, make a key contribution to improving productivity in advanced Western European countries (Hashi, Stojcic, 2013). At the same time, in the CEE, transition economies jointly created process innovations that did not significantly affect productivity, while in-house ones even had an appreciable negative effect. A similar situation is typical for product innovations: in Western European countries they played an important, positive, and statistically significant role, which cannot be said about CEE.

Do these results mean that an economic growth mechanism insensitive to innovation has emerged in CEE? The data for 2013-2014 (Ramadani et al., 2018), however, indicates that product innovations make a high positive contribution to the region's countries' productivity, which refutes the above supposition.

Such a contradictory picture is largely due to the limited time interval covered by most studies, which have to rely on data from numerous firms for the same period (cross section). This is a specific distortion of statistical surveys of innovation activities, which aggregate data for the last three years. Even in the case of a repeat survey, the company sample is usually not maintained (Hall, 2010). As a result, each company's uniqueness (unobserved heterogeneity) is either taken into account insufficiently, or not at all (Crowley, McCann, 2018), despite this factor's fundamental importance for understanding company performance (De Loecker, 2011).

Unsurprisingly, the few studies comprising several rounds and covering more than one time period reveal changes in the PPI's impact over time. For example, there are notable differences between the 1998-2000 and 2002-2004 manufacturing industry surveys in France and Estonia (Mairesse, Robin, 2008; Masso, Vahter, 2008). In the case of France, process innovations dominated during the first period, making an increasingly positive impact upon productivity, while in the second period, this role shifted to product innovations. In Estonia, a significant positive effect was initially recorded only for product innovations, and then only for process ones.

Results like that refer to classic studies (Schumpeter, 1934; Abernathy, Utterback, 1978), which describe innovation cycle models based on alternating PPI, radical and improving ones alike. Applying quantile regression to several samples of the Chilean economy revealed that process innovation yields a significant positive effect only for firms with the lowest or highest sales dynamics (Santi, Santoleri, 2017), but not for companies with median values of this indicator. An analysis of a large sample of small and medium-sized German manufacturing enterprises for 2005-2012 (Baumann, Kritikos, 2016) demonstrated that product innovations make the greatest impact upon business performance of the smallest companies (with less than 10 employees), and it (impact) decreases as company size grows. Thus, even if at a particular moment in time the economic development may be mainly driven by innovations of a certain type, this does not mean the scenario cannot quickly change as the leading industries move through the cycle phases.

This refutes the second and third hypotheses.

Let us more precisely define the place of PPI in the economic cycle of goods and services production. Although innovation is just one of many factors whose inclusion in the correlation equation can significantly change the final estimates, there appears to be no strict inverse relationship between the number of factors taken into account and the strength of PPI's impact. For example, (Arvanitis, 2006) obtained significant and high elasticity values for the effectiveness of PPI on the basis of 13 factors. (Chudnovsky et al., 2006) analyzed 18 factors and found that process innovation played a significant and positive role with a complementary PPI effect. The increased impact from both innovation types if a larger number of factors was taken into account is documented in (Mairesse, Robin, 2008; Hashi, Stojcic, 2013; Martin, Nguyen Thi, 2015; Lin et al., 2016; Vakhitova, Pavlenko, 2010; Alvarez et al., 2015; Edeh, Acedo, 2021; Baumann, Kritikos, 2016).

The PPI effect's sensitivity to introducing additional variables into the model is due not to the number, but to the nature of the factors. The commonly applied science and technology indicators traditionally associated with innovation (which not infrequently

Table 1. **Studies of Product and Process Innovations' Impact on Productivity**

Source	Countries, years	Methodology	Sample	Number of observations	Dependent variable	Innovations' impact on dependent variable		
						Product	Process	Product and process
(Huergo, Jaumandreu, 2004), p. 549, T. 1A	Spain, 1991–1998	Nadaraya-Watson non-parametric kernel estimation	M and MA, all	10735	TFP growth rate	—	0.015***	—
			M and MA: I	7293		—	0.0003	—
(Arvanitis, 2006), p. 28, T. 3.	Switzerland, 1996, 1999, 2002	CDM, 2LSM, PM	MA	1691	LP	0.500***	0.454***	—
		CDM, generalized 2LSM, RE				0.552***	0.411***	—
(Chudnovsky et al., 2006), p. 286, T. A. 3	Argentina, 1992–2001	CDM, LSM, FE	MA	1410	LP	0.088	0.178**	0.136**
(Parisi et al., 2006), pp. 2047–2048, TT. 5–6	Italy, 1995 and 1998	IVM: individual product and process innovations' effects	MA	465	LP growth rate	–0.05	0.17*	—
		IVM: process innovations' effect				—	0.14**	—
		IVM: product innovations' effect				0.08	—	—
		IVM: process innovations' effect adjusted for average knowledge intensity				—	0.11*	—
		IVM: individual product and process innovations' effects		459	TFP growth rate	0.04	0.12	—
		IVM: process innovations' effect				—	0.15**	—
		IVM: product innovations' effect				0.13*	—	—
		IVM: process innovations' effect adjusted for average knowledge intensity				—	0.12*	—
(Griffith et al., 2006), p. 492, T. 5	France, 1998–2000	CDM, IVM	MA	3625	LP	0.060***	0.069**	—
	Germany, 1998–2000	CDM, IVM		1123		–0.053	0.022	—
	Spain, 1998–2000	CDM, IVM		3588		0.176***	–0.038	—
	UK, 1998–2000	CDM, IVM		1904		0.055**	0.029	—
(Goedhuys, 2007), pp. 25–26, TT. 4, 5.	Brazil, 1997, 2000–2002	LSM, PM, not adjusted for available patents	MA	1352	TFP	0.030	–0.102***	—
		LSM, PM, adjusted for available patents				0.016	–0.079**	—
		LSM, PM	MA all firms	1061	Growth of sales	0.001	–0.008	—
			MA: T	529		–0.003	–0.007	—
			MA: I	530		–0.000	–0.042**	—
(Mairesse, Robin, 2008), T. 5.	France, 1998–2000	CDM, ML	MA	3524	LP	0.570***	1.120**	0.520***
	France, 2002–2004		MA	4955		1.090***	0.310	0.350***
			S	3599		3.750***	1.440***	0.590***
(Masso, Vahter, 2008), p. 254, T. 8.	Estonia, 1998–2000	CDM, 2LSM, no time lag	MA	853	GVA	0.207**	–0.055	—
		CDM, 2LSM, one-year lag		855		0.146*	0.046	—
		CDM, 2LSM, two-year lag		862		0.181**	–0.067	—
	Estonia, 2002–2004	CDM, 2LSM, no time lag		676		0.002	0.151***	—
		CDM, 2LSM, one-year lag		635		–0.014	0.169***	—

Table 1 continued

Source	Countries, years	Methodology	Sample	Number of observations	Dependent variable	Innovations' impact on dependent variable		
						Product	Process	Product and process
(Hall et al., 2009), p. 25, T.5.	Italy, SMEs, 1995–2003	CDM, 3LSM not adjusted for investments	MA: all	9674	LP	0.961***	2.624***	—
		CDM, 3LSM adjusted for investments				0.597***	0.193	—
		CDM, 3LSM not adjusted for investments	MA: HT firms	2870		1.314***	2.742***	—
		CDM, 3LSM adjusted for investments				0.700***	0.664	—
		CDM, 3LSM not adjusted for investments	MA: LT firms	6804		0.900***	2.797***	—
		CDM, 3LSM adjusted for investments				0.708***	0.063	—
(Musolesi, Huiban, 2010), p. 73, T.4	France, 1998–2000	CDM, ML according to Heckman (1978) and Maddala (1983)	KIBS	416	GVA	0.324***	0.131	—
		CDM, 2LSM				0.247*	0.301	—
		CDM, IVM according to Wooldridge (2002)				0.271*	0.294	—
(Vakhitova, Pavlenko, 2010), p. 29, T.5.	Ukraine, 2004–2006	CDM, IVM, CSM	MA	792	LP	–0.205	1.137***	—
(Siedschlag et al., 2010), TT. 5, 8, 11.	Ireland, 2004–2008	CDM, IVM, RE	MA and S	1446	LP	0.452***	0.334***	0.271***
			MA	732		0.257**	0.213**	0.163**
			S	714		0.609***	0.450***	0.419***
(Goedhuys, Veugelers, 2012), P. 526, T. 5.	Brazil, 2000–2002	CDM, 2LSM, FE, no PPI complementarity	MA	1503	Average LP growth rate	0.357***	0.014	—
		CDM, 2LSM, FE, PPI complementarity		1503		0.279	–0.071	0.348***
(Hashi, Stojcic, 2013), p. 363, T. 7.	Western, Central and Eastern Europe, 2004	CDM, 2LSM, in-house developed innovations	MA and S	15644	LP	0.528***	0.534***	—
		CDM, 2LSM, innovations developed jointly with other companies				0.266**	0.242**	—
	Western Europe, 2004	CDM, 2LSM, in-house developed innovations		10200		0.904***	1.171***	—
		CDM, 2LSM, innovations developed jointly with other companies				0.581***	0.509***	—
	Central and Eastern Europe, 2004	CDM, 2LSM, in-house developed innovations		5444		0.156*	–0.301***	—
		CDM, 2LSM, innovations developed jointly with other companies				0.052	–0.011	—
(Acosta et al., 2015), p. 59, T. 5.	Spain, 2008–2011	CDM, IVM	MA	1910	LP	0.315***	0.099	0.224***
Alvarez et al., 2015), p. 609, T. 10.	Chile, 2005–2008	CDM, IVM	MA	2679	LP	–4.148**	5.159***	—
			S	3985		2.630	–1.566	—
			KIBS	1572		–3.729	5.155*	—
			TS	2413		1.186	2.191	—
(Ballot et al., 2015), p. 224, T. 3.	UK, 2002–2004	Heckman method	MA	3627	LP	—	—	0.880***
	France, 2002–2004		MA	5691		—	—	0.758***

Table 1 continued

Source	Countries, years	Methodology	Sample	Number of observations	Dependent variable	Innovations' impact on dependent variable		
						Product	Process	Product and process
(Martin, Nguyen Thi, 2015)	Luxembourg, 2004–2006	CDM, ML adjusted for knowledge-intensity	MA and S	364	LP	0.367	0.934*	—
		CDM, ML adjusted for knowledge-intensity and rate of ICT use		364		0.573*	1.380***	—
(Baumann, Kritikos, 2016), p. 36, T.VI.	Germany, SMEs, 2005–2012	CDM, LSM, PM	MA: all	16579	LP	1.258**	0.415	—
			MA: less than 10 empl.	4463		2.610**	–1.878	—
			MA: at least 10 empl.	12116		1.275**	0.394	—
(Lin et al., 2016), p. 160 T. 6 , p. 162 T.7, p. 163 T.8.	Taiwan, 2004–2006	CDM, IVM	MA	1016	TFP growth rate	–1.081	2.913**	0.385
				1046	LP growth rate	–2.006	3.219*	0.045
			MA: OEM	292	TFP growth rate	—	1.708	5.875***
			MA: non-OEM	217		—	1.900	–0.286
			MA: OEM	295	LP growth rate	—	1.352	7.535***
			MA: non-OEM	220		—	0.102	1.764
(Santi, Santoleri, 2017), p. 458, T. 4.	Chile, 2007, 2009, 2012	LSM, PM with lag regressors	MA and S	3336	Growth of sales	0.013	0.025***	—
		LSM, FE with lag regressors				–0.038**	0.017	—
		Quantile regression with lag regressors, 10% quantile				–0.037	0.050**	—
		Quantile regression with lag regressors, 25% quantile				0.001	0.017	—
		Quantile regression with lag regressors, 50% quantile				–0.005	0.015*	—
		Quantile regression with lag regressors, 75% quantile				–0.002	0.026***	—
		Quantile regression with lag regressors, 90% quantile				–0.022	0.042***	—
(García-Pozo et al., 2018), p. 1055, T.5.	Spain, 2008–2013	CDM, IVM	S	22620	LP	0.132***	0.022***	—
(Peters et al., 2018), p. 607, T.5.	Germany, 2006–2008	CDM, IVM	S	1333	LP	0.163***	0.211***	—
	Ireland, 2006–2008			1256		0.089	0.174*	—
	UK, 2006–2008			4346		0.043*	0.065**	—
(Ramadani et. al., 2018), p. 278, T.4.	Central and Eastern Europe, 2013–2014	CDM, IVM	MA and S	2109	LP	0.862**	—	—
(Edeh, Acedo, 2021, p. 8, T. 5.	Nigeria, 2005–2010	CDM, IVM	MA and S	417	LP	2.850***	7.020***	—

* — significance at a 10% level; ** — significance at a 5% level; *** — significance at a 1% level;

Legend:
MI — mining industry; MA — manufacturing industry; HT — high-tech companies; LT — low-tech companies; S — services; KIBS — knowledge-intensive business services; TS — traditional services; T — traditional sector; I — innovation sector; SME — small and medium enterprises; OEM — original equipment manufacturers; IVM — instrumental variables method; LSM — least squares method; 2LSM — two-step least squares method; 3LSM — three-step least squares method; ML — maximum likelihood estimator; PM — pooled sample model; CSM — cross-sectional sample model; FE — fixed effects model; RE — random effects model; CDM — Crepon-Doget-Myriss model (Crepon et al., 1998); LP — labor productivity (sales per employee); TFP — total factor productivity

Source: author.

Table 1a. **Estimation of Product and Process Innovations' Impact on Productivity undertaken in (Morris, 2018)**

Countries, years	Methodology	Sample	Number of observations	Dependent variable	Innovations' impact on dependent variable		
					Product	Process	Product and process
Eastern Europe, Central Asia, Latin America and the Caribbean 2002–2016	CDM, LSM, CSM	MA and S	8906	LP	0.284***	0.168**	0.166**
	CDM, LSM, FE	MA and S	8906	LP	0.304***	0.134*	0.161*
Eastern Europe and Central Asia, 2002–2016	CDM, LSM, FE	MA and S	3096	LP	0.164*	0.219***	0.125
Latin America and the Caribbean, 2002–2016	CDM, LSM, FE	MA and S	4831	LP	0.683***	0.698**	0.728**
Eastern Europe, Central Asia, Latin America and the Caribbean, 2002–2016	CDM, LSM, FE	MA	8816	LP	0.292***	0.152**	0.120
Eastern Europe, Central Asia, Latin America and the Caribbean, 2002–2016	CDM, LSM, FE	S	16810	LP	0.927***	0.787***	1.560***
Eastern Europe, Central Asia, Latin America and the Caribbean, 2002–2016	CDM, LSM, CSM	MA and S	8908	TFP (Olley, Pakes, 1996)	0.483**	0.486**	0.582**
Eastern Europe, Central Asia, Latin America and the Caribbean 2002–2016	CDM, LSM, FE	MA and S	8908	TFP (Olley, Pakes, 1996)	0.324**	0.108	0.275*
Eastern Europe and Central Asia, 2002–2016	CDM, LSM, FE	MA and S	8908	TFP (Olley, Pakes, 1996)	0.243***	0.071	0.157*
Latin America and the Caribbean 2002–2016	CDM, LSM, FE	MA and S	8908	TFP (Olley, Pakes, 1996)	0.438*	0.081	0.487*
Eastern Europe, Central Asia, Latin America and the Caribbean 2002–2016	CDM, LSM, FE	MA	8908	TFP (Olley, Pakes, 1996)	0.204**	–0.016	0.179*
Eastern Europe, Central Asia, Latin America and the Caribbean 2002–2016	CDM, LSM, FE	S	8908	TFP (Olley, Pakes, 1996)	0.172**	0.107**	0.098
Eastern Europe, Central Asia, Latin America and the Caribbean 2002–2016	CDM, LSM, CSM	MA and S	8908	TFP (Levinsohn, Petrin, 2003)	0.456**	0.470**	0.558**
Eastern Europe, Central Asia, Latin America and the Caribbean 2002–2016	CDM, LSM, FE	MA and S	8908	TFP (Levinsohn, Petrin, 2003)	0.301**	0.116*	0.270**
Eastern Europe, Central Asia, 2002–2016	CDM, LSM, FE	MA and S	8908	TFP (Levinsohn, Petrin, 2003)	0.212**	0.023	0.116
Latin America and the Caribbean, 2002–2016	CDM, LSM, FE	MA and S	8908	TFP (Levinsohn, Petrin, 2003)	0.340*	0.084	0.395*
Eastern Europe, Central Asia, Latin America and the Caribbean, 2002–2016	CDM, LSM, FE	MA	8908	TFP (Levinsohn, Petrin, 2003)	0.181**	–0.025	0.152
Eastern Europe, Central Asia, Latin America and the Caribbean, 2002–2016	CDM, LSM, FE	S	8908	TFP (Levinsohn, Petrin, 2003)	0.093	0.063*	0.007

Note: for the Legend see Table 1
Source: author.

substitute it) cannot significantly affect the estimates of the impact under consideration. For example, in Italy (Parisi et al., 2006) process innovations' contribution to the growth of labor and total factor productivity (TFP) remained practically unchanged after the equation was adjusted for average knowledge intensity, and in Brazil (Goedhuys, 2007), after the patent activity was taken into account.[3] Thus, a distinction should be made between science and technology activities on the one hand, and innovation on the other. The latter has pronounced economic specifics, so it would not be correct to approximate it through R&D expenditures or the number of patents issued. An innovative firm may not conduct R&D at all or it may not patent the results obtained.

A study based on Luxembourg data (Martin, Nguyen Thi, 2015) found that the effect of process innovation adjusted for knowledge intensity can be strong

[3] Notably, (Parisi et al., 2006) reported the positive effect of process innovation, while (Goedhuys, 2007) reported a negative one.

and statistically significant. If we also take into account the rate of ICT use, an increase in productivity growth is guaranteed. However, this pattern is not universal: in developing countries innovation activity can be closely correlated with the level of computerization, communication facilities, and infrastructure, which will devalue the economic effect of innovation if variables reflecting the use of ICT are introduced.

It was also demonstrated for the relatively developed Italy that adjusting equations for the amount of investments significantly affects the contribution of process innovations to labor productivity growth (Hall et al., 2009). If without taking this factor into account the impact of this innovation type turns out to be significant (at 2.6-2.8, and increasing) when considered, the impact becomes statistically insignificant. This is true for both high-tech and low-tech industries, i.e., it seems to be a universal pattern, at least for Italy. Firms engaged in process innovation invest in new equipment, which leads to collinearity of indicators. Adjusting for investment also appreciably changes labor productivity's elasticity for product innovations, though the latter remain a powerful and significant factor.

Thus, the fifth hypothesis was partially confirmed.

Future Research Areas

In our opinion, the most problematic areas of the entire body of studies that address PPI's impact on productivity are identifying and meaningfully interpreting "growth points" – environmentally localized segments of the national economy where innovation activity is high, and developing generally accepted methods for the econometric assessment of impact coefficients.

In a number of studies, PPI's contribution to productivity growth in the sectors traditionally seen as innovation development drivers is assessed as insignificant or even negative. In particular, an analysis of a large sample of Spanish mining and manufacturing enterprises for 1991-1998 revealed that process innovations served as a significant driver of TFP growth in all national industries except high-tech ones (Huergo, Jaumandreu, 2004). According to the calculations presented in (Goedhuys, 2007), in the Brazilian manufacturing industry, high-tech process innovations had a statistically significant, slightly negative impact on sales growth.

A strikingly high or low PPI effect in a particular sector can be interpreted in several competing ways. How, from an economic point of view, should the excess or decline of PPI's impact (combined or individual) on productivity at time t be correctly estimated taking into account all statistical flaws and methodological limitations? Does such an effect provide an actual advantage compared to economies (or industries, or enterprises) where it is not observed? What opportunities or limitations for the growth of the national industry and the service sector do such effects create? How long can they and/or should they exist in a regional/industry niche, and what factors affect the length of this period?

In studies which tried to make such assessments based on data from France for 2002-2004 (Mairesse, Robin, 2008), Western Europea for 2004 (Hashi, Stojcic, 2013), Luxembourg for 2004-2006 (Martin, Nguyen Thi, 2015), Taiwan for 2004-2006 (Lin et al., 2016), Ukraine for 2004-2006 (Vakhitova, Pavlenko, 2010), Chile for 2005-2008 (Alvarez et al., 2015), Nigeria for 2005-2010 (Edeh, Acedo, 2021), and Germany for 2005-2012 (Baumann, Kritikos, 2016), meaningful interpretation of the econometric results was simply omitted. Meanwhile, we are talking about very different economies at different phases of their economic cycle. Even applying relevant econometric analysis techniques to the same sample of enterprises (statistical survey results) often yields widely different outcomes.

For example, two studies analyzed a sample of the French manufacturing companies for 1998-2000 (Griffith et al., 2006; Mairesse, Robin, 2008). Though both of them were conceptually based on the CDM model[4] (Crepon et al., 1998) and demonstrated a statistically significant positive correlation between the application of PPI and labor productivity, differences in econometric techniques led to a radical mismatch in the level of the obtained estimates. Whereas in (Griffith et al., 2006) the elasticity of productivity to PPI was estimated at 0.06-0.07, in (Mairesse, Robin, 2008) it was 0.6-1.1. Thus, from an unremarkable (but statistically significant) factor, PPI turns into one of the most important economic development drivers of the same firms at the same time.

Opposite examples are also known, when changing the methodology did not significantly affect calculation results. However, all such cases were reported in individual studies that were not verified or revised in other works. A similar French sample for 1998-2000, but of the specific knowledge-based business services companies (Musolesi, Huiban, 2010) was analyzed using several econometric techniques. The authors found that regardless of the assessment method, product innovations were a strong factor that increased added value, while process ones did not make a significant impact. On the basis of Swiss manufacturing industry data for 1996, 1999, and 2002 (Arvanitis, 2006), it was demonstrated that a

[4] The CDM (Crépon-Duguet-Mairesse) model takes into account three main innovation process stages: making a decision to invest in R&D, applying the innovations, and productivity.

high positive elasticity of productivity to both innovation types remained robust to changes in the panel regression assessment method.

Contradictory conclusions also follow from comparing calculations based on different productivity variable indicators.

In a number of cases PPI affected various performance indicators in approximately the same way. For example, in (Parisi et al., 2006) performance in the Italian manufacturing industry in 1995 and 1998 was estimated via labor productivity and TFP growth rates. It was established that both these indicators experienced a statistically significant positive impact from process innovation, including in equations adjusted for the average knowledge intensity. However, the growth in TFP was also significantly affected by product innovation, while its contribution was insignificant in equations that used labor productivity growth rates. Similar performance indicators were applied in (Lin et al., 2016). The authors found the results to be equally consistent. The performance of the Taiwanese manufacturing industry in 2004-2006, in terms of both labor productivity and TFP growth rates, was strongly positively affected by process innovation, while product innovations' contribution was insignificant. The same applies to the complementary PPI effect, which for original equipment manufacturers was obviously statistically significant. This also holds true for both labor productivity and TFP equations.

Meanwhile PPI impact assessments based on labor productivity and TFP generally tend to be different, as indicated, in particular, by the detailed set of calculations presented in (Morris, 2018): a major study of 40,500 enterprises from 43 developing countries (in Eastern Europe, Central Asia, Latin America, and the Caribbean) for 2002-2016. The estimates of PPI's impact on labor productivity and TFP obtained with the help of the Olley-Pakes method (Olley, Pakes, 1996), and on TFP with the help of the Levinson-Petrin method (Levinsohn, Petrin, 2003) have pronounced discrepancies between them. The high positive values of labor productivity elasticity to PPI were found first of all in the service sectors of the countries included in the sample. The complementary PPI effect on labor productivity in the service sector even exceeds 1, which suggests an economy of scale-like increase due to the synergy of the two innovation types. Thus, service innovations appear to be a key development driver for a significant proportion of the world's economy.

As to PPI impact's on TFP, the tertiary sector's role no longer looks exclusive. Product and process innovations alike had a small positive effect on the TFP of the relevant companies in the sample, calculated using the Olley-Pakes method (Olley, Pakes, 1996). On the other hand, if TFP was measured using the Levinson-Petrin method (Levinsohn, Petrin, 2003), only process innovations appeared to make a small positive impact. The complementary effect on TFP in the service sector measured by the both methods was statistically insignificant. In the manufacturing industry, it turned out to be weakly significant only when the Olley-Pakes toolkit was applied (Olley, Pakes, 1996).

Conclusion

Technological innovations make a tangible contribution to increasing companies' productivity, which can be reliably measured with various modern economic research methods. However, these approaches have certain limitations. In particular, what is actually measured is not the effect of PPI, but the "innovativeness" of companies which apply product or process innovations, individually or in combination (complementarity). While product innovations can be expressed in value terms (sales of goods), the effect of process innovations estimated with binary variables only tends to be negative, regardless of the sample and calculation technique (which in fact requires a separate analysis). A firm is considered to be innovative if it has implemented innovations during the previous three years. This is believed to be important for productivity growth, regardless of other closely related factors such as R&D, patenting, and staff training.

Also, the spatial distribution and dynamics of PPI's effects are much better explained by classic innovation cycle theories than by modern concepts of innovation in high- and low-tech industries. Accordingly, the need to develop new relevant theories comes to the fore. The innovation type predominant in terms of productivity impact is not country- or industry-specific, but mainly depends on the innovation cycle phase. Therefore, if the objective is to step up productivity, it would be incorrect to *a priori* rely on, for example, product innovations in a high-tech industry, as certain countries seem to be doing. The same is true for the complementary effect of PPI: studying the accumulated data array did not reveal that combining these two innovation types has an obvious practical value. On the contrary, there is evidence that the complementary effect of PPI can be statistically insignificant.

When predicting PPI's effects, one should distinguish between the impact innovations make on various aspects of companies' and industries' activities, if possible applying several statistical methods to evaluate it. Minor product innovations can make a tangible positive contribution to sales growth, but do not affect labor productivity or TFP at all. Similarly, a radical capital-saving process innovation will produce modest observable results when measured in terms of short-term labor productivity growth.

The effectiveness of PPI as a productivity driver can easily become an object of statistical manipulations, which may have a particularly painful effect on the ideology behind and the results of state innovation policy.

Finally, due to the reasons described above the mechanics of technological innovations' interaction with productivity, despite the century-long experience in evaluating the relevant indicators and their relationships, remains a kind of "thing in itself". The state should contribute to increasing and maintaining the level of innovation activity in economic sectors and regions. But which sectors and regions, specifically? Which innovation types (product, process, organizational, marketing, etc.) would be more effective to focus on if the industry allows one to apply different ones? Should a pronounced positive (negative) correlation between innovation and productivity always be interpreted as a positive or negative result? Perhaps the current generation of empirical innovation studies based on enterprise surveys (a subject-based approach) cannot provide meaningful answers to such questions in principle. In that case, international science will have to develop new ways of measuring innovation, just as the subject-based approach (enterprise surveys) since the early 1990s began to dominate patent statistics, which in its turn has replaced R&D statistics in the 1960s and 1970s.

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