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R&D Cooperation and Knowledge Spillover Effects for Sustainable Business Innovation in the Chemical Industry

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Abstract: This paper investigates the influence of research and development (R&D) cooperation on the creation of spillover effects for sustainable firms in the chemical industry. We explore the evidence for the origin of knowledge spillovers derived from cooperation amongst firms and universities and R&D organizations as well as to test the influence of internal/external financial support on these effects. The results confirm that when firms acquire knowledge from internal sources, this leads to increased innovation and sustainable performance. We have proved that internal expenditure results in increased internal knowledge spillovers. These findings may be specific for Central and Eastern (CEE) transition countries, indicating their efforts to build path-dependent structures based on knowledge institutions and businesses as well as knowledge networks. However, this study also provides a more "global" contribution to the knowledge spillover effect theory. It shows that a firm's cooperation both with universities and with other firms promotes different types of knowledge spillovers and can affect diverse modes of sustainable activities in innovation.

Keywords: spillover effects; chemical industry; innovation; sustainability

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1. Introduction

Knowledge-based theories indicate that it is possible for a firm to attain economic growth through innovation development while integrating local knowledge, the intensity (and frequency) of knowledge transfer processes among other local firms [1], and the variety of knowledge within the firm [2]. Such innovation may also be dependent on the "intensity" and "variety" of the knowledge sources available to a firm. The process of generating knowledge does not only enable cooperation between the firms in the region but also enables the external acquisition or purchase of knowledge; for example, via integration into business networks, industrial clusters or cooperating international trade networks [3], or from universities or R&D institutes. Knowledge spillovers from universities to firms are considered critical mechanisms as to how knowledge generated by one economic unit is exploited by another [4]. However, this process is not limited to university–firm relationships but involves a range of firm activities with other economic units, such as firms, customers, research institutes, etc. Previous research has reported that knowledge spillovers promote both innovation and cooperation [5,6]. While the former has been thoroughly studied since the seminal work by Romer [7], the latter has only been extensively investigated in the last decade. The positive effect of knowledge spillovers on the decision to cooperate stems from the belief that the emergence of cooperation in R&D requires both intensive contacts and a high level of trust arising from preceding informal knowledge spillovers [8]. However, additional knowledge spillovers can be generated via cooperation activities. This makes the effects difficult to measure. Moreover, several scholars have shown that cooperation is an important driver of innovation activity [9]. This paper seeks to address these issues and examines the indirect and direct effects (those with and without cooperation, respectively) of knowledge spillovers on innovation activity. Specifically, the goal of this paper is to introduce evidence of the creation of knowledge spillovers resulting from the cooperation of firms in the chemical industry with universities and R&D institutes as well as to test the influence of internal and external financial support on these knowledge spillovers. In contrast to previous studies [10,11], we have focused on the difference between the cooperation of firms with both universities and with other firms as well as their influence on innovation activities. Moreover, we focus on sustainable business innovation that is defined by the European Commission [12] as: "*the production, assimilation or exploitation of a novelty in products, production processes, services or in management and business methods, which aims, throughout its lifecycle, to prevent or substantially reduce environmental risk, pollution and other negative impacts of resource use (including energy)*". Sustainable business innovation needs to move beyond incremental adjustments [13,14]. Sustainable innovations are particularly relevant in the chemical industry because their adoption (by firms and customers) does not exclusively depend on their instrumental attributes. Firms and customers may be motivated to adopt sustainable innovations because of their positive environmental and symbolic attributes. End users as well as politicians and managers increasingly are considering the impacts of innovation processes (throughout their life-cycle). As indicated above, sustainable innovations are usually radical rather than incremental. Therefore, they often depend on collaborative efforts that go beyond traditional business alliances and supply chains [15]. Specifically, various internal and external collaborative partners are incorporated into the sustainable innovation process, such as green supply chains, universities, or government entities. A degree of concerted action (collaboration and mutual learning) is required for sustainable innovation [16]. The need for these collaborative efforts can also be explained by the theories of institutional, stakeholder, and ecological modernization [15].

Although the level of cooperation and innovation is still low in CEE countries, the process of transition has increased the involvement of firms in these activities [17]. This is particularly true for knowledge-intensive manufacturing industries such as electric and chemical industries. The chemical industry was chosen for analysis because it is a traditional type of manufacturing industry, has a significant impact on sustainable development, can be compared internationally, frequently engages in cooperation on open innovation with other sectors, and is often supported by public financing. Recent literature has called attention to the novel concept of responsible research and innovation in industry [18,19]. In addition to an economic value, social value is also expected to be achieved by innovation activities. This is relevant to numerous industry sectors, including the chemical industry. The chemical industry is science-driven; basic research is given a high degree of importance which leads to highly innovative and unpredictable results [20]. Moreover, the chemical industry claims a significant percent of the Czech Republic's (and of most CEE countries') manufacturing output. The Czech chemical industry is notable as an industry that was significantly affected in the wake of the Czech Republic's entry into the EU, thanks to public support from EU funds and changes in the funding structures of universities. In addition, chemical faculties are some of the most important sources of basic research in the Czech Republic. Applied research also evolves quickly because of changes in the methods for evaluating research and development with institutional support from the public sector; these changes aim to increase university–firm cooperation. Accordingly, we expect a high degree of transferability of results to CEE transition countries.

Hypotheses for attaining this goal are defined in the next section. In addition, Section 2 lays out the theoretical dimensions of the research. Section 4 describes the collection and statistical characteristics of the data. In Section 5, structural equation models are employed to test the hypotheses. The final section discusses the results, presents the implications and limitations of this study, and concludes the paper.

2. Theoretical Background

It has been demonstrated that any type of knowledge and skill transfer (knowledge transfer is the process by which one entity is affected by the experience of another [21]) results in knowledge spillover effects. These are effects that occur either through the interaction of entities (primary knowledge spillover effects) or subsequently occur as an aftereffect of spillover between participating entities and others (secondary knowledge spillover effects) [22]. These positive effects influence the innovation capacity of firms as well as the research abilities or absorptive capacity of universities and R&D institutes. These effects occur in cooperating, often related, value chains [2]. Frenken et al. [23] demonstrate that a higher number of technologically related sectors in the region correlate to a higher level of inter-sector knowledge spillover between entities. Positive effects were demonstrated using several activities which led to the creation of patents as well as those seen in the so-called unrelated variety. The unrelated variety can cause other unmeasurable side effects [24].

Both internal knowledge and knowledge bought on the market are necessary to hasten the development of open innovation, as is knowledge that is a product of cooperation (either between firms or within the firm–university framework or regional triple helix). The university and R&D institute sectors are essential for generating knowledge [10]. It has been demonstrated that universities help to increase the number of patents in industrial fields [25] and that universities themselves are influenced through cooperating entities and cooperative projects [11].

Universities and R&D institutes must enter a cooperative relationship with industry to make their research fields compatible to foster the practical application of both knowledge transfer and knowledge acquisition (especially in knowledge-intensive industrials). Schartinger et al. [26] demonstrated that knowledge-oriented firms from intensive industrial sectors have among the highest levels of intensity in terms of interaction and cooperation. The chemical industry ranked among the top ten industries in terms of R&D interaction intensity [26]. By contrast, assumptions of a strong attempt to cooperate were not met by either the electrical industry, electronics, or machinery manufacturing in Austrian business sectors. From an economic perspective, it is even possible to specify industrial sectors that rely on a wider spectrum of scientific findings in their innovative processes and, at the same time, embody a high level of generation and transfer of findings between firms and universities. The chemical industry clearly belongs to knowledge-intensive sectors. These sectors fundamentally need interdisciplinary knowledge; they need cooperating entities to help to generate new scientific research. Therefore, they frequently cooperate or even establish their own scientific research centers. Various studies demonstrate that particularly strong university–industry linkages occur between the technical sciences and manufacturing sectors, including chemical engineering, pharmaceuticals, and biotechnology in Western countries [27,28]. Public research usually provides expert knowledge and technological infrastructure for sustainable innovation activities in these sectors [26].

The proximity of firms in the chemical industry to suitably oriented universities and research centers allows for considerable mobility of knowledgeable workers and accordingly the emergence of spillover effects (for example, see [26,29,30]). These studies demonstrate that the proximity between a university and a chemical firm enables intensive cooperation, not only on the basis of communal research activities and projects but also on the basis of educating firm employees or external lectures for university students [31].

The case study presented here focuses on the chemical industry of a CEE country, the Czech Republic. It presents new findings and enriches the existing literature. It is necessary to emphasize that individual CEE countries are largely pro-export economies with similar historical factors affective of societal and economic developments; this includes a primary dependence on the German economy or on the economies of other Western countries as well as a similar research character that is historically distant from the application sphere (which greatly affects the transfer of knowledge and innovation co-operation). They demonstrate distinct knowledge spillover and the emergence of external knowledge spillovers under the influence of marked supplier–consumer cooperation which affects most company production processes. With regards to the size and maturity of CEE economies, it is necessary to acknowledge that external knowledge as well as foreign direct investment (and the public systems supporting it) do not have as marked an impact on this region's creation of innovation or the reinforcement of competitive standing as they do for companies cooperating inside countries such as Great Britain, Germany, or the Netherlands. There are no studies that provide valid information on the use of knowledge and R&D cooperation in specific economies such as the CEE countries' economies. The chemical industry was selected to make it easier to compare results with those of Western countries. This industry represents one of the most technology intensive manufacturing industries in the EU with a major impact on economic growth [32]. In fact, the European chemical industry has a strong market position, accounting for about 18% of the sales of chemical firms worldwide. Moreover, the EU chemical firms' R&D activity is high in terms of patent applications and innovation is largely generated via industry–academia collaboration or in chemical clusters [33].

3. Hypotheses

Recent findings have shown that collaboration promotes innovation activity (sometimes innovative cooperation). This has been demonstrated for both collaboration inside individual enterprises [34] and collaboration with other partners [35–37]. Incoming knowledge spillovers have been found to be another important determinant of innovation activity. However, previous studies have largely focused on the direct effects of incoming knowledge spillovers [35,38,39]. We have assumed that a collaborative environment increases the effects of knowledge spillover. In other words, we are exploring spillover effects that result from a firm's innovation activity without apparent cooperation with other entities as well as those that result from cooperation with other entities on the creation of innovation.

On one hand, internal sources of knowledge are critical for chemical firms; they require specific management strategies such as enlisting scientists to support internal collaboration (collaboration within the enterprise or enterprise group [40,41]). Internal knowledge spillovers generate a sustainable competitive advantage based on unique knowledge and technologies; they also aid in the creation of external knowledge spillovers [42]. Thus, chemical firms solve the inability of universities to produce results in a short time (this is due to the dichotomy in business and university goals). Therefore, we propose the following hypothesis:

Hypothesis 1. *When firms from the chemical industry acquire knowledge from internal sources, it results in cooperation within the enterprise leading to the existence of significantly higher internal knowledge spillovers.*

On the other hand, external collaboration for innovation activities has been identified as a crucial component of an open innovation model [41,43]. External collaboration includes several modes, such as collaboration with universities, R&D institutes, and market entities.

Cassiman and Veugelers [44] demonstrated that a higher percentage of incoming knowledge spillovers from the publicly available pool of knowledge promotes firms' collaboration in R&D with universities and R&D institutes. In contrast, firms that benefit from protected information are more likely to engage in collaborative agreements with other enterprises. Cassiman and Veugelers [45] further demonstrated the importance of knowledge spillovers produced by research centers and universities on the mode of innovation activities, internal R&D, or external knowledge acquisition (which supports the open innovation paradigm). Belderbos et al. [46] found that institutional knowledge spillovers are more generic in nature and increase R&D cooperation. Un et al. [47] argued that firm–university collaboration increases (open) innovation activity when compared with collaboration with other enterprises. For chemical industries, the intensity (depth) rather than the variety (breadth) of knowledge acquisition from publicly available sources has been demonstrated as singularly important [48]:

Hypothesis 2. *When firms from the chemical industry acquire knowledge from publicly available sources (universities or research institutes), the probability of firms' cooperation with universities is increased, leading to the existence of significantly higher external (firm-university) knowledge spillovers.*

We have also assumed that the effect of knowledge spillovers will be greater when the input knowledge is diversified, i.e., using knowledge acquired on the market (from suppliers, clients, and the competition) [49]. Reniers et al. [50] postulated that chemical companies are increasingly engaged in collaborative activities which promotes sustainable chemical production. External knowledge spillovers occur as a result of human mobility and the high mobility of R&D activities. For many industries, this can present necessary but insufficient conditions for innovation [42]. Knowledge acquired from clients is particularly important for new product development within chemical firms [51]. Cho and Lee [52] examined the roles of user innovation in supporting sustainable business innovations in firms. It was shown that industries differ in the modes of user innovation models. Various tools are used to acquire knowledge from specific users. Collaborative market relationships not only help firms integrate and link operations to increase effectiveness but they also support continuous innovation [53]. In the case of CEE countries, this has been found to be particularly related to horizontal spillovers (within the same industry [54]). Generally, innovation in chemical firms requires an interaction between their internal R&D activities and external knowledge sources [55]. Zhu et al. [56], who analyzed internal and external crowdsourcing in the chemical industry, pointed to similar considerations. They found that the success of chemical projects depends on externally purchased knowledge and human resources. Given that a market participant's competitors operate in the same sustainable environment, we assume that market participants have similar goals and accordingly solve similar problems. This forces them to cooperate within a specific time period. On the basis of the facts presented above, we hypothesize the following:

Hypothesis 3. *When firms from the chemical industry acquire knowledge from market participants, the probability of firms' cooperation with other firms is increased, leading to the existence of significantly higher external (firm–firm) knowledge spillovers.*

Becker and Dietz [34], Abramovsky et al. [57], and many other studies have reported that the intensity of in-house R&D promotes the probability of R&D collaboration with other enterprises or institutions. As noted above, in contrast to other industries, R&D intensity is critical for innovation activities in the chemical industry [33].

Busom and Fernández-Ribas [58] have found that public support significantly increases the probability of firm collaboration with a public research organization but that this effect is smaller for cooperation with other firms. Hottenrott and Lopes-Bento [49] found that public support is important for innovation activity and is especially effective when supporting internationally collaborating firms towards open innovation creation. When supported by public funds, innovation should become a collective good. However, in the practice of chemical firms, this only happens in the long run unless an innovation is patented [31].

Current European public policies which target the economic development of individual countries are largely focused on the development and support of their own regions. These policies should be conducted in a decentralized way [59]; they should not be focused only on creating a scheme for financial support (in the form of redistribution measures), but appropriate tools should be utilized to support the creation of investments with capacity-building effect, i.e., increasing absorptive capacity [37]. Ferreras-Méndez et al. [60] claim that absorption capacity mediates the effect between the intensity of the external knowledge search and the firm's performance. It is possible to influence this through the effective use of knowledge, learning ability, and cooperation between the various economic sectors (for example, [61]). The triple helix is an example of the application of this cooperation principle between the nonprofit sector and the for-profit sector [62]. The so-called laissez-faire triple helix is rooted in individual sectors cooperating on research as well as the creation of innovation.

Here, the university sector has the role of implementing basic research and providing knowledge while the business sector uses new findings to create commercialized innovations [34]. The public sector (the government at different levels) has the task of preventing market failure which could damage the cooperation of the individual entities.

Das and Icart [33] demonstrate that EU funding not only drives chemical companies to participate in projects but it also promotes collaboration with universities, research institutes, and even other enterprises.

We incorporated the role of in-house and public R&D expenditure in the following hypotheses:

Hypothesis 4. *Internal R&D expenditure leads to increasing the effect of internal knowledge spillovers on sustainable business innovation activity.*

Hypothesis 5. *Government and EU support leads to increasing the effect of external knowledge spillovers on sustainable business innovation activity.*

4. Research Methodology

4.1. Conceptual Models

Taken together, the hypotheses listed above can be illustrated by the conceptual models in Figures 1 and 2.

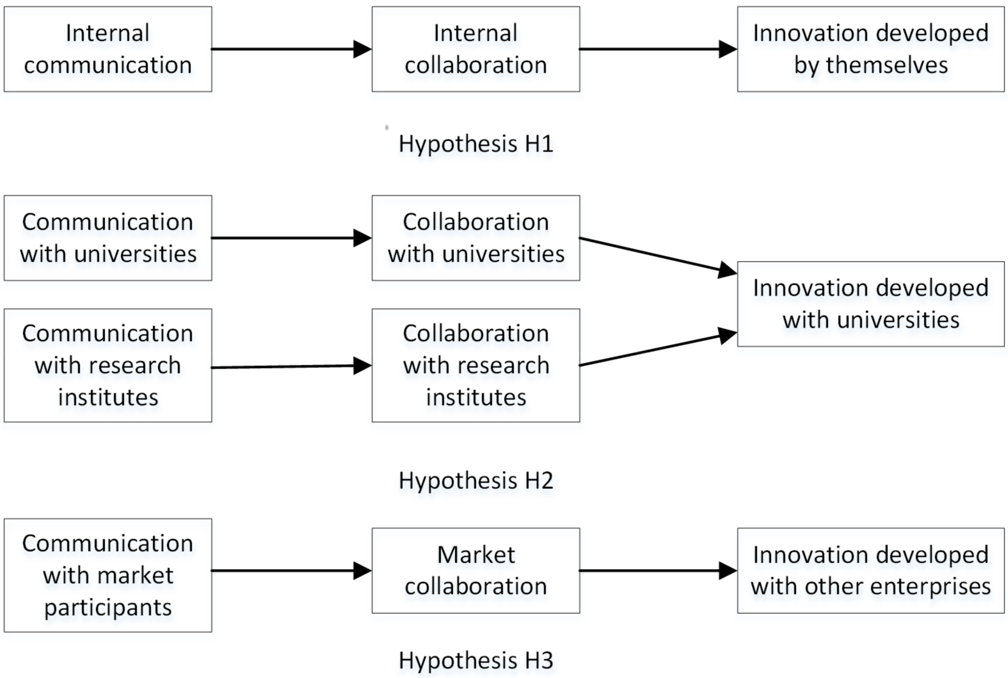

Figure 1. Conceptual model for Hypotheses H1, H2, and H3.

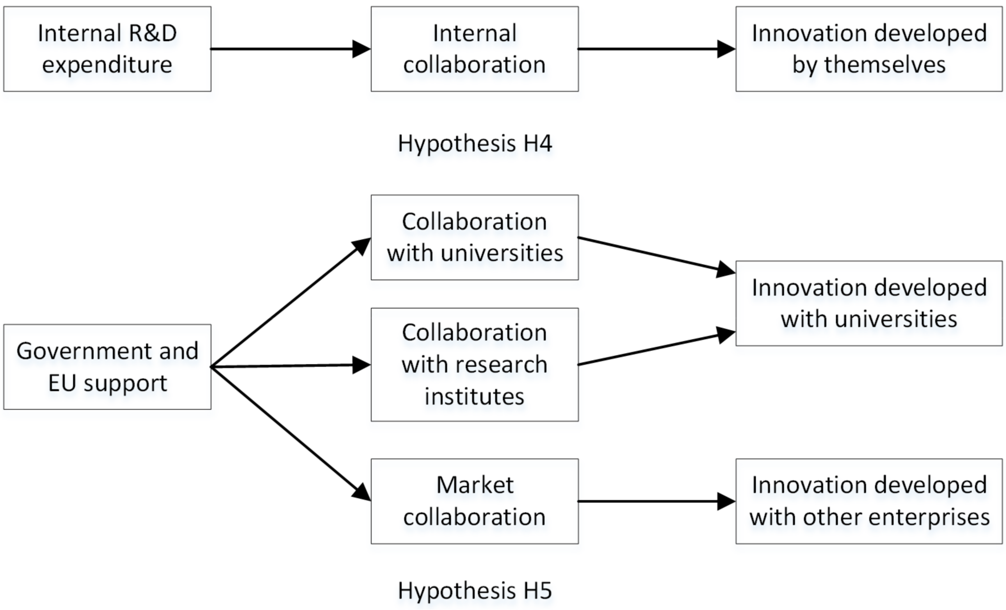

Figure 2. Conceptual model for Hypotheses H4 and H5.

To verify these hypotheses, we developed a structural equation model which can test both the mediation effects of R&D collaboration (Hypotheses H1, H2, and H3) and the moderator effects of internal R&D expenditure and external financial support (Hypotheses H4 and H5). Specifically, this proposed model can be described in the following way. Let X_1 (internal knowledge spillovers), X_2 (market knowledge spillovers), X_3 (university knowledge spillovers), X_4 (research lab knowledge spillovers), X_5 (other external knowledge spillovers), X_6 (internal R&D expenditure), and X_7 (government and EU financial support) be causal predictors of Y_1 (sustainable business innovation developed by the firm itself), Y_2 (sustainable business innovation developed with universities), and Y_3 (sustainable business innovation developed with other enterprises). Additionally, let M_1 (internal collaboration), M_2 (collaboration with universities), M_3 (collaboration with research institutes), and M_4 (market collaboration) be mediator variables. Then X_i influences Y_k directly as well as indirectly through mediator variables M_j causally located between X_i and Y_k.

4.2. Data Collection and Characteristics

For the subsequent empirical analysis, we used the data obtained within the Community Innovation Survey (CIS). The survey was conducted at firm level in the Czech Republic for the years 2008–2010. Details on sample selection can be found at the web portal of Eurostat. As a part of this survey, data was gathered for a total of 5151 firms with more than 10 employees (response rate >60%). Only firms from the chemical industry were considered (523 firms), corresponding to NACE categories 20–23.

The firm's innovation activity was specified according to whether the firm introduced a new or significantly improved product (goods or services) or process (a production process, distribution method, or supporting activity) to the market. Moreover, only sustainable business innovation was considered. These were identified according to the firms' innovation objectives. Specifically, business innovations were regarded as sustainable when a firm's innovation objectives were medium or high in at least one of the three following areas: (1) the reduction of energy and material costs; (2) the reduction of environmental impacts; and (3) the improvement in employees' health or safety. Out of the 523 firms, 218 firms (41.7%) were innovative and 305 (58.3%) were non-innovative.

For both discrete and continuous missing data, we employed a multiple imputation method [63]. The basic descriptive statistics for the determinants of innovative activity we observed are presented in Table 1. From this, it can be seen that the majority of innovative firms cooperated on innovative activity but mostly within their own group of firms. Accordingly, government and EU support was more likely directed towards innovating firms.

Table 1. Descriptive statistics of the innovative firms.

	Innovative	
	No	Yes
Cooperation—no	184	98
Cooperation—yes	121	120
In-house		70
With universities		21
With other enterprises		29
Government support—no	260	165
Government support—yes	45	53
EU support—no	260	176
EU support—yes	45	42

The paired *t*-test demonstrated on the scale of significance that both innovating firms and firms cooperating on innovation have significantly higher personal expenses for R&D (Figure 3).

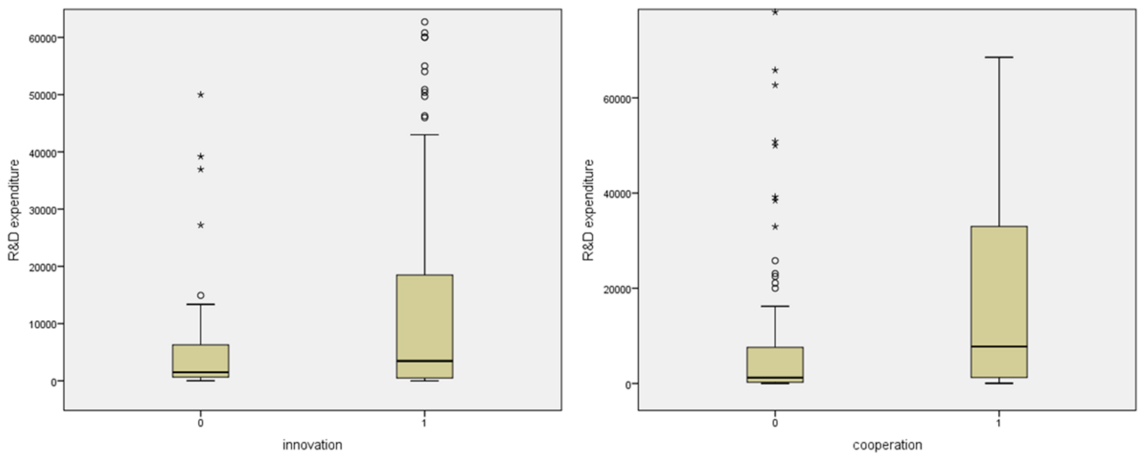

Figure 3. Internal R&D expenditure (minimum, first quartile, median value, third quartile and maximum value).

All variables used in the modeling of knowledge spillovers are described in detail in Appendix A.

5. Modeling Knowledge Spillovers

Adopting the approach of Simonen and McCann [8] or Montoro-Sanchez et al. [5], incoming knowledge spillovers were approximated by evaluating the importance of chosen communication sources. The chemical firms were asked to assign a level of importance to the following communication sources: (1) internal, (2) the market, (3) universities, (4) research institutes, and (5) other sources. First, a confirmatory factor analysis was carried out. Maximum likelihood estimates were used in this analysis. The average weights (AW) for the three models (the firms developed the innovation by themselves/with universities/with other firms) are shown in Table 2. To assess the models' internal consistency, Cronbach's alpha was computed (all values at least acceptable, >0.60).

Table 2. Results of confirmatory factor analysis for communication sources.

	Market	AW	Other	AW
Communication Sources	Suppliers	0.335	Conferences	0.662
	Customers	0.690	Scientific journals	0.871
	Competitors	0.700	Professional associations	0.564
	Consultants	0.345	Internet	0.566
Cronbach's alpha		0.603		0.755

In Table 3, we examined the mediation role of cooperation. In this model, communication sources X_i, i = 1,2, ... ,5 (internal, market, ... , other) and R&D expenditure X_i, i = 6 (internal) and i = 7 (government and EU) influence innovation activity Y_k (k = 1 for innovation by themselves, k = 2 with universities and k = 3 with other firms) directly as well as indirectly through mediator variables (cooperation) M_j causally located between them (M_1 for internal, M_2 for firm-universities, M_3 for firm-research institutes, and M_4 for firm-market), see Figure 4. The effects (direct and indirect) can be estimated as follows:

$$M_j = i_M + a_i \times X_i + e_M, \quad (1)$$

$$Y_k = i_Y + c_i \times X_i + b_j \times M_j + e_Y, \quad (2)$$

where c_i is the estimate of the direct effect of communication sources on sustainable business innovation activity (knowledge spillovers emerging in the process of knowledge acquisition), and $a_i \times b_j$ estimates the indirect effect (knowledge spillovers emerging in the process of cooperation).

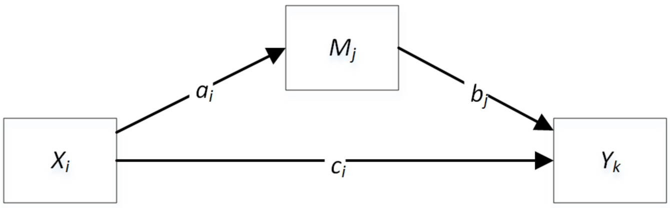

Figure 4. Structural equation model.

Knowledge spillover modeling was carried out by using the structural equation models in the LISREL 9.2 software package [64]. In addition to regression coefficients and fit indices of the structural equation model presented in this section, Appendix B shows the covariance matrix of the used variables. The condition number of this matrix was 7.427, indicating no multicollinearity in the data.

Internal communication creates knowledge spillovers only when there is innovation by a solitary firm or if they cooperate with other firms (Tables 3 and 4). However, it was not utilized in innovative cooperation with universities (the impact was lower). Communication and innovation development in cooperation with the market participant did not show any significant results. When the firms decided to develop innovation with the university or R&D institutes, the overall influence on innovation capacity remained positive. Table 3 shows the importance of communication with universities even when they introduce the innovation alone or in collaboration with other enterprises. Creating knowledge spillovers was, together with government scientific research organizations, the most important for innovation development in all models of innovation development. However, it was demonstrated that, although knowledge gained from universities, research institutes had the most significant indirect effect; firms did not continue with innovation development in cooperation with these organizations and instead used this knowledge for cooperation on sustainable business innovation with other firms (Table 4).

Table 3. The effects of knowledge spillovers on collaborative activities (standard errors).

	Collaboration			
Variable	**Internal**	**With Univ.**	**With Res. Inst.**	**With Market Partic.**
Communication				
Internal	0.0948 (0.0169) ***	0.0510 (0.0155) ***	0.0183 (0.0103) *	0.0733 (0.0209) ***
With univ.	0.0429 (0.0201) **	0.1290 (0.0183) ***	0.0162 (0.0122)	0.0282 (0.0247)
With res. inst.	0.0082 (0.0258)	0.0215 (0.0235)	0.0697 (0.0157) ***	−0.0064 (0.0317)
With market partic.	0.0053 (0.0218)	0.0132 (0.0199)	−0.0098 (0.0133)	0.0344 (0.0268)
Other	0.0121 (0.0179)	0.0066 (0.0164)	0.0096 (0.0109)	0.0264 (0.0221)
Internal R&D expend.	0.0346 (0.0155) **	0.0040 (0.0142)	−0.0226 (0.0095) **	−0.0234 (0.0191)
Gov. and EU support	0.0074 (0.0354) **	0.0785 (0.0323) **	0.0995 (0.0215) ***	0.1410 (0.0436) ***
Blocked-Error-R^2	0.1030 (0.0073)	0.2120 (0.0061)	0.1410 (0.0027)	0.0834 (0.0111)

Notes. Univ. = universities, res. inst. = research institutes, market partic. = market participants, expend. = expenditure, * significant at $p < 0.10$, ** significant at $p < 0.05$, *** significant at $p < 0.01$.

Abramovsky et al. [57] report that R&D expenditure and public support promote collaborative innovation. Therefore, we also examined the effects of: (1) expenditure on R&D (0—lower than the median 3300 thousand CZK, 1—greater than this median), and (2) government and European financial support.

A firm's expenditure on R&D positively influences its ability to cooperate on innovative activities. These are necessary when using knowledge acquired on the market, from universities, or from other sources. However, as shown in Table 3, internal R&D expenditure significantly promoted only internal collaboration. In contrast, government and EU support strongly contributed to firms' collaboration with universities, research institutes, and market participants.

Concerning direct effects between knowledge acquisition and innovation activities (Table 4), firm resources supported innovations generated by the firm alone or in cooperation with other enterprises. These resources were important when using knowledge acquired from research institutes (when developing innovation on its own) and knowledge acquired from universities (when developing innovation in cooperation with other firms). Government and EU resources then supported innovation created in collaboration with other firms or with universities. In the latter case, communication with other resources appeared to be critical.

Table 4. The effects of knowledge spillovers on innovation activities (standard errors).

	Sustainable Business Innovation Developed		
Variable	**By Themselves**	**With Univ.**	**With Enterpr.**
Communication			
Internal	0.0048 (0.0241)	0.0034 (0.0196)	−0.0997 (0.0217) ***
With univ.	0.0080 (0.0285)	−0.0119 (0.0232)	0.1480 (0.0257) ***
With res. inst.	0.0575 (0.0354) *	−0.0690 (0.0289) **	0.0934 (0.0320) ***
With market partic.	−0.0164 (0.0294)	0.0277 (0.0240)	0.0214 (0.0266)
Other	−0.0739 (0.0242) ***	0.0337 (0.0198) *	−0.0906 (0.0219) ***
Internal R&D expend.	0.0872 (0.0212) ***	−0.0241 (0.0173)	0.0617 (0.0191) ***
Gov. and EU support	−0.0662 (0.0494)	0.0747 (0.0403) *	0.0809 (0.0446) *
Collaboration			
Internal	0.3880 (0.0594) ***	0.0357 (0.0484)	−0.1520 (0.0536) ***
With univ.	−0.1320 (0.0650) **	−0.0458 (0.0530)	0.1560 (0.0586) ***
With res. inst.	−0.0034 (0.0975)	0.1620 (0.0795) **	0.1440 (0.0879)
With market partic.	−0.0003 (0.0482)	−0.0076 (0.0393)	−0.3100 (0.0435) ***
Blocked-Error-R^2	0.1390 (0.0133)	0.0399 (0.0089)	0.3050 (0.0108)

Notes. Univ. = universities, res. inst. = research institutes, enterpr. = other enterprises, * significant at $p < 0.10$, ** significant at $p < 0.05$, *** significant at $p < 0.01$.

Given the combined results of Tables 3 and 4, the ability to transform cooperation into real sustainable business innovation was supported by a firm's own expenditure. These resources were important not only for innovations created in-house but also for those created in cooperation with other firms. Government or EU support influenced the ability to transform cooperation into innovation only via collaboration with research institutes.

To determine model fit, we used fit indices of the proposed structural equation model as has been recommended in the literature [65]. Specifically, we employed (1) absolute fit indices (the maximum likelihood ratio chi-square test, RMSEA, and SRMR) to estimate how well the model fit the sample data and (2) incremental fit indices (CFI and NFI) to compare the chi-square value to a baseline model. For the absolute fit indices, a good model fit is achieved when there is an insignificant result for chi-square, RMSEA <0.08, and SRMR <0.08 [65]. Similarly, CFI >0.90, NFI >0.95 and PGFI >0.90 indicate a good fit. The results in Table 5 suggest a poor fit in terms of the chi-square test.

However, this measure assumes multivariate normality and performs poorly for large samples. Therefore, RMSEA and SRMR have recently been preferred to estimate the absolute fit. Our model is acceptable particularly in terms of SRMR. In addition, the model can also be deemed acceptable in terms of the incremental fit indices.

Table 5. Goodness of fit statistics.

Statistics	Value
Maximum Likelihood Ratio Chi-Square	27.546 [a]
Root Mean Square Error of Approximation (RMSEA)	0.125
Standardized Root Mean Square Residual (SRMR)	0.024
Comparative Fit Index (CFI)	0.969
Normed Fit Index (NFI)	0.968

Notes: [a] degrees of freedom = 3 and p = 0.000.

6. Discussion

It is possible to make the following conclusions about the research hypotheses that were established (see Figure 5 for Hypotheses H1–H3 and Figure 6 for Hypotheses H4 and H5). Hypothesis H1 was confirmed. The results confirm that chemical firms in the Czech Republic acquire knowledge from internal sources and cooperate with entrepreneurs in their industry. The study of Murovec and Prodan [66] carried out on the CIS data for Czech industries support our results. This reflects a large gap between research and the application sphere in the Czech Republic and CEE countries. This cooperation and these sources of internal knowledge lead to significantly higher internal knowledge spillover. The results confirm previous assumptions from other studies (West and Bogers [34] achieved the same results). These results confirm that cooperation in the chemical industry in a small open economy is essential for maintaining competitive advantage. In a business network, cooperation that is exclusively internal leads to an effective use of resources, the ability to conceal new knowledge, and no risk of time delay. However, it can be assumed that there are high costs for R&D as well as investments into new technologies and educated workers for this type of cooperation and knowledge (this is confirmed by the results obtained in Chesbrough and Crowther [43]). This reflects the small willingness of small and medium enterprises (SMEs) to invest in technology and the development of knowledge potential. Therefore, the increased costs are shared and can be optimized in business networks or within clusters. Other authors also confirm these results (for example, biotechnology firms in Spain by Ferreras-Méndez et al. [60]). Finally, the role of technology readiness and system readiness must be highlighted [67]. Specifically, sustainable innovations might fail on the market as a result of the insufficient maturity of a technology. Moreover, the connectivity of sustainable innovations with the system in its environment is increasingly crucial as opposed to the level of the technology [68].

Hypothesis H2 was confirmed only for (public and private) R&D institutes; it was rejected in the case of university cooperation. The results showed that cooperating universities contributed to the creation of innovation less frequently than R&D institutes. This finding is in line with Perez and Sánchez [69]. This may be attributable to different goals; the teaching of the students is the traditional mission of universities in CEE countries. The situation was different when chemical firms did not have enough resources for their own research or they wanted to collaborate with research institutes for some other reason (in CEE countries, this is typically a result of drawing subsidies from EU funds; see J. Stejskal et al. [6]). Direct enterprise–university communication was proved to be significantly effective. However, other effects leading to innovation creation were not significant. Conversely, communication and cooperation with research institutes resulted in knowledge spillover effects. When a chemical firm in the Czech Republic collaborated with research institutes, this resulted in significant positive effects for both parties. Similar results were observed in Czech high-tech industries [70]. The reason is that research organizations must effectively raise funds for their existence (more than 50% of their costs are not subsidized) and they must therefore be able to overcome obstacles and meet the firms' requirements (by being flexible and dynamic, not having a time delay risk, preparing legislative framework, being able to protect knowledge and patents, etc.).

As indicated above, the specific context of CEE countries suggests that the level of cooperation and innovation is still low. This is attributed to the lower quality of physical and human capital, knowledge institutions, weak global connectivity, and insufficient involvement in business and knowledge networks based on the triple helix concept [71]. The knowledge networks are particularly important for the generation of knowledge spillover effects which substantially differ in terms of stakeholders involved. Brem and Radziwon [72] refer to the following types of stakeholders and corresponding knowledge spillovers: (1) project initiators (higher quality of environment for project applications, higher credibility towards the industry, etc.), (2) universities (establishing long-term relationships with government and industry, gathering experience in developing sustainable innovation projects), (3) government (development towards sustainable goals), and (4) industry (sustainable innovations, knowledge transfer from universities, etc.).

In terms of CEE countries, it is apparent from the results that the ability to effectively support the creation and transfer of findings is very sensitive to "crowding out" factors such as bureaucracy, legal environment, requirements for sustainable development, culture (including "not invented here" culture [34]), and the performance or efficiency of a given organization's operation. This corroborates the findings of Dachs et al. [71], suggesting that cooperative behavior is dependent on national factors and deeply rooted in the underlying innovation system. These factors must be investigated further to better allocate public funds to prevent a crowding out effect, not only the crowding out of private investments by public ones but also of private efficiency by public inefficiency. This effect was also investigated and confirmed in P. McCann et al. [73].

The third option for knowledge acquisition is the market. A lack of high-quality knowledge on the market is a unique characteristic of the chemical industry in the Czech Republic. Currently, this leads to cooperation. The results show that innovative performance was affected negatively by knowledge obtained on the market. Therefore, hypothesis H3 was rejected. This finding supports the literature as to the role of cooperative relationships in knowledge generation [74]. In prior research, the question was raised as to the suitable types of cooperative relationships for relevant knowledge spillovers [74]. Here, we contribute to this discussion by concluding that, on the one hand, cooperative relationships with research institutes is effective for university–industry knowledge spillover effects. On the other hand, university–industry cooperative R&D activities are not a suitable medium for generating knowledge spillovers.

Hypothesis H4 was confirmed. We have proved that internal R&D expenditure led to an increased effect of internal knowledge spillovers on sustainable business innovation activity. Investment directed towards exclusively internal cooperation greatly enhanced the ability to create innovation. These results expand previous findings on the role of R&D expenditure in innovation activity [73]. In addition, our findings confirm that internal resources had greater importance for sustainable (eco-)innovations [75]. Internal spillover effects are certain to arise in this situation. This is a new insight for transition and emerging economies, indicating their path to competitiveness based initially on the presence internal knowledge spillovers. However, it can be anticipated that external knowledge spillovers will become stronger in future as a result of the development of knowledge institutions and networks. This finding corroborates those reported by Bouncken et al. [76].

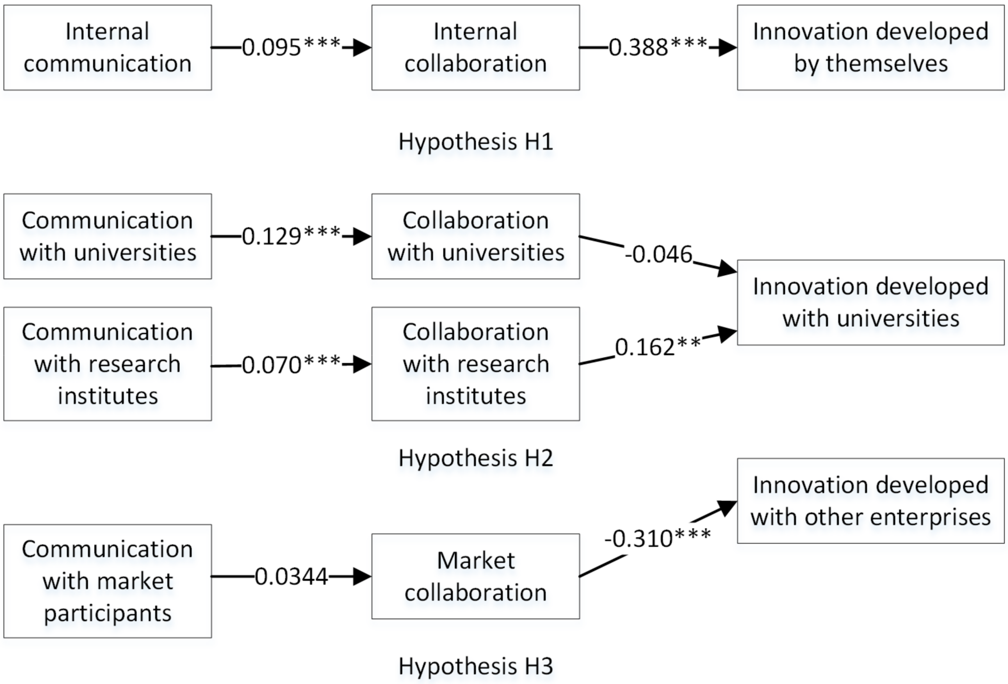

Figure 5. Results of the analyses for Hypotheses H1–H3.

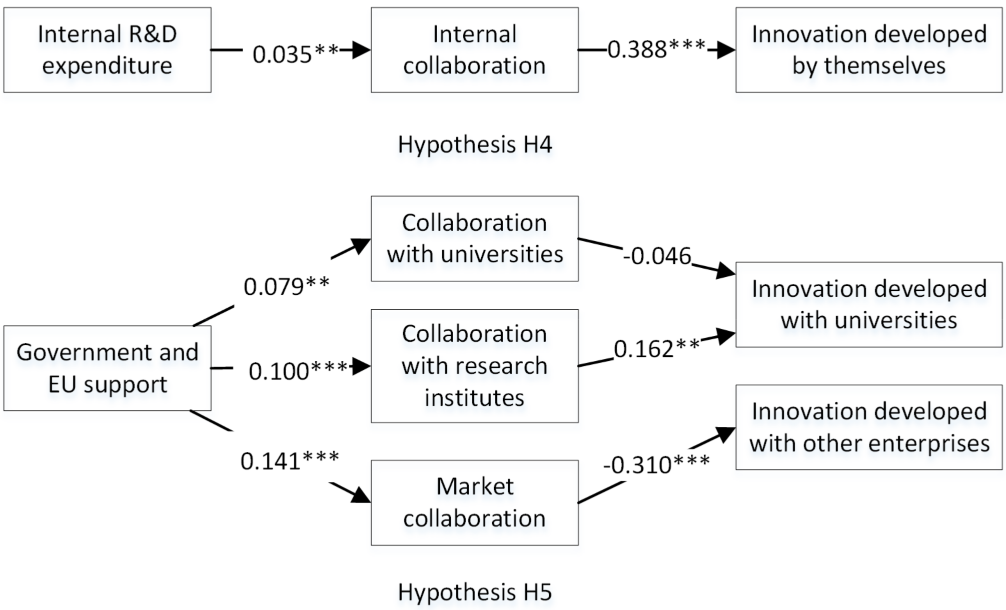

Figure 6. Results of the analyses for Hypotheses H4 and H5.

In several studies, government and EU support show varying efficiency (this varies between both countries and industries [70]). In fact, doubts remains as to the effectiveness of EU investment. Doubts are largely related to the legacy of economic specialization of the past, including physical resources and heavy industries [76–80]. Varying support efficiency was also observed in this study. Hypothesis H5 was confirmed only for cooperation with research institutes. The results showed a small positive effect for this type of support. This is a situation specific to CEE economies. A lack of flexibility, the actors' varying goals, legislative obstacles, and a long time delay contributed to these results. The results show that firms did develop cooperation with universities but positive effects for creating innovation did not result (specifically, the results were not significant). Our results support the findings from Vokoun [81]. We posit that firms often established cooperation with universities, conducted research with them, and eventually, the firms discontinued the cooperation. The firms most likely perceived obstacles and did not see any benefits for the discernible time period. However, the firms needed to make the responsible R&D investment yield a profit, so the firms continued to cooperate with other firms (for details about responsible R&D, see Gurzawska et al. [82]). The firms used all external knowledge; however, if other internal knowledge was added, this form of cooperation led to highly positive results concerning innovation creation. This specific fundamental outcome also supports the recent findings of Belderbos et al. [83], indicating that firm–university collaboration is more effective in the presence of high scientific absorptive capacity. Absorptive capacity generally helped firms turn broadly sourced external knowledge into sustainable (eco-)innovation [84]. This was obviously not the case for Czech chemical firms. Therefore, the availability of scientists at universities seemed to be important when establishing university collaboration from the perspective of the chemical industry's sectoral innovation system [85]. In this context, the concept of open science has recently been discussed [86].

7. Conclusions

The goal of this paper was to analyze the influence of knowledge as an input in production of sustainable business innovations arising from both individual chemical firms and other entities (universities and research institutes). It further analyzed the support of these firms and entities by national or European governments.

Chemical firms were selected for their innovative qualities, because they frequently have knowledge-intensive production, and typically cooperate with universities and research institutes. These firms show demonstrably higher firm expenditures on R&D. The markets in which they participate, including supra-national European and global markets, force them into such expenditure as a result of an effort to maintain market share via the creation of innovation.

On the basis of these results, it is possible to anticipate changes in managers' deliberation and decision-making, particularly when building partnerships specifically open to innovation. We have corroborated the findings of Laursen and Salter [48], suggesting that the firms' external focus may represent important business opportunities. Therefore, managers should steer firms towards participating in knowledge-intensive cooperative chains or networks (but they have to address the issue of industrial property rights and patents). Firm participation in industrial clusters also has positive benefits. For objectivity, it should be noted that too much firm openness can also cause problems especially when firms collaborate with competitors [87].

In conclusion, it is necessary to mention certain shortcomings of this study. Further empirical studies are necessary to determine whether the conclusions are applicable for different sectors of manufacturing industry as well as for other countries. Second, the influence of government and EU support was greatly simplified which is a result of the limitations of the CIS questionnaire's current form. The relatively small sample size and the chemical industry design are also potential limitations of the study. The various concepts of sustainable innovations (in the chemical industry we encounter a high degree of innovation patentability) is a specific barrier for application in practice. The difficult transferability of these results to Western countries is another limitation (the innovative models of the CEE countries and Western countries differ significantly). In the future, it would be advisable to focus on specific forms of public support and their influence on knowledge spillover effects, namely in relationship to managerial decision-making as to what type of cooperation to include as part of open innovation processes.

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Appendix A

Table A1. Variables Used in This Study.

Variable	Explanation	Measurement
Innovation activity	A new or significantly improved product or process developed: (a) by itself, (b) together with universities or (c) together with other enterprises	Dummy variable: Yes (1)/No (0)
Cooperation	Collaborative innovation activity with other firms or institutions	Dummy variable: Yes (1)/No (0)
Sources of knowledge: Internal Market Universities Research institutes Other sources	How important is the following information source to innovation activities: Within an enterprise or enterprise group Customers, suppliers, competitors and consultants Universities (higher education institutions) Research institutes (government or public) Conferences, trade fairs, journals and professional associations	 Ordinal variable: Not used (0) Low (1) Medium (2) High (3)
R&D expenditure	Total R&D expenditure—including in-house R&D, external R&D and external knowledge acquisition	Dummy variable: Greater than median value (1)/Smaller than median value (0)
Government and EU support	The enterprise received public financial support for innovation activities from the local, regional, central government or from the EU	Dummy variable: Yes (1)/No (0)

Appendix B

Table B1. Covariance Matrix.

	X_1	X_2	X_3	X_4	X_5	X_6	X_7	M_1	M_2	M_3	M_4	Y_1	Y_2	Y_3
X_1	0.839													
X_2	0.062	0.853												
X_3	0.008	0.284	0.465											
X_4	0.141	0.230	0.184	0.651										
X_5	0.135	0.368	0.208	0.353	0.988									
X_6	0.043	0.195	0.073	0.055	0.124	1.002								
X_7	0.044	0.141	0.076	0.060	0.081	0.076	0.211							
M_1	0.086	0.058	0.023	0.035	0.049	0.050	0.016	0.131						
M_2	0.057	0.137	0.057	0.057	0.077	0.040	0.040	0.071	0.124					
M_3	0.020	0.046	0.043	0.021	0.034	−0.005	0.028	0.020	0.034	0.051				
M_4	0.077	0.060	0.026	0.055	0.066	0.001	0.039	0.089	0.090	0.038	0.195			
Y_1	0.019	0.005	0.013	−0.017	−0.049	0.092	−0.008	0.043	0.010	0.001	0.017	0.243		
Y_2	0.015	−0.002	−0.014	0.020	0.031	−0.021	0.015	0.005	0.003	0.008	0.008	0.005	0.148	
Y_3	−0.102	0.142	0.084	0.017	−0.018	0.087	0.035	−0.031	0.005	0.006	−0.052	0.035	0.018	0.246

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