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Knowledge Spillovers from Patent Citations: Evidence from Swiss Manufacturing Industry

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Abstract**—**Our paper attempts to examine how Swiss manufacturing firms manage to learn from patent citations to improve their innovation performance. We argue that the assessment of these effects needs a detailed analysis of spillovers according to the source of knowledge with respect to formal and informal patent citations made in European and internal search, the horizontal and vertical mechanisms by which knowledge spillovers take place, and the technological characteristics of innovative firms that able them to absorb external knowledge and integrate it in their existing innovation process. We use Organisation for Economic Co-operation and Development (OECD) data and find evidence that knowledge spillovers occur only from horizontal and backward linkages. The importance of these effects depends on the type of citation, in which the references to non-patent literature (informal citations made in European and international searches) have a greater impact. In addition, only firms with high technological capacities benefit from knowledge spillovers from formal and informal citations. Low-technology firms fail to catch up and efficiently learn external knowledge from patent citations.

Keywords**—**Innovation performance, patent citation, absorptive capacity, knowledge spillover mechanisms.

I. Introduction

THE study of innovation and knowledge diffusion have attracted significant attention from scholars in the last three decades. This attention is illustrated by the doubling of the total number of patent applications in the OECD in the 1990s. The surge in patenting can be explained by changes in global competition, the rise of new technology fields like biotechnology and ICT, or more generally by improvements in R&D processes [1], [2].

The most important assignment of firms is to create knowledge and then transfer it into value added activities [3]. Therefore, knowledge is one of the most relevant sources of competitive advantage of firms [4], [5] and plays an important role in increasing of the firm's innovation performance. Knowledge-based view regards knowledge as the main competence of firms [6]. New competencies are the preconditions to generate new products or/and process. However, many firms cannot afford to develop and build up all the knowledge need. These firms must call upon external knowledge resources [7], expecting to benefit from knowledge spillovers.

Patent citations are widely used in the literature as a source of knowledge [8] that could spillover to improve firms' research and development and determine then their innovation performance. An emerging body of work has analysed the existence of knowledge spillovers patent citations on firms' innovation performance. Nonetheless, the empirical results are rather mixed and evidence on this kind of spillovers demonstrates considerable heterogeneity [9]-[19].

This paper proposes some components for a more detailed research agenda on knowledge spillover effects in terms of patent citations. It highlights that the capability to leverage external knowledge is a crucial element of innovative capacities [20]. and argues that the assessment of knowledge spillovers benefit needs a detailed analysis of these effects according to the insights provided by existing literature on formal and informal patent citations, the mechanisms facilitating knowledge spillovers, and the technological characteristics of innovative firms that able them to absorb external knowledge and integrate it in their existing innovation process. Firms equipped with higher levels of absorptive capacity will be able to extract greater benefits from external knowledge, and therefore surpass competitors in their innovation activity [21].

The structure of the paper is as follows: following this introduction, Section II analyses the theoretical background underlying our hypotheses, together with a review of the relevant empirical studies. Section III presents our hypotheses, Section IV describes the econometric model, Section V discusses the regression results, and Section VI concludes the paper.

II. Theoretical Background

As noted previously, the innovative activity of firms could be a valuable source of knowledge, allowing them to start innovating and/or to intensify their innovative activities. This gives rise to externalities that are a central theme in the literature on innovation in industrial economics [22], [23]. An effective approach to address this spillovers problem is to assume the diffusion of new private knowledge leading to a "spillover pool of knowledge" from which other economic agents can extract valuable information for their own innovative activities [24].

An emerging body of work has analysed the existence of knowledge spillovers. Nevertheless, the empirical results present a mixed picture, and there is considerable heterogeneity in the evidence regarding this type of spillovers [19]. For example, [25] investigated the relationship between knowledge

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spillovers and innovation performance measured by the number of patents and found positive and significant effects of knowledge spillovers on patents for a panel of US firms for the period 1981-2001. Reference [26] also found a positive impact of knowledge spillovers on the number of patents of 147 US regions in the period 1975-1996. However, [27] failed to find evidence on knowledge spillovers, schowing that the probability of introducing a product or process innovation is negatively correlated with knowledge spillovers. Reference [28] examined R&D spillovers into US based firm productivity over the period 1980-2000 and failed as well to find evidence on Knowledge spillovers.

We argue that leveraging external knowledge plays a critical role in developing innovative capabilities [29]. The assessment of knowledge spillovers benefit needs a detailed analysis of these effects according to knowledge sources in terms of formal and informal patent citations. The mechanisms of knowledge spillovers and the technological characteristics of innovative firms that facilitate their ability to assimilate external knowledge are built into their innovation processes.

On the Role of Knowledge Sources and Spillover Mechanisms

Patent citations are widely used in the literature as a source of knowledge [8] and a determinant of innovation performance underlying the invention described in the patent document [30], [31]. Firms active in the research and development of new products or processes refer to patented innovations and cite them in their research report used to define an invention's patentability and the legitimacy of the claims of the new patent application. A patent includes not only formal citations to other patents, but also informal citations usually known as citation to non-patent literature (NPL) such as citation to scientific papers which might be an important source of knowledge. The rationale for including scientific citations as a determinant of innovation performance relies on capturing the complexity and science intensity of the current patent [32]-[34]. Patents from universities and those that refer to scientific publications receive more citations [35]. Patents citing academic science "are of significantly higher quality than patents that do not" [36].$

Patent citations are commonly used as a measure of knowledge flow or knowledge spillovers [8], [37].

Generally, knowledge spillover benefits can take place through a variety of mechanisms and thus the assessment of these effects calls upon a detailed analysis according to the mechanisms by which they take place. Horizontal linkage mechanisms can encourage knowledge transfer via, first, demonstration effects which can stimulate firms' innovative activities through learning-by-doing or by analyzing and observing the outputs of innovative firms' research and development (R&D) projects. Knowledge and skills can inspire and stimulate other firms to develop new product and/or processes [38]. Second, there are competition effects following the presence of innovative firms, which increases competition and forces other firms to innovate. Third, there are labour mobility effects when trained managers and skilled workers who were previously trained by and/or worked in an innovative firms may leave the firm to join an existing firm or open a new one. Knowledge embedded in these workers may enhance their firms' innovation performance [39]. Vertical linkage mechanisms could also stimulate knowledge transfer from nearby industries among suppliers and customers and enhance the firm's innovation performance by learning about the designs of new products and technology through interaction with innovative suppliers and customers [40].

Scholars have largely analysed the effect of knowledge spillovers from patent citations on firms' innovation performance, according to formal and informal knowledge sources and horizontal and vertical spillover mechanisms. Nevertheless, empirical analyses draw mixed results and spillover effects are not yet conclusive. For example, [10] found that backward non-patent citations are significantly related to innovation performance and consequently the firm's innovation capacity. Using R&D expenditure as a unit of measure of innovation performance, [41] also found a positive correlation between backward patents citations and firms' innovation capacity. Reference [42] similarly identified a positive correlation between backward patent citations and firms' acquisition of new technologies. In the same context, numerous studies have also proved a positive and significant relation between backward patent citation and the innovation performance [8], [17], [41]. However, [34] pointed out that scientific papers citations in patents do not significantly explain especially the forward non-patent citations, and that the linkage to science is more important at the firm level than at the patent level. Alike, different empirical studies failed to found support for a positive relationship between the economic value of a patent and the forward patents citations received using different data and methodologies (e. g., [15], [16], [43], [44])

To sum up, it seems that backward patent citations is the main mechanism for knowledge spillovers, increasing research and development activities and then firms' innovation performance.

On the Role of Technological and Absorptive Capacities

The concept of absorptive capacity and its role in firm's innovation performance have been very debated in knowledge transfer and spillover literature.

In a wide sense, absorptive capacity can be defined as the firm's ability to acquire, assimilate, and exploit new external source of knowledge [23], [45]-[48]. Leveraging external knowledge plays a crucial role in fostering innovative capabilities [20].

The ability of firms to derive greater benefits from external knowledge is positively associated with higher levels of absorptive capacity. Knowledge absorption also often leads to new knowledge creation, which in turn improves the ability to gain and sustain competitive advantage [46], [47], [49]. As an absorptive capability, knowledge absorption is concerned with the consolidation of the newly created knowledge with existing knowledge stocks, as well as with the experimentation of past knowledge bases for innovative applications [50].

Scholars have considered firms with a greater absorptive capacity are open to new knowledge and better able to use them for innovation [48], [51], [59]. For example, [53] explored the effect of absorptive capacity on innovation performance in Taiwanese manufacturing industry by using questionnaire survey method, they found that absorptive capacity positively influences upon innovation performances of firms. In the same context, the study of [54] was also based on questionnaire surveys collected from the top 500 manufacturing firms in a typical emerging market, Taiwan. The results also showed a positive relation exists between knowledge absorption and innovation performance. In addition, the effects varied for firms with high and low innovation investment. Based on survey data from 379 high-tech companies in the electronic information industry in China, [55] found that there are positive relationships between knowledge absorptive capacity and firms' innovation performance.

A lot of studies have considered firms with a greater absorptive capacity are open to new knowledge and better able to use them for innovation [48], [52], [51]. In this regard, most scholars agree that firms should have a certain degree of knowledge absorptive capacity to stimulate innovation. With the accelerated change in the business environment, organizations increasingly realign their structures to keep pace [56], remain competitive [57], and create capabilities [58] that will enable them to seize opportunities linked to innovation performance [59].

III. Hypotheses

According to the above arguments, we expect the following hypotheses:

H1. Knowledge spillovers on the innovation performance of Swiss manufacturing firms are more likely to be vertical, particularly from backward formal and informal citations than from forward citations.

H2. Knowledge spillovers on the innovation performance of Swiss manufacturing firms are higher as the level of local absorptive capacity increases.

IV. Regression Model

We use panel vector autoregression (PVAR) method in order to study the dynamic role of spillover on Swiss manufacturing firm's innovation performance.

The PVAR model takes the following form:

$$Y_{i,j,t} = \alpha + \beta Y_{i,t-1} + \gamma X_{j,t-1} + \varepsilon_{i,j,t} \quad (1)$$

where the subscripts i, j and t denote respectively firm, industry and time. Y_i denotes the vector of firms control, it includes RD which is measured by the total of R&D expenditures, $Patent$ is the total number of patent applications, $Size$ the logarithm of the firm's total sales, VA its value added and $Comp$ the degree of competition on its principal market as perceived by the firm. X_i denotes the vector of industry control [$HorizIndCits$, $BackndCits$, $ForwIndCits$] and ε represents the error term. The coefficients $\beta$and γ represent the relationship between the lags of the variables and the current value.

Table I describes the variables and their measurements.

TABLE I
VARIABLE DEFINITIONS

Variables	Definition
RD	The firm's expenditure on domestic R&D in the firm.
$Patent$	Total number of patents in the firm.
VA	The added value of the firm.
$Comp$	The price markup at firm level measured by the difference between firm's total sales and costs over total sales.
$Size$	The log of the firm's total sales.
$HorizIndCits^{All\_Cits}$	Horizontal spillover stemming from the innovation experience in firms' competitors, measured as the total number of citations in the same manufacturing sector.
$BackIndCits^{All\_Cits}$	Backward spillover stemming from the innovation experience in firms' customers, measured as the total number of citations in downstream manufacturing sectors.
$ForwIndCits^{All\_Cits}$	Forward spillover stemming from the innovation experience in firms' suppliers, measured as the total number of citations in upstream manufacturing sectors.
$HorizIndCits^{EP\_Formal}$	Horizontal spillover stemming from the innovation experience in firms' competitors, measured as the total number of EP formal citations in the same manufacturing sector.
$BackIndCits^{EP\_Formal}$	Backward spillover stemming from the innovation experience in firms' customers, measured as the total number of EP formal citations in downstream manufacturing sectors.
$ForwIndCits^{EP\_Formal}$	Forward spillover stemming from the innovation experience in firms' suppliers, measured as the total number of EP formal citations in upstream manufacturing sectors.
$HorizIndCits^{EP\_InFormal}$	Horizontal spillover stemming from the innovation experience in firms' competitors, measured as the total number of EP informal citations in the same manufacturing sectors.
$BackIndCits^{EP\_InFormal}$	Backward spillover stemming from the innovation experience in firms' customers, measured as the total number of EP informal citations in downstream manufacturing sectors.
$ForwIndCits^{EP\_Informal}$	Forward spillover stemming from the innovation experience in firms' suppliers, measured as the total number of EP informal citations in upstream manufacturing sectors.
$HorizIndCits^{WO\_Formal}$	Horizontal spillover stemming from the innovation experience in firms' competitors, measured as the total number of WO formal citations in the same manufacturing sectors.
$BackIndCits^{WO\_Formal}$	Backward spillover stemming from the innovation experience in firms' customers, measured as the total number of WO formal citations in downstream manufacturing sectors.
$ForwIndCits^{WO\_Formal}$	Forward spillover stemming from the innovation experience in firms' suppliers, measured as the total number of WO formal citations in upstream manufacturing sectors.
$HorizIndCits^{WO\_InFormal}$	Horizontal spillover stemming from the innovation experience in firms' competitors, measured as the total number of WO informal citations in the same manufacturing sectors.
$BackIndCits^{WO\_InFormal}$	Backward spillover stemming from the innovation experience in firms' customers, measured as the total number of WO informal citations in downstream manufacturing sectors.
$ForwIndCits^{WO\_Informal}$	Forward spillover stemming from the innovation experience in firms' suppliers, measured as the total number of WO informal citations in upstream manufacturing sectors.

With respect to horizontal and vertical knowledge spillover mechanisms: $HorizIndCits$ reflects horizontal knowledge spillovers, measured as the total number of citations included in a patent in the same industry. $BackIndCits$ and $ForwIndCits$ reflect vertical knowledge spillovers from backward and forward linkages, respectively.

$BackIndCits$ is a proxy for the number of backward citations included in a patent within the same industry or sector.

Following existing spillovers literature such as [65]-[66], the backward effects for industry j are computed as:

$$BackIndCits_{ij} = \sum_{j \neq k} \alpha_{jk}\ HorizIndCits_{ik}$$

where α_{jk} is the proportion of industry j's output which is supplied to industry k. This measurement captures the extent of backward linkages between innovative firms in upstream sectors and downstream sectors.

The forward effects for industry j are computed as:

$$ForwIndCits_{ij} = \sum_{j \neq k} \beta_{jk}\, HorizIndCits_{ik}$$

where β_{jk} is the proportion of sector k's output supplied to industry j. This measure captures the extent of forward linkages between innovative firms in downstream customer sectors and upstream supplier sectors. The values of α_{jk} and β_{jk} are obtained from the Input-Output Table of Swiss economy published by the Federal Statistical Office of Switzerland [60]. Following existing empirical studies (see for example [61]), we model the effect of knowledge spillover for the firm i , industry j and time t from 2015 to 2018 as follow:

$$D(RD) == C(1) * D(RD(-1)) + C(2) * PATENT(-1) + C(3) * D(VA(-1)) + C(4) * D(Comp(-1)) + C(5) * D(Size(-1)) + C(6) * HorizIndCits(-1) + C(7)$$

$$D(RD) == C(1) * D(RD(-1)) + C(2) * PATENT(-1) + C(3) * D(VA(-1)) + C(4) * D(Comp(-1)) + C(5) * D(Size(-1)) + C(6) * BackIndCits(-1) + C(7)$$

$$D(RD) == C(1) * D(RD(-1)) + C(2) * PATENT(-1) + C(3) * D(VA(-1)) + C(4) * D(Comp(-1)) + C(5) * D(Size(-1)) + C(6) * ForwIndCits(-1) + C(7)$$

R&D investment is often considered a good measure for innovation performance because it is directly related to the development and introduction of new products, processes, or technologies. Additionally, R&D is considered a key driver of long-term growth and competitiveness for many firms.

Patents can also be a useful measure of innovation performance; however, they do not take into account the quality or impact of the patents, and some firms may choose to not patent their innovations for strategic or financial reasons. Additionally, the patent process can be costly and time-consuming, which may not be feasible for all firms [62], [63].

Alike most analyses on international knowledge transfer and spillovers [19], our regressions are based on OECD firm-level data, in particular the following databases:

- OECD Triadic Patent Families database, August 2022, which covers patent applications filed to the EPO, the JPO and the USPTO that share a same set of priorities;
- OECD Citations database, August 2022 covers curated data on patent and NPL references as provided in patents filed at the EPO's PATSTAT;
- The database on the IP Bundle of Top Corporate R&D Investors - the JRC/OECD COR&DIP© database, v.3. 2021, which contains information about the R&D activity and IP assets (i.e. patents and trademarks) of the top 2 000 corporate R&D investors worldwide.

Tables VIII-X report the descriptive statistics of our dependent and independent variables.

V. Results

This section presents empirical results. Model (1) is estimated using the PVAR method to analyse the dynamic role of knowledge spillovers on innovation performance of Swiss manufacturing firms.

In order to have robust regressions, we first conducted a unit root test to assess the stationarity of the variables (see Table II). For Swiss manufacturing firms' data, $Patent$, $HorizIndCits$, $BackIndCits$ and $ForwIndCits$ were identified as stationary variables, but RD, VA, $Comp$ and $Size$ are non-stationary variables. Therefore, we applied the first-difference method on non-stationary variables, we found that they became stationary after the first differentiation.

TABLE II
Panel Unit Root Tests

	RD	VA	$Comp$	$Size$	$d(RD)$	$d(VA)$	$d(Comp)$	$d(Size)$
ADF	28.29	7.24	65.35	6.51	97.99***	68.83**	181.183***	79.64***
PP	29.26	6.72	69.67	6.03	98.1***	68.87**	183.783***	81.92***

Note: ADF is the Augmented Dickey–Fuller unit root test. PP is the Phillips Perron panel unit root test. ***, **, * Denote significance at 1%, 5%, and 10% levels, respectively.

Columns 1-3 of Table III present estimation results when considered patent citations as a whole. Column 1 reports horizontal knowledge spillovers, column 2 vertical backward results, and column 3 forward knowledge spillovers. Columns 4-6 report horizontal and vertical spillovers in terms of formal patent citations made in European search, while columns 7-9 report these effects from informal patent citations (NPL). Columns 1-3 of Table IV report spillovers from formal citations made in international search with respect to horizontal, backward and forward linkages, while regressions in columns 4-6 report theses effects from informal patent citations. Tables V-VII present knowledge spillover results using subsamples of high and low technology firms. Table V reports these results using all citations, Tables VI and VII report these results from formal and informal citations made in respectively, European and international search.

TABLE III
PVAR REGRESSIONS FOR KNOWLEDGE SPILLOVERS FROM ALL CITATIONS AND FROM PATENT (FORMAL) AND NPL (INFORMAL) CITATIONS MADE IN EUROPEAN (EP) SEARCH

	All_Cits			EP_Formal_Cits			EP_Informal_Cits		
Column/Regression	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
RD	0.327^{***}	0.33^{***}	0.328^{***}	0.322^{***}	0.326^{***}	0.328^{***}	0.37^{***}	0.376^{***}	0.319^{***}
$Patent$	0.088	0.078	0.161	0.114	0.092	0.166	0.084	0.07	0.144
VA	0.062^{**}	0.062^{***}	0.057^{***}	0.062^{***}	0.062^{***}	0.055^{***}	0.045^{***}	0.04^{***}	0.061^{***}
$Comp$	8.263	7.994	6.662	7.326	7.444	6.772	10.5	10.26	8.038
$Size$	-98.41	-100.8	-122.9	-107.19	-105.8	-122.7	-102.9	-106	-102.4
$HorizIndCits^{All\_Cits}$	0.03^{***}								
$BackIndCits^{All\_Cits}$		0.04^{***}							
$ForwIndCits^{All\_Cits}$			-0.013						
$HorizIndCits^{EP\_Formal}$				0.019					
$BackIndCits^{EP\_Formal}$					0.033				
$ForwIndCits^{EP\_Formal}$						-0.016			
$HorizIndCits^{EP\_InFormal}$							0.501^{***}		
$BackIndCits^{EP\_InFormal}$								0.697^{***}	
$ForwIndCits^{EP\_Informal}$									0.244
R2	0.458	0.459	0.421	0.427	0.44	0.423	0.589	0.601	0.425
F-statistic	9.323	9.373	8.172	8.344	8.751	8.214	15.127	15.86	8.286
Observation	120	120	120	120	120	120	120	120	120

Note: *, * *, and * * * denote significance at the 10%, 5%, and 1% levels, respectively.

TABLE IV
PVAR REGRESSIONS FOR KNOWLEDGE SPILLOVERS FROM PATENT (FORMAL) AND NPL (INFORMAL) CITATIONS MADE IN INTERNATIONAL (WO) SEARCH

	WO_Formal_Cits			WO_Informal_Cits		
Column/Regression	(1)	(2)	(3)	(4)	(5)	(6)
RD	0.328^{***}	0.333^{***}	0.323^{***}	0.387^{***}	0.392^{***}	0.322^{***}
$Patent$	0.137	1.222	0.147	0.111	0.102	0.168
VA	0.058^{***}	0.057^{***}	0.059^{***}	0.037^{***}	0.036^{***}	0.058^{***}
$Comp$	10.16	10.2	6.834	10.45	10.3	9.436
$Size$	-85.64	-85.41	-116.2	-119	-122.3	-99.09
$HorizIndCits^{WO\_Formal}$	0.208^{***}					
$BackIndCits^{WO\_Formal}$		0.32^{***}				
$ForwIndCits^{WO\_Formal}$			-0.014			
$HorizIndCits^{WO\_InFormal}$				1.601^{***}		
$BackIndCits^{WO\_InFormal}$					2.178^{***}	
$ForwIndCits^{WO\_Informal}$						1.775
R2	0.486	0501	0416	0.622	0.633	0.452
F-statistic	10.33	10.9	8.028	17.24	17.97	9.141
Observation	120	120	120	120	120	120

Note: *, * *, and * * * denote significance at the 10%, 5%, and 1% levels, respectively.

The estimated coefficients of $HorizIndCits$ and $BackIndCits$ are positive and significant for columns 1 and 2 in Table III. This indicates that when considering the total number of formal and informal patent citations made in European and international, as a whole, Swiss manufacturing firms take benefits from horizontal and backward knowledge spillovers, which seems to boost the ability of Swiss manufacturing firms to invest in research and development activities and consequently improve their innovation performance. This knowledge effect becomes higher when Swiss firms cited patents and non-patent literature arising from backward linkages. This result confirms existing literature [17], [42], [43], [64]. Knowledge effects from forward citations (column 3 in Table III) are negative and insignificant.

Regressions in columns 4-9 in Table III and 1-6 in Table IV test knowledge effects regarding the type of citation "formal versus informal" and the type of region where patent and non-patent citations are made in. Horizontal and backward knowledge effects remain positive and significant from formal and informal citations made in international search, in which the references to NPL have a greater impact. The effect from citations made in European search are significant only when coming from NPL, such as journal article. This result demonstrates that the importance of knowledge spillovers on the innovation performance of Swiss manufacturing firms differs accordingly to formal (patent) and informal (NPL) citations. In addition, these effects are particularly higher when Swiss firms take advantage of knowledge from backward citations. The effect from forward patent and non-patent citations made in European and international search remain insignificant. These results confirm our hypothesis 1, in which Knowledge spillovers on the innovation performance of Swiss manufacturing firms are more likely to be vertical from backward formal and informal citations than from forward citations.

TABLE V
PVAR REGRESSIONS FOR KNOWLEDGE SPILLOVERS FROM ALL CITATIONS FOR SUBSAMPLES OF LOW AND HIGH TECHNOLOGY FIRMS

Column/Regression	All_Cits					
	(1)		(2)		(3)	
	Low Gap	High Gap	Low Gap	High Gap	Low Gap	High Gap
RD	-0.396	0.246*	-0.4	0.251*	-0.394	0.278*
$Patent$	0.011	0.586*	0.013	0.574*	0.01	0.565*
VA	0.09*	0.053*	0.089*	0.053*	0.09*	0.047
$Comp$	7.697	7.539	7.734	6.976	7.764	3.799
$Size$	-278	-20.59	-277.2	-26	-275.8	-73.85
$HorizIndCits^{All\_Cits}$	-0.0003	0.041*				
$BackIndCits^{All\_Cits}$			0.001	0.51*		
$ForwIndCits^{All\_Cits}$					0.00003	-0.0031
R2	-0.035	0.531	-0.035	0.528	-0.035	0.467
F-statistic	0.869	7.617	0.869	7.258	0.869	6.124
Observation	48	72	48	72	48	72

Note: *, * *, and * * * denote significance at the 10%, 5%, and 1% levels, respectively.

In order to test knowledge effects regarding the type of firm technological capacity "high versus low", we split the sample of Swiss firms and make regressions for each sub-sample (regressions in columns 1-6 in Table V) and found significant and positive horizontal and backward knowledge spillovers only for high technology firms, indicating that both European and international patented and non-patented inventions cited by Swiss firms seem to boost the ability of high technology Swiss manufacturing firms to invest in research and development activities.. Low technology firms do not seem to take benefits from knowledge spillovers to improve their innovation performance. This result corroborates our hypothesis 2. We found a significant and positive effect from formal and informal citations made in international search and from informal citations made in European search, arising from horizontal and backward linkages. Upstream supplier linkages seem to benefit Swiss innovation performance only when high technology firms cited non-patented literature made in internal search.

For all regression estimates, the coefficients of firm level characteristics are insignificant except lagged RD and value added which are positive and significant for almost all regressions in Tables I-VII. Patents become positive and significant for high technology firms indicating that the number of patents made by this type of firms improves their R&D investment and then their innovation performance.

TABLE VI
PVAR REGRESSIONS FOR KNOWLEDGE SPILLOVERS FROM FORMAL AND INFORMAL CITATIONS MADE IN EUROPEAN SEARCH FOR SUBSAMPLES OF LOW AND HIGH TECHNOLOGY FIRMS

Column/Regression	EP_Formal_Cits						EP_Informal_Cits					
	(1)		(2)		(3)		(4)		(5)		(6)	
	Low Gap	High Gap	Low Gap	High Gap	Low Gap	High Gap	Low Gap	High Gap	Low Gap	High Gap	Low Gap	High Gap
RD	-0.393	0.243	-0.4	0.247	-0.391	0.282**	-0.395	0.338***	-0.395	0.343***	-0.394	0.248
$Patent$	0.009	0.625*	0.013	0.614*	0.008	0.555*	0.104	0.351	0.0104	0.336	0.01	0.606*
VA	0.09*	0.531*	0.09*	0.052*	0.09*	0.046	0.09*	0.037	0.09*	0.037	0.09*	0.052*
$Comp$	7.664	5.476	7.718	5.155	7.65	3.796	7.687	10.53	7.683	10.118	7.669	7.95
$Size$	-279.1	-30.68	-277	-35.61	-279.6	-77.46	-278.3	-71.44	-278.4	-74.66	-279	-29.66
$HorizIndCits^{EP\_Formal}$	0.0003	0.033										
$BackIndCits^{EP\_Formal}$			-0.001	0.039								
$ForwIndCits^{EP\_Formal}$					0.0007	-0.006						
$HorizIndCits^{EP\_InFormal}$							-0.001	0.541***				
$BackIndCits^{EP\_InFormal}$									-0.001	0.727***		
$ForwIndCits^{EP\_Informal}$											0.001	0.562
R2	-0.035	0.495	-0.035	0.492	-0.035	0.468	-0.035	0.644	-0.035	0.649	-0.035	0.462
F-statistic	0.869	6.718	0.869	6.661	0.869	6.134	0.869	11.56	0.869	11.79	0.869	6.669
Observation	48	72	48	72	48	72	48	72	48	72	48	72

Note: *, * *, and * * * denote significance at the 10%, 5%, and 1% levels, respectively.

VI. CONCLUSION

This paper aims to contribute to the growing body of research on the impact of knowledge spillovers from innovative firms on Swiss manufacturing firms. By testing the size and the extent of these effects, this study aims to provide a deeper understanding of the role of knowledge spillovers and their potential to enhance the performance of manufacturing firms in Switzerland. The findings of this research will provide valuable insights for policymakers and practitioners seeking to harness the benefits of knowledge spillovers.

It hypothesizes that the effect of knowledge spillovers from innovative firms is a challenging research topic, since knowledge transfer is not an automatic process and the resultant effects of knowledge spillover depend on different key factors, such as the knowledge sources in terms of formal and informal patent citations, the mechanisms through which knowledge spillovers occur and the technological characteristics that innovative firms possess.

TABLE VII
PVAR REGRESSIONS FOR KNOWLEDGE SPILLOVERS FROM FORMAL AND INFORMAL CITATIONS MADE IN INTERNATIONAL SEARCH FOR SUBSAMPLES OF LOW AND HIGH TECHNOLOGY FIRMS

Column/Regression	WO_Formal_Cits						WO_Informal_Cits					
	(1)		(2)		(3)		(4)		(5)		(6)	
	Low Gap	High Gap	Low Gap	High Gap	Low Gap	High Gap	Low Gap	High Gap	Low Gap	High Gap	Low Gap	High Gap
RD	-0.399	0.297**	-0.4	0.306**	-0.399	0.282**	-0.393	0.374***	-0.393	0.378***	-0.392	0.273**
$Patent$	0.01	0.387	0.01	0.345	0.01	0.575**	0.01	0.301	0.01	0.287	0.01	0.551**
VA	0.089*	0.051**	0.089*	0.051**	0.089*	0.045	0.09*	0.029	0.09*	0.029	0.09*	0.047
$Comp$	7.791	11.53	7.797	11.61	7.745	2.637	7.656	9.596	7.654	9.354	7.651	10.25
$Size$	-276.4	-52.69	-276.5	-56.6	-276.9	-79.54	-280.1	-104.3	-280.3	-107.7	-280.6	-46.35
$HorizIndCits^{WO\_Formal}$	-0.005	0.29**										
$BackIndCits^{WO\_Formal}$			-0.008	0.42**								
$ForwIndCits^{WO\_Formal}$					-0.004	-0.076						
$HorizIndCits^{WO\_InFormal}$							0.015	1.628***				
$BackIndCits^{WO\_InFormal}$									0.242	2.172***		
$ForwIndCits^{WO\_Informal}$											0.025	3.12**
R2	-0.034	0.55	-0.034	0.559	-0.035	0.469	-0.035	0.661	-0.035	0.666	-0.035	0.529
F-statistic	0.871	8.138	0.871	8.399	0.869	6.159	0.869	12.39	0.869	12.64	0.869	7.575
Observation	48	72	48	72	48	72	48	72	48	72	48	72

Note: *, * *, and * * * denote significance at the 10%, 5%, and 1% levels, respectively.

TABLE VIII
DESCRIPTIVE STATISTICS WHEN CONSIDERING ALL THE SAMPLE OF SWISS MANUFACTURING FIRMS

Variables	Obs	Mean	Std.dev	Min	Max
RD	120	806.48	2117.0	23.815	9797.94
$Patent$	120	63.166	104.90	2.0000	526.000
VA	120	9917.0	1683.5	44.918	77668.6
$Comp$	120	4.5267	3.3104	0.3965	30.782
$Size$	120	8.1408	1.5717	3.8245	11.303
$HorizIndCits^{All\_Cits}$	120	1212.23	720.718	86.000	2397.0
$BackIndCits^{All\_Cits}$	120	893.35	560.75	45.263	1881.8
$ForwIndCits^{All\_Cits}$	120	801.12	589.81	19.592	1942.3
$HorizIndCits^{EP\_Formal}$	120	941.83	586.31	68.000	2171.0
$BackIndCits^{EP\_Formal}$	120	697.76	466.34	35.790	1704.4
$ForwIndCits^{EP\_Formal}$	120	641.39	510.44	15.492	1759.1
$HorizIndCits^{EP\_InFormal}$	120	82.633	87.361	1.0000	294.00
$BackIndCits^{EP\_InFormal}$	120	60.268	65.331	0.5263	223.78
$ForwIndCits^{EP\_Informal}$	120	46.100	40.092	0.2278	98.520
$HorizIndCits^{WO\_Formal}$	120	166.53	131.18	13.000	360.00
$BackIndCits^{WO\_Formal}$	120	120.087	94.595	6.8422	274.02
$ForwIndCits^{WO\_Formal}$	120	103.49	88.968	2.9617	232.17
$HorizIndCits^{WO\_InFormal}$	120	21.233	30.241	0.0000	5.0000
$BackIndCits^{WO\_InFormal}$	120	15.234	22.840	0.0000	3.5217
$ForwIndCits^{WO\_Informal}$	120	10.136	11.037	0.0000	3.6298

TABLE IX
DESCRIPTIVE STATISTICS WHEN CONSIDERING LOW TECHNOLOGICAL SWISS MANUFACTURING FIRMS

Variables	Obs	Mean	Std.dev	Min	Max
RD	48	366.29	528.67	38.023	1869.6
$Patent$	48	75.000	139.52	4.0000	526.00
VA	48	11189	20098	770.27	77668
$Comp$	48	4.663	1.9606	1.9874	9.5479
$Size$	48	8.5898	1.1230	6.6907	11.303
$HorizIndCits^{All\_Cits}$	48	11151	627.29	25.000	2397.0
$BackIndCits^{All\_Cits}$	48	821.30	477.14	115.11	1881.8
$ForwIndCits^{All\_Cits}$	48	849.71	528.98	62.385	1942.3
$HorizIndCits^{EP\_Formal}$	48	888.33	505.29	144.00	2171.0
$BackIndCits^{EP\_Formal}$	48	638.81	398.36	66.306	1704.4
$ForwIndCits^{EP\_Formal}$	48	656.78	428.59	35.933	1759.1
$HorizIndCits^{EP\_InFormal}$	48	70.083	55.831	7.0000	130.00
$BackIndCits^{EP\_InFormal}$	48	48.769	38.43	4.9889	88.419
$ForwIndCits^{EP\_Informal}$	48	52.170	4.741	4.7412	98.520
$HorizIndCits^{WO\_Formal}$	48	176.58	124.58	26.000	309.00
$BackIndCits^{WO\_Formal}$	48	122.88	86.706	16.214	210.16
$ForwIndCits^{WO\_Formal}$	48	128.90	98.268	16.682	234.17
$HorizIndCits^{WO\_InFormal}$	48	16.083	15.406	0.0000	34.000
$BackIndCits^{WO\_InFormal}$	48	10.845	10.543	0.0000	23.125
$ForwIndCits^{WO\_Informal}$	48	11.852	11.936	0.0000	25.766

Our results show that Swiss firms benefit from knowledge spillovers to enhance their R&D investment and then their innovation performance. Knowledge spillovers occur only from horizontal and backward linkages and depend on the type of citation, in which the references to NPL such as journal article (informal citations made in European and international search) have a greater impact. Formal citations have positive and significant effects only when patents are made international search. In addition, only firms with high technological capacities benefit from absorbing knowledge spillovers from formal and informal citations. Low technology firms fail to catch-up and efficiently learn knowledge from patented and non-patented citations.

On the policy front, suggestions to promote innovative activities should take into account the importance of a firm's innovative efforts as catalysts for its innovation performance. Our findings suggest that both horizontal and vertical linkages with industry are crucial for firms' innovation capabilities and propensity. Therefore, policy actions should aim to foster these types of linkages to enhance firms' innovation performance. Policy actions should aim to promote collaboration between firms at mainly horizontal and backward linkages to enhance the flow of knowledge, and to facilitate the processes of assimilation and absorption of knowledge. However, it is important to recognize that different innovative firms may have different preferences for how they link up to stimulate innovation. Furthermore, firms must invest in the capability to absorb knowledge in order to effectively increase their knowledge base. To enhance their innovation performance, firms must also engage in continuous learning activities in response to technological changes and growing global competition, in order to enhance their innovation capabilities.

TABLE X
DESCRIPTIVE STATISTICS WHEN CONSIDERING HIGH TECHNOLOGICAL SWISS MANUFACTURING FIRMS

Variables	Obs	Mean	Std.dev	Min	Max
RD	72	1099.9	2666.1	23.815	9797.9
$Patent$	72	57.277	73.946	2.0000	278.00
VA	72	9068.8	14338	44.918	46832
$Comp$	72	4.4358	3.9881	0.3965	30.782
$Size$	72	7.8415	1.7545	3.8245	10.828
$HorizIndCits^{All\_Cits}$	72	1253.0	778.40	86.000	2397.0
$BackIndCits^{All\_Cits}$	72	941.39	608.66	45.263	1881.8
$ForwIndCits^{All\_Cits}$	72	768.73	628.63	19.592	1942.3
$HorizIndCits^{EP\_Formal}$	72	977.50	635054	68.000	2171.1
$BackIndCits^{EP\_Formal}$	72	737.07	505.50	35.790	1704.4
$ForwIndCits^{EP\_Formal}$	72	631.13	561.10	15.492	1759.1
$HorizIndCits^{EP\_InFormal}$	72	91.000	102.71	1.0000	294.00
$BackIndCits^{EP\_InFormal}$	72	42.053	37.287	0.2278	98.520
$ForwIndCits^{EP\_Informal}$	72	67.935	77.633	0.5263	223.78
$HorizIndCits^{WO\_Formal}$	72	159.83	135.84	13.000	360.00
$BackIndCits^{WO\_Formal}$	72	24.666	36.685	0.0000	102.00
$ForwIndCits^{WO\_Formal}$	72	118.22	100.06	6.8422	274.02
$HorizIndCits^{WO\_InFormal}$	72	86.546	78.398	2.9617	234.17
$BackIndCits^{WO\_InFormal}$	72	18.160	27.912	0.0000	77.640
$ForwIndCits^{WO\_Informal}$	72	9.9931	10.322	0.0000	28.766

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