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DISTRIBUTION OF INDUSTRIAL RESEARCH & INNOVATION ACTIVITIES: AN APPLICATION OF TECHNOLOGY READINESS LEVELS

The Technology Readiness Levels (TRLs) approach is relevant to map the functional decomposition of companies' R&D value chains. TRLs matter for corporate location choices.

Knowing what distinct types of R&D&I activities (or TRLs) stay, go and come back in EU territories – and why – is central for policies supporting local industrial and innovation ecosystems and clusters, and the identification and integration into strategic value chains.

Fast-developing local strengths of Asian countries such as China, Japan and South Korea, in Automotive, and in Electronics and related fields are shaping companies' geographical decomposition of R&D&I activities.

While the EU has strong value chains in e.g. automotive (network of combustion engine) and pharma (highly skilled labour force and strong research institutions), corporate R&D&I investments are finding their way to novel applications in emerging technologies in Asia.

1. Introductory background

"*It is essential for Europe to support the competitive development of strategic value chains of the future*" (European Commission, 2018).[1] Understanding how companies organise and split up their research and innovation activities is essential to inform policies targeting the integration of local firms into (future) value chains and the attractiveness for knowledge-intensive projects and strategic activities in the EU.

This policy brief contributes to the latest developments in the analysis of R&D internationalisation and builds upon recent evidence from case studies undertaken within the European Commission's GLORIA project. [2] The main rationale relates to the need to understand the organisational and geographical patterns of corporate R&D and innovation dynamics. With this objective in mind, this note suggests avenues for a finer and better collection of evidence on industrial research and innovation (IRI) at the microeconomic level.

Policy objectives like attracting investments in innovative sectors with relevant growth potential and higher value added activities are doomed to remain an empty shell without a comprehensive understanding of global innovation networks or the functioning of corporate value chains. Territories benefit a lot from the ability to strategically position themselves therein in order to develop unique competitive advantages.[3] For example, even if two regions perform automobile-related R&D, the local firms may not be competent in the same segments of the value chains or activities. These activities may also not require the same mixes of skills and resources, giving rise to knowledge gaps for policymakers such as:

- *Which R&D and Innovation (R&D&I) activities - sub-functions/tasks - are actually performed in the territory?*
- *By which type of firms or organisations?*
- *What are the location and governance specific patterns?*

Such knowledge would facilitate the identification and attraction of territory-specific innovation activities and a better-fitted integration strategy for local companies and organisations. This is even more important for less developed regions, which are often not well connected at the EU and global levels and where critical mass is hardly achievable in most R&I domains. Furthermore, such knowledge and positioning constitute relevant inputs for both innovation policy and research in order to apprehend the differentiated effects of corporate strategies on territorial industrial and innovation dynamics and development.

[1] See also European Commission, 2017.

[2] See Box 1 on the GLORIA project

[3] See e.g. the positioning exercise of the Lombardy region in emerging and fast-growing technologies compared to a peers group in: Vezzani et al. (2017): "Smart Specialisation, seizing new industrial opportunities" JRC technical report.

To shed light on these issues, this brief first provides updated evidence on the functional decompositions of innovation activities for the sampled companies. Then, important reasons why policy and research should consider finer data collection on R&D&I processes and organisation at the firm level are put forward.

2. Literature snapshot

The studies related to the functional decomposition of corporate R&D and innovation activities can be analysed from three different angles: the micro-, meso- and macro-angle (Ramirez, 2018). Micro-studies address the firm-level relations between production and innovation, but mostly disregard the inter-firm collaboration and task decomposition, for which there is a different literature on modularity. These two however disregard the global internationalisation aspects that have taken place. Meso- or industry level works generally do not look the distinction between higher-level innovation and other GVC tasks, like production. Finally macro-level studies focus on aggregate-based studies by scholars of International Business (IB), geographers, as well as aggregate studies by international organisations such as OECD.

These different streams of research on corporate R&D internationalisation and economic geography have greatly improved our knowledge on the nature, scale and spatial dimensions of (international) innovation processes. Most systematic empirical analyses have exploited measures derived from Foreign Direct Investments (FDI), Mergers and Acquisitions (M&A), industrial properties (patents and patent citations, designs), R&D activities or expenditures and innovation collaborations (see for instance Iammarino and McCann 2013; Dachs et al 2014). However the differences between innovation and production networks or the potential offered by new manufacturing technologies or digitisation of organisational processes has been neglected. Recent qualitative studies and surveys show the increasingly intertwined nature of the global innovation and production networks taking advantage of new organisational modes and linked to the emergence of serious competition from e.g. Chinese companies.[4] Thus, more disaggregated data are needed to map corporate activities or functions that form the R&D and innovation chains and their importance and meaning in different industrial contexts.

Box 1. GLORIA project in brief

Since 2004, the European Commission's JRC and DG-RTD have been jointly implementing the Global Research & Innovation Analyses (GLORIA) project and its predecessors. These provide evidence for the EU innovation policy agenda based on a science-to-policy approach building upon the annual monitoring of the world's top R&D-investing firms. The projects' analyses rely on quantitative and qualitative research methods in order to address the following broad thematic issues:

- *the characteristics, drivers and impacts of corporate R&D and innovation investments and their industrial properties (patents, trademarks, industrial designs); this is complemented with specific sector analyses.*
- *the technological profiles of top R&D investors and the development of specific technologies, e.g. digital technologies, KETs, at the firm, industry and regional levels.*
- *the geographical dimension of R&D&I organisation: European and international location of corporate R&D&I activities, corporate global innovation networks and value-chains.*

The GLORIA project: http://iri.jrc.ec.europa.eu/home

EU Industrial R&D Investment Scoreboards: http://iri.jrc.ec.europa.eu/scoreboard.html

The EU Surveys on R&D Investment Business Trends: http://iri.jrc.ec.europa.eu/survey.html

3. Functional decompositions of corporate R&D and innovation activities

During 2017, case studies on 10 main global R&D investors were performed in order to better understand the functional fragmentation of R&D&I activities and the associated geographical distributions.[5] The companies include 10 top R&D-

[4] See e.g. Ramirez (2018), Cantwell (2017) and Rezk et al (2016).

[5] The case-studies and interviews were implemented in collaboration with Idea Consult/VDI, see "R&D and innovation activities in companies across Global Value Chains: Summary Report", Idea Consult/VDI, 2018

investing firms that operate in three EU strategic sectoral groups – pharmaceuticals, mobility (aerospace, automobiles) and ICT. In total, 60 structured interviews were performed on the basis of an ex ante agreed upon questionnaire (about 6 per company) and case-study information compiled from public sources. This note focuses on the outcomes of these interviews in relation to (1) the functional decomposition of their R&D&I processes (distinct activities) and (2) the patterns and rationales of locational dynamics at the activity level.

In order to analyse the fragmentation of R&D&I processes of these companies, the Technology Readiness Levels (TRLs) approach has been adopted (see Table 1 in the Annex). Indeed, TRLs allow mapping the steps in the different R&D&I processes (European Commission, 2011). In addition, companies were also asked to provide detailed information of their non-R&D innovation activities, also displayed in Table 1.

Why do TRLs matter? Insights from case studies

The right columns of Table 1 illustrate the decompositions for companies in the investigated sectors for which information on approximate and indicative budget shares and staff ranges were available. Results confirm that **TRLs enable a more detailed functional description of R&D activities, alongside non-R&D innovation activities of companies**. Furthermore, the table also confirms that companies actually grant different importance and budget to distinct TRLs; here it appears that activities within TRL 5 to 8 attract non negligible share of the R&D investments.

Heterogeneity appears also across companies in the same sector. For instance, one company from the automotive sector confirms relatively more sizeable investments granted to technological research (TRL 2-4) and product demonstration (TRL 5-8), while it reports relatively lower investments in fundamental research (TRL 1) and competitive manufacturing (TRL 9).[6] Differently, another automotive company highlights competitive manufacturing (TRL 9) as a key focus area for investments in its R&D value chain. In comparison, the pharma companies' interviews reveal that high proportions of R&D investments are dedicated to clinical trials/clinical studies (TRL 6-8) in order for instance to achieve drug approval for new medicines. Basic research (lower TRLs) increasingly takes place in CROs, universities, spin-offs and start-ups.

The interviews also confirm that the importance of non-R&D activities is sector- and sub-function specific. The interviews suggest that more investigation and evidence at the (within) firm level are needed to better understand whether specific non-R&D innovation activities matter more for the performances of firms in different industries. Although R&D expenditures are widely used, with caveats, and can be computed or proxy from company accounts (see EU Scoreboards of the GLORIA project), detailed information on non-R&D innovation activities are more difficult to obtain, especially given the international accounting standards (see Annex for some clarifications on the issue).

The EU R&D Survey[7] finds further support to these findings. The automotive sector invests the second largest proportion of their total R&D to applied research and technological development (43%, after Chemicals) and the smallest proportion to basic research (3%). On the other hand, ICT services and Pharma have the highest proportion of R&D dedicated to the market launch, where for the latter this is mainly related to the costs for clinical trials to get new drugs approved.

While these findings are hardly generalizable, they call upon a better account of and a finer mapping of R&D&I activities across strategic value chains.

4. An application of finer data: distribution of IRI activities in selected subsectors

Finer and more systematic data on the decomposition of firms' R&D and innovation processes is needed in order to better understand the locational decisions and behaviours of companies - *i.e. where and why they locate, co-locate or relocate their distinct R&D&I sub-activities/functions or tasks* – and their impact of these decisions on the local innovation systems in the EU.

Expectedly, R&D&I location dynamics feature techno-sectoral specificities. For instance in the automotive industry, (re)-location scope is limited by factors such as the high-capital intensity, the existence of strong

[6] Similar patterns came up for one aerospace company, where fundamental research activities (TRL 1) often take place through external collaborations with research organisations.

[7] Potters and Grassano (2018)

local networks and knowledge clusters as well as expert knowledge of local legal and economic frameworks. Besides, pharma companies confirm that external collaborations can take place all along the technology readiness levels, either with universities or contract research organisations[8] depending on the TRL stages.
The following lines further illustrate the TRLs-oriented (co)locational dynamics from different sectoral perspectives.

Pharmaceutical sector

The case study confirms that the location decision patterns depend on the type of R&D activities or TRLs in the pharmaceutical sector. Results suggested an increasing shift of activities at the later stages of the TRL towards Asia, for cost-, regulation- and market size considerations. More applied innovative activities (e.g. TRL 7-9) are often driven towards regions with large market demand (e.g. China), while early stage research activities (TRL 1-3) generally occur in traditionally more advanced regions (triad EU-Japan-US), that are endowed with highly-skilled labour force, strong research institutions and universities. Besides, co-location also exhibit some R&D sub-functional specificities, as some later-TRL activities (e.g. TRL 8 or phase 3 trials) need close connection to manufacturing facilities.

Automotive sector

In the Automotive sector, interviews suggest that offshoring patterns of R&D activities are mainly driven by proximity to customers, value chain considerations (original equipment manufacturers (OEMs) will be strongly co-located with their clients, such as the large car manufacturers), labour costs and the availability of technological capabilities and skills. Here also, a shift towards Asia (e.g. South Korea, Japan and China) is underlined, mainly due to the local strengths in electronics and related industries, such as *hybrid technology and battery development, battery and cell manufacturing for electric vehicles, electronics and battery manufacturing base, telematics, etc*., and their increasing importance in the automotive industries. On the other hand, the EU automotive industry is characterised by OEMs that are traditionally specialised in combustion engines that consist of many more and completely different parts than electrical motors, which leads to a mismatch in the (innovation and production) infrastructure and the company needs. For these companies, co-location seems to be more common between non-R&D innovation activities and production and the product characteristics certainly influence the organizational patterns of R&D&I activities in this sector.

Aerospace sector

Companies from the aerospace sector confirm the existence of rather geographically consolidated supply chains due to their complexity and to the presence of high technological and economic barriers. Locations with high technological capabilities are clearly preferred, while R&D outsourcing increases but remains limited and mainly at earlier stages (e.g. TRL 1-2) in order to access new technologies, capabilities or skills that are not available at home (home-based augmenting activities). In addition, collaborations at lower TRLs are also established with local or foreign highly-specialized universities, technological centres or start-ups; this is done also through the development of local ecosystems where large companies often act as incumbent technology leaders as or key participant.[9] Nevertheless, the core of R&D&I activities in this sector is rather seen in closer-to-market R&D stages and performed in-house. These higher TRL activities would often be co-located with manufacturing facilities or assembly lines for the purpose of costs-efficient testing and technological demonstration in real environments.

ICT sector

In the ICT sector, an important degree of R&D integration within the manufacturing process is expected. In the electronic & parts and systems sub-sector, front-end and back-end manufacturing activities may present different location patterns; the latter ones being more frequently located in Asia, while product design, technological research, research and development activities are rather concentrated in Europe and the US. In the software sub-sector, (foreign) innovation activities may require co-location with production.

5. Concluding remarks

This brief provides evidence based on firms level data and shows the importance of better collection and more research on the functional decomposition and geographical distribution of R&D&I activities. Such firm- and activity-levels evidence is needed because of the implications it raises for the (co)location and

[8] See also a previous brief based on an IRIMA workshop on the topic (Dosso et al 2017).

[9] See also the earlier JRC brief on the leading role of R&D investors in the dynamics of ecosystems (Dosso et al 2015)

relocation of companies' R&D&I and production in the EU.

The interviews have confirmed the need for Europe to further strengthen technology-specific capabilities of regions in relation to targeted strategic value chains. Yet, a balance between regional specialisation and regional adaptability has to be found in order to facilitate sustainable transitions towards the 4th Industrial era.

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Annex I

Table 1. Approximate shares of R&D investment at different Technology Readiness Levels (TRLs)

<table>
<tr><th>LEVELS</th><th>DEFINITIONS</th><th>Automotive companies</th><th>ICT companies</th><th>Pharma</th><th>Aerospace</th></tr>
<tr><td colspan="6">Approximate investment shares in R&D INNOVATION ACTIVITIES</td></tr>
<tr><td>TRL 1</td><td>Basic principles observed</td><td>5-10%</td><td>1-10%</td><td rowspan="2">10-15%</td><td>5-10%</td></tr>
<tr><td>TRL 2</td><td>Technology concept formulated</td><td rowspan="3">15-20%</td><td rowspan="3">30-45%</td><td rowspan="3">25-35%</td></tr>
<tr><td>TRL 3</td><td>Experimental proof of concept</td><td rowspan="3">15-20%</td></tr>
<tr><td>TRL 4</td><td>Technology validated in lab</td></tr>
<tr><td>TRL 5</td><td>Technology validated in relevant environment
(industrially relevant environment in the case of key enabling technologies)</td><td rowspan="4">15-50%</td><td rowspan="4">15-45%</td><td rowspan="4">60-70%</td></tr>
<tr><td>TRL 6</td><td>Technology demonstrated in relevant environment
(industrially relevant environment in the case of key enabling technologies)</td><td rowspan="3">45-55%</td></tr>
<tr><td>TRL 7</td><td>System prototype demonstration in operational environment</td></tr>
<tr><td>TRL 8</td><td>System complete and qualified</td></tr>
<tr><td>TRL 9</td><td>Actual system proven in operational environment (competitive manufacturing in the case of key enabling technologies)</td><td>~15%</td><td>5-20%</td><td>15-20%</td><td>5-10%</td></tr>
<tr><td colspan="6">Approximate investment shares in NON-R&D INNOVATION ACTIVITIES</td></tr>
<tr><td></td><td>Management of R&D&I projects</td><td>1-5%</td><td>5-10%</td><td rowspan="5">10%</td><td rowspan="5">10%</td></tr>
<tr><td></td><td>Staff training</td><td>1-5%</td><td>1-10%</td></tr>
<tr><td></td><td>Technology forecasting / foresight</td><td>1-5%</td><td>1-3%</td></tr>
<tr><td></td><td>Acquisition of machinery &equip.</td><td>5-10%</td><td>3-20%</td></tr>
<tr><td></td><td>Design to improve / adapt existing products & processes</td><td>5-30%</td><td>1-4%</td></tr>
</table>

Source: TRLs from own adaptations of the H2020 General Annexes (http://ec.europa.eu/research/participants/data/ref/h2020/other/wp/2016-2017/annexes/h2020-wp1617-annex-ga_en.pdf), R&D investment shares estimated on IDEA Consult/VDI internal report on a sample of large European firms with the methodology described in the text from desk research, case studies and interviews.