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Knowledge acquisition, elicitation, and management in innovative firms

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Abstract

Knowledge has emerged as a key commodity in smart manufacturing and as a critical resource for innovation and entrepreneurship in Industry 4.0. Innovative firms develop competitive advantages through knowledge exploitation and exploration, whether acquired externally or developed internally. Knowledge management, that is the management of the processes of knowledge creation, sharing and storage, is essential for effective innovation. Software tools to support knowledge management have had limited success in their attempt to address equally well a multitude of sources of knowledge. The data-driven analysis of this paper, however, demonstrates that knowledge acquisition is largely focused within the firm and thus the integrative perspective of considering both internal and external sources of knowledge might be an impediment for the development of appropriate supporting technologies. In this context, the focus should shift to knowledge elicitation and the corresponding development of tools to support it within the firm.

Keywords: Knowledge management; knowledge acquisition; knowledge elicitation.

1. Introduction

Industry 4.0 is the new vector of growth and development of the knowledge economy as information resources account for an increasingly larger share of the structure of the cost of manufactured goods and services [1]. Indeed, innovation-active companies developing new leading production technologies support the development of the knowledge economy as a platform for the new industrial revolution [2]. In this context, knowledge becomes a commodity in smart manufacturing and knowledge acquisition, elicitation and management emerge as critical processes in innovative firms.

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In an era of globalization, the mobility of resources (such as capital and labor) and the information flows of a wired world create unique challenges and opportunities for enterprises today. Knowledge management, the process of converting resources and information flows to useful knowledge and ultimately into enduring value for an organization, requires a conscious effort by the enterprise and the environment in which it operates [3].

Effective knowledge management increases the intellectual capital of the firm, that is the intangible assets that contribute to firm performance and reflect the sum of the knowledge contained within the organization [4]. Intellectual capital (IC) is broadly defined as the sum of three distinct parts:

- *human capital*, the knowledge embedded in the people of the organization and in its human resource management system.
- *relational capital*, the knowledge embedded in the relationships of the organization with the outside world; and
- *structural capital*, the knowledge embedded in the processes of the organization.

Human capital is the collective value of the skills, expertise, and talent of the employees of an organization and expresses an organization's combined human capability for solving business problems and exploiting its intellectual property. As human capital is inherent in people and cannot be physically owned, it can leave an organization when people leave, and management has failed to provide for controlled succession where others can pick up their know-how [5].

Structural capital expresses the supportive non-physical infrastructure, processes and databases of the organization that enable its human capital to function. Structural capital includes patents, trade secrets, copyrights, and trademarks as well as the organization's procedures, culture, operating philosophy, information systems, and databases [6].

Relational capital reflects the value of an organization's external linkages such as customer and supplier relationships, trademarks and trade names, licenses, and franchises. The quality and level of the relational capital of an organization is reflected in client and supplier loyalty and in the quality of its communication with customers, suppliers, partners and competitors [7].

The level of intellectual capital of the firm and the effective management of its knowledge assets have been identified as a critical business success factor [4]. A direct relationship exists between the effectiveness of an organization's knowledge management and its ability for sustainable innovation, mediated by the mechanism of organizational learning. Indeed, from the initial steps of ideation to the final steps of market-ready implementation, knowledge management plays a critical supporting role for organizational innovation through knowledge acquisition, sharing and storage [5].

Knowledge management has been positively related to innovation performance in a direct relationship that is mediated by several factors reflecting the quality and sophistication of its mechanisms for organizational learning [8, 9, 10]. Organizational learning involves four distinct constructs and processes: acquiring knowledge; distributing knowledge; interpreting knowledge; and organizational memory [5]. Given the volume of information flows in a globalized world, technological resources are needed to support organizational learning and to affect the quality and effectiveness of knowledge management. There is a vigorous debate however on whether it is possible to use information and communication technology tools to share tacit knowledge [11, 12].

One issue that may explain the different views is that technological tools and methodologies to support organizational learning adopt an agnostic view of the sources of information, trying to address a wide range of knowledge whether acquired externally or developed internally. This is because the breadth of external sources of knowledge is associated with positive innovation performance in literature [6].

The objective of this paper is to examine whether assuming a priori the existence of a wide range of sources does reflect reality. By focusing on the innovative firms of an advanced economy, such as Germany, the issue of the plurality of knowledge sources and their relative importance is examined in a data-based framework.

The paper is organized as follows. In Section 2, a detailed overview of the knowledge sources and their relative importance is presented with the results of the analysis mediated by firm size and sector. In Section 3, a similar analysis is performed on the actual innovation expenditures of the firms to assess their priorities in their innovation effort. Finally, in Section 4, the results of the analysis are presented in a coherent framework that elucidates some of the issues set forth and future research suggestions are suggested to ameliorate some of the limitations of the present study.

2. Knowledge sources

In the European Union, innovation surveys called the Community Innovation Surveys (CIS) are being conducted biannually based on a harmonized methodology [13]. The public release normally takes place two and half years after the end of the survey reference period. It is customary for the survey instruments in CIS to be updated between editions with some sections revised or significantly edited to reflect new interests regarding innovation.

CIS data on sources of information is being studied in the research literature to identify differences between firm sizes or to map information and communication technologies to knowledge management processes within the enterprise [5, 6, 7]. The research in this paper extends these studies past firm size to include key sectoral characteristics and more importantly to map them with innovation expenditures.

The CIS data regarding sources of innovation for Germany that are studied in this paper (online data code INN_CIS10_SOU in [13]) were released in January 2019 and included the list of twelve sources in Table 1, classified according to the taxonomy presented in [5].

Table 1. List of knowledge sources for innovation in CIS 2016.

Classification	Code	Explanation
Internal	GROUP	Enterprises within the enterprise group
Market	SUPPL	Suppliers of equipment, materials, components or software
	PRIVT	Clients or customers from the private sector
	PUBLC	Clients or customers from the public sector
	COMPT	Competitors or other enterprises of the same sector
	CONSLT	Consultants or commercial labs
Institutional	UNIVS	Universities or other higher education institutions
	GOVRN	Government or public research institutes
	RESIN	Private research institutes
Other	FAIRS	Conferences, trade fairs or exhibitions
	PRINT	Scientific/technical journals or trade publications
	ASSOC	Professional or industry associations

It should be noted that as of January 2021 there is a newer version of the data (online data code INN_CIS11_SOU in [13]), however the focus has been shifted from *twelve* knowledge sources of information to *eight* channels of information such as standardization documents, social web-based networks, and reverse engineering. The presentation that follows is based on CIS10 (and not CIS11) data because of its richer content and refinement vis a vis knowledge sources for innovation.

2.1. Importance of knowledge sources across firm sizes

Over 36,000 German innovative firms were asked to vote for the sources of knowledge they deemed "highly important" in their innovation activities. Table 2 summarizes their votes and breaks them down by firm size (SML from 10-49 employees; MED from 50-249 employees; and LRG from more than 250 employees). It should be noted that a firm could vote for more than one source of knowledge if appropriate. With 36,212 firms depositing 91,661 votes, each firm on the average recognized about three sources of knowledge as highly important.

The percentage of votes that each source of knowledge received is summarized in Table 3. The percentages in Table 3 do *not* add up vertically and require careful interpretation. For example, GROUP received 37% of all of the 91,661 votes cast while PRIVT received 20% of all the 26,109 votes cast by MED firms. (There were no votes cast for RESIN.)

Table 2. Characterization of knowledge sources for innovation as highly important (votes).

	GROUP	SUPPL	PRIVT	PUBLC	COMPT	CONSLT	UNIVS	GOVRN	FAIRS	PRINT	ASSOC	SUM
SML	20,452	3,228	12,123	2,545	4,712	1,102	2,001	771	4,611	2,459	1,260	**55,264**
MED	9,890	1,167	5,331	1,035	2,431	782	1,035	426	2,091	999	922	**26,109**
LRG	3,451	407	2,111	421	1,214	317	552	207	766	451	391	**10,288**
SUM	**33,793**	**4,802**	**19,565**	**4,001**	**8,357**	**2,201**	**3,588**	**1,404**	**7,468**	**3,909**	**2,573**	**91,661**

Table 3. Characterization of knowledge sources for innovation as highly important (% of votes).

	GROUP	SUPPL	PRIVT	PUBLC	COMPT	CONSLT	UNIVS	GOVRN	FAIRS	PRINT	ASSOC	SUM
SML	37%	6%	22%	5%	9%	2%	4%	1%	8%	4%	2%	**100%**
MED	38%	5%	20%	4%	9%	3%	4%	2%	8%	4%	4%	**100%**
LRG	34%	4%	21%	4%	12%	3%	5%	2%	7%	4%	4%	**100%**
SUM	**37%**	**6%**	**21%**	**4%**	**9%**	**2%**	**4%**	**2%**	**8%**	**4%**	**3%**	**100%**

The results of Table 3 are depicted in Figure 1, for the totality of votes cast and across individual sizes. From the diagram it is apparent that GROUP and PRIVT are the top two sources in terms of importance. COMPT and FAIRS form the second group of importance, while all other sources received 5% of the votes or less. There is surprisingly little difference across company sizes with LRG firms emphasizing GROUP slightly less and COMPT slightly more compared to SML and MED firms. These ±3% differences are of course insignificant within the broader context.

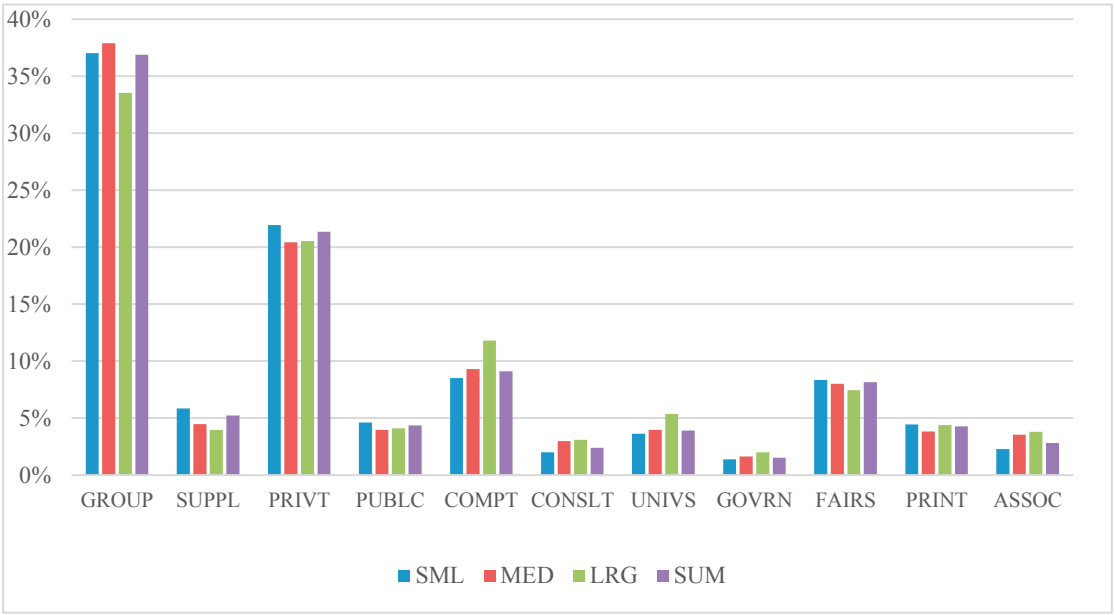

Fig 1. Knowledge sources for innovation ranked in terms of importance (votes cast).

2.2. Importance of knowledge sources across sectors

To assess whether there might be sectoral differences of interest, an additional analysis was performed for two key sectors: Manufacturing (MFG) and Information and Communication (INF). Tables 4 and 5 summarize the pertinent data. It is apparent that in this case as well there is no discernible difference between the two sectors the characteristics of the firms of which diverge significantly. Figure 2 displays the situation for these two sectors. MFG firms emphasize PRIVT slightly less and FAIRS slightly more compared to INF firms, but the differences are less than ±5%.

Table 4. Characterization of knowledge sources for innovation as highly important (votes).

	GROUP	SUPPL	PRIVT	PUBLC	COMPT	CONSLT	UNIVS	GOVRN	FAIRS	PRINT	ASSOC	SUM
MFG	21,558	3,465	13,964	2,154	5,518	1,125	2,392	908	5,799	2,452	1189	**60,524**
INF	6,844	592	3,229	1,337	1,370	464	948	305	1,076	1,074	280	**17,519**

Table 5. Characterization of knowledge sources for innovation as highly important (% of votes).

	GROUP	SUPPL	PRIVT	PUBLC	COMPT	CONSLT	UNIVS	GOVRN	FAIRS	PRINT	ASSOC	SUM
MFG	36%	6%	23%	4%	9%	2%	4%	2%	10%	4%	2%	**100%**
INF	39%	3%	18%	8%	8%	3%	5%	2%	6%	6%	2%	**100%**

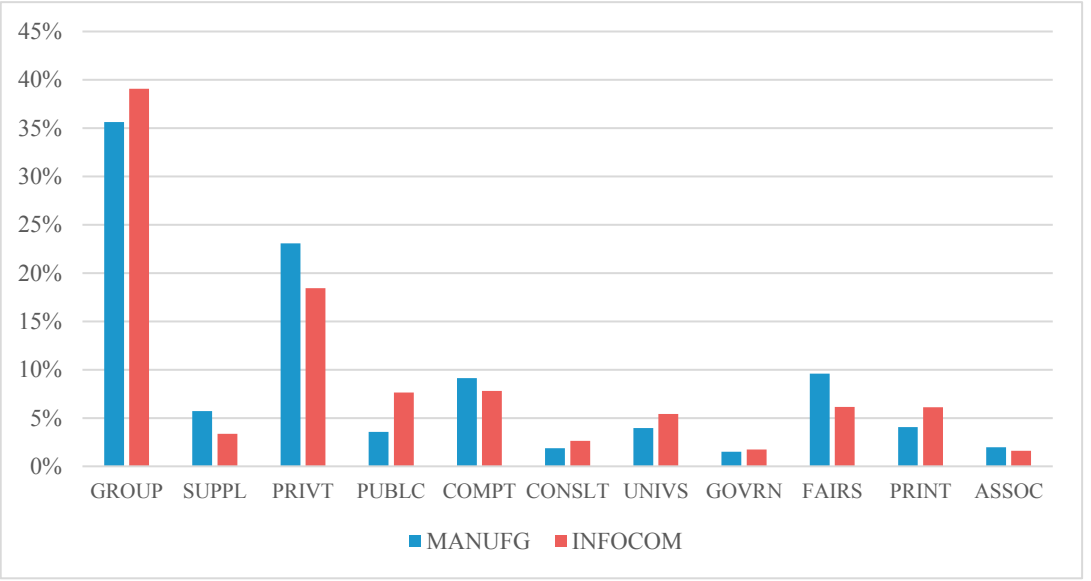

Fig 2. Knowledge sources for innovation ranked in terms of importance for two sectors (% votes cast).

2.3. Importance of knowledge sources

The fundamental conclusion from this part of the analysis is that innovative firms in Germany obtain their knowledge for innovation internally or from enterprises within the enterprise group (37%) and externally from their clients or customers from the private sector (21%). Secondary sources are competitors or other enterprises of the same sector (9%) and conferences, trade fairs or exhibitions (8%). Every other source is listed at less than 5%. This ranking of the sources of knowledge is quite robust across firm sizes and sectors.

The Pareto diagram in Figure 3 indicates that the top five sources account for 80% of the knowledge base for innovation. Interestingly, internal sources (GROUP) account for 37%, market sources (SUPPL, PRIVT, COMPT) account for 36% and other sources (FAIRS) account for 8%.

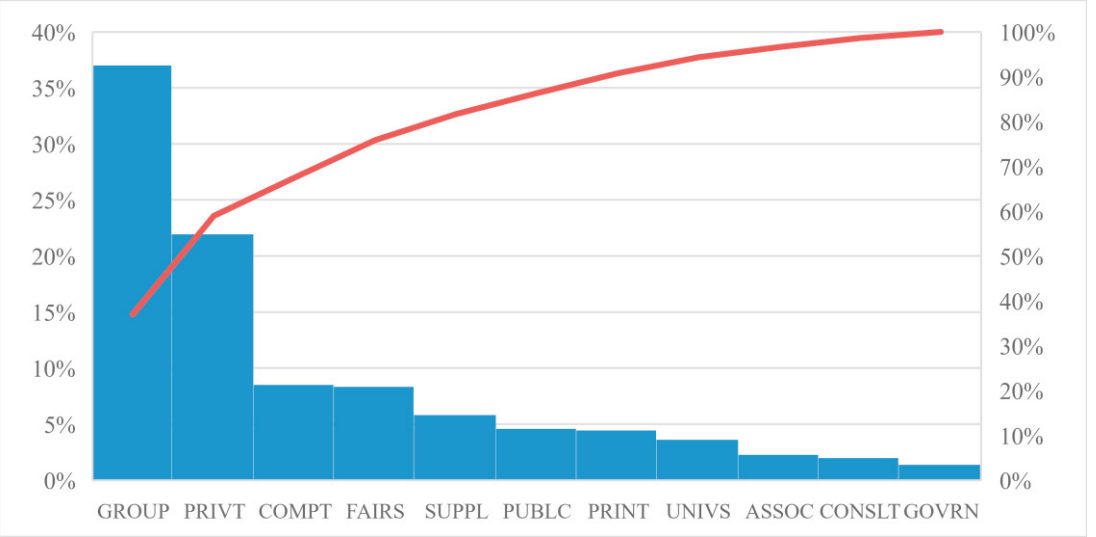

Fig 3. Pareto diagram of the knowledge sources for innovation for German innovative firms.

3. Innovation expenditures

The 36,000 German innovative firms polled were asked additionally to report the level of their actual expenditures for innovation activities in 2016 across three categories [13]:

- *Internal R&D*
  - research and development activities undertaken by the firm to create new knowledge, including software development in-house that meets this requirement
- *External R&D*
  - research and development activities contracted to other firms (include enterprises in the same group) or to public or private research organizations
- *Acquisition of external knowledge*
  - acquisition of existing know-how, copyrighted works, patented and non-patented inventions, etc. from other firms or organisations

3.1. Innovation expenditures across firm sizes

Tables 6 and 7 delineate the reported innovation expenditures in internal R&D, external R&D and acquisition of external knowledge while Figure 4 depicts the innovation expenditures across firm sizes. It is apparent that irrespective of size, these firms devote an impressive 82% of their innovation expenditures to internal R&D activities and a mere 12% and 5% to external R&D and to the acquisition of external knowledge.

Table 6. Sectoral innovation expenditures (in million EUR).

	Internal R&D	External R&D	Acquisition of External Knowledge	TOTAL
SML	2,905	413	221	**3,539**
MED	5,207	750	365	**6,322**
LRG	65,528	13,549	1,873	**80,950**
TOTAL	**73,640**	**14,712**	**2,459**	**90,811**

Table 7. Sectoral innovation expenditures across firm sizes (%).

	Internal R&D	External R&D	Acquisition of External Knowledge	TOTAL
SML	82%	12%	6%	**100%**
MED	82%	12%	6%	**100%**
LRG	81%	17%	2%	**100%**
TOTAL	**82%**	**13%**	**5%**	**100%**

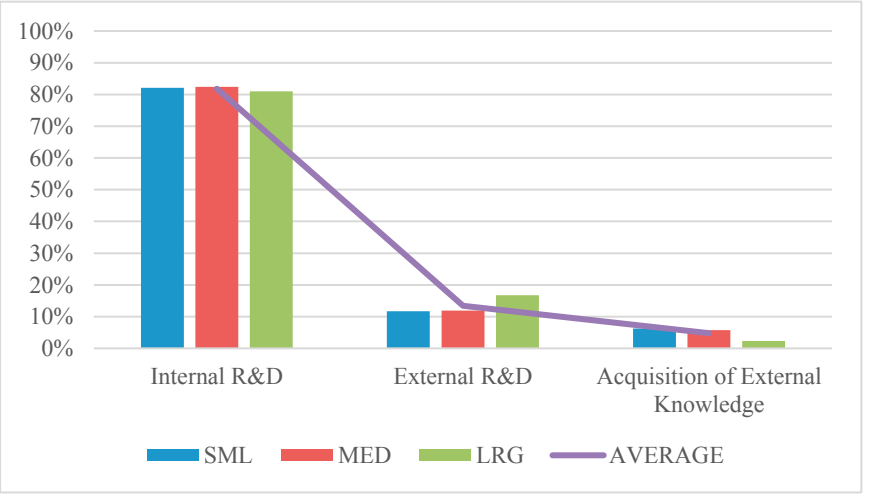

Fig 4. Innovation expenditures across firm sizes.

3.2. Innovation expenditures across sectors

To assess whether there might be sectoral differences of interest in the expenditures, an additional analysis was performed for two key sectors: Manufacturing (MFG) and Information and Communication (INF). Tables 8 and 9 summarize the pertinent data while Figure 5 depicts the innovation expenditures across firm sizes. It is apparent that in this case as well that both sectors devote about 80% of their expenditures to internal R&D. there MFG firms tend to emphasize external R&D over the acquisition of external knowledge while INF firms split their external expenditures almost evenly between them.

Table 8. Innovation Expenditures across firm sizes (in million EUR).

	Internal R&D	External R&D	Acquisition of External Knowledge	TOTAL
MFG	63,600	13,266	1,211	**78,077**
INF	4,04	656	713	**6,273**

Table 9. Innovation Expenditures across firm sizes (%).

	Internal R&D	External R&D	Acquisition of External Knowledge	TOTAL
MFG	81%	17%	2%	**100%**
INF	78%	10%	11%	**100%**

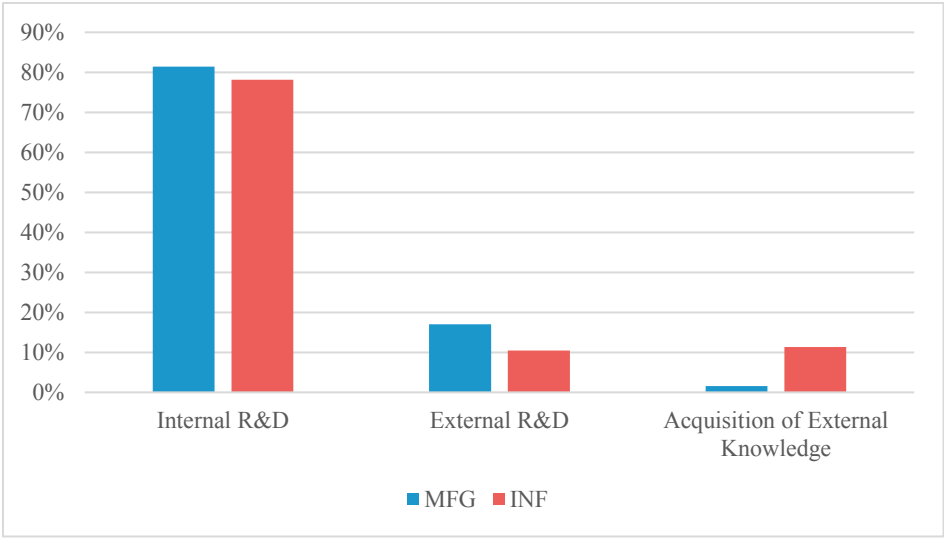

Fig 5. Innovation expenditures for two key sectors.

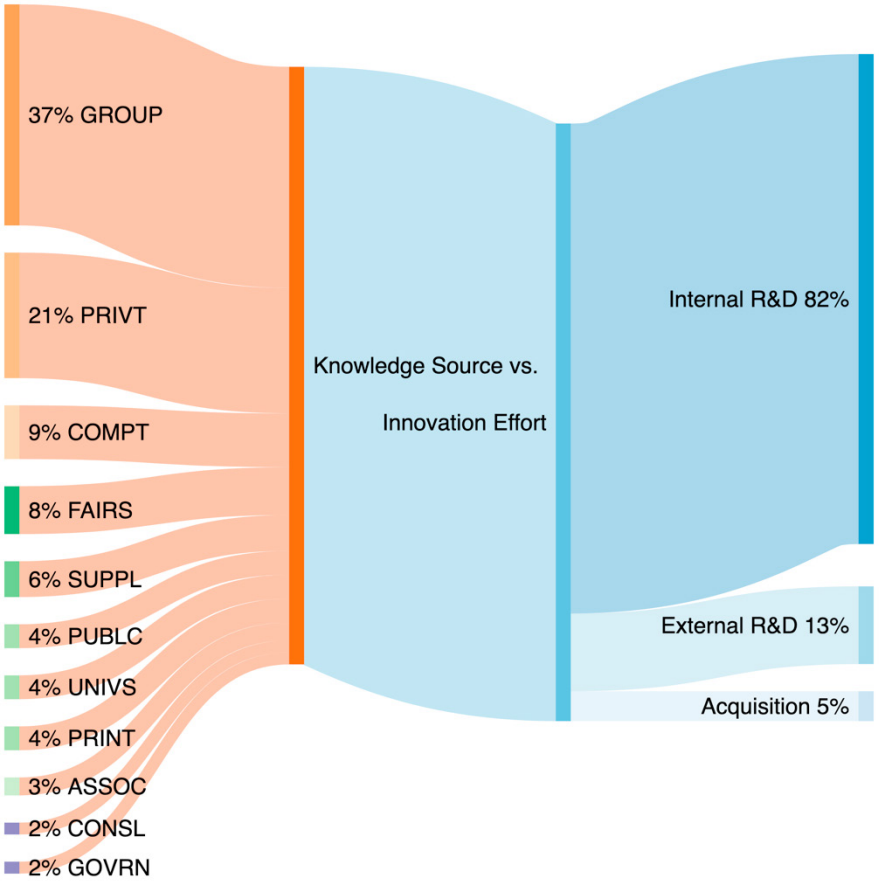

Fig 6. Sankey diagram of knowledge sources for innovation vs innovation expenditures.

4. Discussion

From the analysis of the previous two sections a clear picture emerges naturally. Despite the multitude of available knowledge sources for innovation, innovative firms depend mostly on internal sources (including enterprises within the enterprise group) and to a much lesser extent to market sources (primarily clients or customers from the private sector). This observation is further amplified by the fact that the lion's share of innovation expenditures is devoted to internal R&D with very limited resources targeting external contract research or outright acquisition of knowledge from third parties.

Figure 6 illustrates succinctly the outcomes of the analysis, which are true across the board and are not mediated in any meaningful way by firm size or sector. The insularity in the acquisition of knowledge is deeper, considering that the 82% of innovation expenditures does *not* include enterprises in the same group. (Resources devoted to R&D performed by other firms in the same group are counted in the external R&D expenditures.)

This insularity is puzzling considering that German firms are at the forefront of innovation, having significant resources to expend and operating in a modern, fully networked environment that is conducive to efficient information flows.

5. Conclusions

Naturally, knowledge is an asset that must be managed effectively, especially in the context of Industry 4.0 and smart manufacturing. Knowledge management processes that get the right knowledge to the right people at the right time and in the right form are essential for innovation. The results of this paper indicate that broad knowledge acquisition from any source becomes increasingly knowledge elicitation within the narrow environment of the firm.

The goal of knowledge elicitation is to acquire, preserve and make available organizational knowledge and expertise [14]. Knowledge elicitation of course will generate representations of knowledge that may or may not be exploited in the context of conventional expert systems. There is an urgent need therefore to support organizational knowledge creation through the transformation of tacit knowledge into explicit knowledge and ultimately as intellectual capital of the firm. The fact that knowledge is specified, developed, and deployed primarily *within* the firm, defines an appropriate context for knowledge engineering in support of innovation [15, 16].

The results of this study are of course limited by the fact that they refer to only one country, Germany. Future research should focus on examining similar issue for a wider set of countries and their innovative firms.

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