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The relationship between technology forecasting and R&D

Doctoral (PhD) Thesis - Thesis booklet

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TABLE OF CONTENTS

1. RELEVANCE OF THE RESEARCH AND THE STRUCTURE OF THE DISSERTATION

The rapid development of new technologies and the constantly changing industrial environment are fundamentally transforming the way companies operate. Technological advancements not only play a supporting role, but are a strategic factor in determining the direction of competitiveness. At the same time, the spread of digitalisation, artificial intelligence and automation, for example, requires new capabilities from organisations - in particular in the areas of technological competence, anticipation and adaptability.

In parallel, but at different levels, there is also a growing focus on knowledge and competence management. As Nonaka and Takeuchi (1995) pointed, knowledge has moved from being a resource to being 'the resource'. Harnessing knowledge and proactively adapting to future changes has become the key to the competitive survival and development of organisations (Keczer, 2016), a process that structured technology management can support. The systematic application of technology foresight and technology management has, in many cases, not yet been fully integrated into business practices, particularly among small and medium-sized enterprises (Demeter et al., 2020). However, maintaining competitiveness requires forward-looking thinking, a strategic approach to new technologies, and continuous competence development (Teece, 2018; Davenport & Prusak, 1998). In contrast, when examining large enterprises, the systematic application of these practices is more prevalent (Demeter et al., 2020; Roper et al., 2008). The literature often examines technology foresight and (knowledge, competence, and technology) management practices separately. However, an integrated analysis of these areas at both the organisational and system levels would provide a deeper understanding of corporate operations and better inform strategic decision-making.

This thesis offers a new approach by focusing on priority topics such as forecasting, technological choices, and the links between competence management, based on corporate responses. The thesis is divided into four main sections. The first part presents the literature review, framing the concepts of technology, technology foresight, technology management, and technological competence, and discussing theoretical approaches to corporate decision-making and organisational characteristics. Furthermore, it lays the foundation for the logical structure of the research model and the key aspects of the study. In the second part, the empirical phase of the research begins, presenting quantitative analyses structured around the four research questions. For each research question, I formulate associated hypotheses. The relationships

between corporate responses are examined using statistical and network analysis methods. The third part summarises the responses and theses formulated during the research and also addresses the evaluation of the hypotheses' fulfilment. In addition, it briefly presents the limitations of the research. In the fourth part, I formulate practical recommendations, complemented by an outline of a management-focused framework model, and outline directions for further research.

2. THE AIM OF THE RESEARCH AND THE RESEARCHER'S MOTIVATION

The choice of research topic is based on personal interest and professional commitment. I hold a degree in Mechatronics Engineering. I further developed my knowledge through postgraduate studies in Engineering Management (MSc) and Research and Innovation Management. Throughout my studies and professional experience, I have consistently been surrounded by environments where technological solutions and their practical application were part of everyday life. I work in an organisation where knowledge-based services are a priority, and where technological development and its utilisation are not only opportunities but necessities. This environment and perspective have led me to focus my research not merely on the presence of technology, but also on its organisational role, its systematic approach, and its value-creating potential. I have always been interested in how a technological solution can be transformed into real, commercially valuable added value, and what conditions must be met at the levels of organisational goals, forecasting practices, and competences to achieve this.

The primary aim of my research is to explore, based on a unique interview-based dataset collected from 102 Hungarian enterprises, the relationships between organisational characteristics, technological features, technology forecasting and management practices, and the development of technological competences. The objective of the study is not merely to examine these domains in isolation, but to approach them through a systemic and logical perspective — that is, to investigate how companies' forecasting activities and main objectives, methods, organisational and technological characteristics, and management practices are interconnected.

The analysis does not approach the examination of technological decisions and management methods in isolation but adopts a systemic perspective. In the course of my research, I explore how the following elements are interconnected (1. Table):

- the organisational characteristics of companies and their R&D activities (Objective C1),
- the relationship between the technological portfolio, forecasting objectives, and organisational background (Objective C2),
- the logic behind corporate objectives, forecasting directions, and technological decisions (Objective C3),
- the interrelation between the methodological approach to technology forecasting, technology management, and the development of technological competences (Objective C4).

1. Table: Research plan summary

Area	**Organisational and Technological Characteristics**	**Characteristics of the technological portfolio, Organisational characteristics and Technological objectives**	**Corporate objectives, Technological decisions, and Forecasting objectives, Methodological approach to Technology forecasting**	**Technology Management, Technological competence, and Knowledge and Competence management**
Research objectives	**Research objective C1**: The analysis seeks to identify the relationship between companies' organisational characteristics and their R&D activities. As R&D activities are a key element of technological innovation, the study examines which organisational factors are associated with R&D engagement among the surveyed companies.	**Research objective C2:** The analysis examines the existing technological characteristics and the presence of new or disruptive technologies. The aim is to obtain an overview of the technologies that characterise the database. Subsequently, the study explores which organisational characteristics are associated with the identified forecasting objectives.	**Research objective C3:** The aim is to explore the relationship between the main objectives and forecasting goals of the surveyed companies, as well as their decision-making criteria related to technologies. Subsequently, the methodological approach to technology forecasting is examined. The objective is to demonstrate how the methodological rigour of technology forecasting is related to information-gathering practices and the application of specific forecasting methods.	**C4 research objective:** The aim is to explore the relationship between technology forecasting and technology management. Subsequently, the objective is to demonstrate the "emphasis" placed on technological competence in relation to the different levels of methodological rigour in forecasting and technology management. Finally, the study seeks to identify the connections between various organisational backgrounds and the application of systematic management practices.
Research questions	**K1**	**K2**	**K3**	**K4**
Hypotheses	**H1**	**H2a, H2b**	**H3, H4**	**H5**

The aim of the research is not only to identify generalisable relationships but also to detect patterns that can help to better understand how technological practices are structured within Hungarian enterprises. The objectives also include capturing both the technical and human dimensions of technological competence, as well as mapping the extent to which companies' management processes demonstrate systematic functioning. The results of the research are intended to provide practical feedback to companies while also laying the groundwork for future investigations, such as exploring the relationship between technological decision-making and corporate performance.

3. LITERATURE REVIEW AND CONCEPTUAL FRAMEWORK

" A vision without systems thinking ends up painting lovely pictures of the future without a deep understanding of the forces that must be mastered to move from here to there "

- Peter M. Senge (The Fifth Discipline)

3.1 Conceptual introduction to technology, forecasting, and technology management

Technology

The technological profile and innovation capabilities of companies are significantly shaped by their organizational characteristics. The literature examines these relationships from various perspectives, particularly focusing on the linkages between ownership structure, company size, sectoral and regional factors, as well as corporate governance and R&D activities.

According to the findings of Teng and Yi (2017), ownership background determines both the extent and the direction of investments in R&D. Enterprises owned by the central state typically show higher R&D intensity, while locally or privately owned companies tend to exhibit more restrained technological activity. In the case of family businesses, Sciascia et al. (2014) highlight the impact of overlapping ownership and managerial roles, which influences risk-taking and long-term innovation decisions. Cohen and Klepper (1996) argue that large corporations are more successful in incremental innovations, whereas SMEs can be more competitive in radical renewals due to their greater adaptability. Piskóti et al. (2012) note that small firms are often hindered in their innovation efforts by financial and knowledge constraints. Based on Pavitt's (1984) technological trajectory theory, industries relate differently to innovation: knowledge-intensive sectors focus on creating technology, while traditional industries concentrate on its adaptation. In the domestic context, Zedtwitz and Gassmann (2002) suggest that the internationalization of R&D can follow multiple models

(e.g., home-based or market-driven). International presence enhances innovation performance, particularly when companies are able to combine foreign and domestic knowledge sources. Hungarian studies by Györi and Czakó (2019) and Kiss and Kazai Ónodi (2023) confirm that ownership structure and company size influence R&D intensity but do not determine it in isolation. For Hungarian SMEs, internal resources, a skilled workforce, and collaborative partners are especially important factors.

Based on the reviewed literature, organizational factors—such as ownership structure, company size, governance, and sectoral classification—fundamentally determine firms' technological activities. In my own research, several of these variables were included; in addition to the nature and scope of R&D, ownership background, workforce size, and sectoral classification were also incorporated into the analyses.

Management decisions

Understanding the relationship between technological decision-making and forecasting objectives is essential for shaping corporate strategy. Therefore, this study examines organizational characteristics—such as ownership structure, company size, and sources of revenue—to explore how these factors influence a firm's forward-looking mindset and how they are reflected in the formulation of forecasting goals.

The forecasting process is one of the key tools for adapting to changes in the external environment, and it has become increasingly important in today's rapidly evolving technological context. Haleem et al. (2019) emphasize that effective technology forecasting partly depends on how well firms can align their forecasting objectives with their overall organizational goals. According to Sciascia et al. (2014), family-owned businesses often adopt a longer-term perspective, which supports the formulation of forward-looking objectives—although they may also exhibit a more risk-averse attitude. At the same time, foreign or multinational ownership tends to foster more structured forecasting practices (Demeter et al., 2020).

Company size is another decisive factor: while large enterprises have the resources to maintain dedicated forecasting activities, SMEs often define their technological outlook in an informal, ad-hoc manner (Piskóti et al., 2012; Cohen & Klepper, 1996). Consequently, their forecasting objectives are likely to be less formalized.

A firm's source of revenue—whether it primarily generates income from product sales or service provision—can also influence how forecasting objectives are formulated. For product-based firms, technological changes often have a direct impact on manufacturing, development, or product portfolio renewal, which necessitates a proactive, forward-thinking approach (Porter & Heppelmann, 2015). In the case of service-oriented firms, technological innovation not only supports operations but can also become a key source of competitive advantage, requiring dedicated technological development or integration (Baines et al., 2009; Neely, 2008). The advance of digitalization further blurs these boundaries, as many traditionally product-based companies now integrate service elements—such as data-driven services—into their operations, leading to the emergence of new types of forecasting objectives (Teece, 2018b; Parida et al., 2014).

The characteristics of a company's technological portfolio and the presence of new or emerging technologies are often associated with the emergence of forecasting objectives. Schwab (2016) and Rotolo et al. (2015) highlight that the uncertainties surrounding novel technologies require foresight and the exploration of future application areas. When a technology is closely tied to the firm's "core business," forward-looking thinking and corresponding information-gathering and decision-making practices are more common (Teece, 2018).

Overall, the literature confirms that forecasting objectives do not exist in isolation within firms; rather, they are closely linked to organizational characteristics and the underlying technological base. The presence—and quality—of forecasting objectives can serve as an indicator of a company's strategic preparedness and should therefore be examined from multiple perspectives.

Technology management, technological capabilities and performance

Systematic technology forecasting and technology management, along with the deliberate development of technological capabilities, can serve as supportive activities for sustaining a company's competitiveness. These factors should not be regarded as isolated areas; rather, they represent mutually reinforcing and interrelated organisational capabilities that build upon one another.

The literature emphasises that technology forecasting becomes truly effective when it is not applied in isolation but is integrated with technology management (Porter et al., 2004; Walk, 2012). A systematic forecasting practice — when aligned with strategic goals — supports the deliberate shaping of technology portfolios, the mapping of development trajectories and

preparedness for anticipated challenges (Bright, 1970; Cho, 2013). Methodological diversity — for example, combining qualitative and quantitative approaches — enhances the robustness of decision-making and provides a foundation for defining competence development directions as well (Martino, 1993; Hyndman & Athanasopoulos, 2018).

Methodical technology management presupposes the coordinated governance of internal knowledge elements and competencies, the inclusion of internal and external knowledge sources, and coherence with strategic objectives (Cetindamar et al., 2009; Nonaka & Takeuchi, 1995).

Technological competence refers to the organisational capabilities that enable firms to identify, adapt and exploit new technologies successfully. This competence encompasses both technical dimensions (use of equipment and infrastructure) and human dimensions (knowledge, skills and learning capabilities) (Giget, 1997; Prahalad & Hamel, 1990). Leonard-Barton (1992) and Grant (1996) also highlight that the management, development and institutionalisation of technological competence are crucial for sustaining competitiveness.

The ownership structure of companies can influence their technological development trajectories, as well as the degree of structure in their competence and knowledge management practices. Fitza and Tihanyi (2017) and Anderson and Reeb (2003) point out that in family-owned businesses, the prioritisation of long-term value preservation and conservative risk management often leads to distinctive approaches to knowledge and technology management. In contrast, foreign-owned firms tend to adopt more formalised practices aligned with international standards.

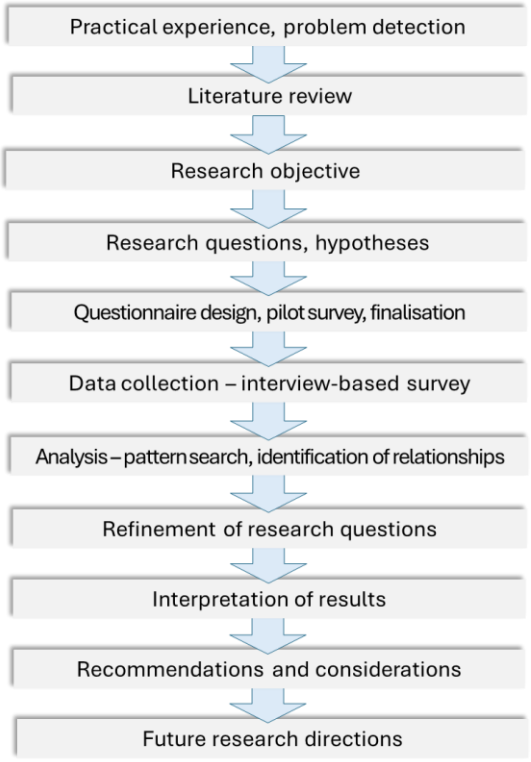
In my research, particular attention was therefore given to exploring the relationship between ownership background and the practices of knowledge and competence management. The aim was to reveal under what organisational conditions a higher level of methodological rigor is more likely to emerge.

4. RESEARCH METHODOLOGY

4.1 Research process

The aim of the research was not only to examine certain factors in isolation, but also to explore their interrelationships within a complex, data-driven framework. The logical structure of the

study is organised into four main units (K1–K4), which gradually guide the reader from the organisational foundations to the domain of technological competence.



1. Figure Research process

4.2 Research methods

The methodology applied in the research followed a data-driven approach, aiming to explore the relationships between the examined corporate characteristics, technological practices, and management methods using various quantitative techniques. The responses collected through the structured interviews were converted into binary data (1, 0) to ensure a uniform and manageable data structure for association and statistical analyses. The research procedures combined multiple analytical methods, allowing the interpretation of the data from different perspectives and enhancing the reliability of the results. The sequential and combined application of various techniques, following the principle of triangulation, ensured the complexity of the interpretation and the validity of the conclusions.

The following analytical procedures were applied in the research:

- Frequency analysis: Served as the primary tool for mapping the questionnaire data. Based on descriptive statistics, the most common responses and distribution patterns could be identified.

- Residual (standardised residual) Analysis: Examined cell-level deviations between expected and observed frequencies in contingency tables under the assumption of independence. This method was useful for identifying positive or negative associations.
- Fisher's exact test: Applied in cases of small sample sizes and rare response pairs. Interpretations were conducted at both the full table and individual response pair levels, identifying stronger associations based on the 1-p value, where values closer to 1 indicated stronger relationships.
- Cosine similarity analysis: Measured the similarity of binary response patterns, enabling the identification of frequently co-occurring patterns. Values were interpreted on a scale from 0 to 1, where 0 indicated complete dissimilarity and 1 indicated complete similarity.
- Association Rule Mining (ARM): ARM analysis was conducted both within individual questions and across combinations of responses from two questions. The analysis considered support, confidence, and lift indicators. The rules were refined according to the sample characteristics, and the filtered rules were then analysed.
- Network Analysis (VOSviewer): Used to visually explore the relationships between variables and to form clusters. VOSviewer supported the clarity and interpretability of complex association patterns and facilitated clustering.
- Combined Frequency Table: Applied during multivariate analyses, primarily for the detailed examination of response pair occurrences. This approach also supported the preparation of ARM and network analyses.
- Triangulation: Played a key role in the research. By comparing the results of the residual analysis, Fisher's exact test, cosine similarity analysis, and alternative methods (ARM, VOSviewer), the interpreted associations were strengthened. If a particular method could not be applied, I aimed to interpret the results based on at least three other methods.
- Based on the companies' technological forecasting and management systematicity as well as their technological competence, I performed a hierarchical cluster analysis using the Ward method in Python. The dendrogram supported the selection of the optimal number of clusters, and the analysis effectively revealed patterns and differences among the corporate profiles.

The evaluation of technological competence was carried out by introducing two quantitative indicators:

- Knowledge intensity: Represented the level of workforce expertise, based on the gross average wage.
- Technical Intensity: Measured the ratio of the value of technological assets to revenue, indicating the significance of technological infrastructure.

For the K4 research question, I also conducted a rank correlation analysis (Kendall's Tau) to evaluate the methodological rigour of the companies.

In the analyses, I did not focus solely on statistically significant relationships but also sought connections that are practically relevant and interpretable. The applied approach aligns with the recommendations of Amrhein et al. (2019), McShane et al. (2019), Lee (2010), Pedhazur and Schmelkin (1991), Yates (1984), and Little (1989), who emphasize the primacy of practical significance and methodological consistency over rigid reliance on significance levels. Accordingly, when a given method did not reach the significance threshold, I re-examined the relationship using other methods and also explored potential connections at the level of variable pairs.

5. RESEARCH RESULTS AND THESES

This chapter presents the main findings of the dissertation. Based on the results, the research questions were addressed, and the corresponding theses were formulated accordingly. The theses were derived directly from the empirical findings, taking into account both the relationships between variables and the patterns identified at the level of response pairs.

5.1 Q1 research question, H1 hypothesis and T1 thesis

The first research question focuses on exploring the relationships between various organisational characteristics and technological features. Organisational characteristics include, for example, company size and ownership background, while technological features are represented by R&D activities.

Q1 Is there a relationship between companies' ownership background, size, sectoral (TEÁOR) classification, and the type of R&D activities carried out (basic research, applied research, experimental development), as well as their focus (new product, new technology, process innovation)?

For this research question, I formulated a hypothesis assuming that there are relationships between certain organisational and technological characteristics, and that, for example, the background of a company is associated with its R&D activities.

H1 I assume that the ownership structure, size, and scope of activity of companies are related to the type and focus of the R&D activities they carry out. It is expected that larger and multinational companies are more likely to engage in higher-level development activities, potentially including basic research. In contrast, smaller enterprises and domestically owned family businesses are more likely to focus on applied research or smaller-scale development activities, or they may not engage in formal R&D activities at all.

In Section 5.1 of the dissertation, I examined the relationships using multiple variables, which are discussed in detail there. The key findings are briefly presented here through summary tables. The summary tables contain the values that were significant according to the applied methods. In several cases, three methods jointly confirmed specific response pairs, while in other cases, only two methods highlighted them — in these cases, the results are used as guidelines. For the response pairs presented, the values indicate a sufficiently strong relationship.

Based on the results, general relationships were identified between the examined organisational characteristics and R&D activities, in addition to the specific response pair associations. The findings indicate that a company's ownership structure and size are related to the type and focus of its R&D activities. Multinational companies tend to engage in the development of new technologies, while firms with a majority Hungarian corporate ownership are more likely to conduct basic research. In contrast, family-owned businesses typically focus on smaller-scale process innovations or often do not pursue R&D activities at all. Regarding company size, larger firms are more frequently associated with basic research, whereas small enterprises are predominantly engaged in experimental development. Among micro-enterprises, the absence of R&D is common, which aligns with the assumptions previously outlined.

The hypothesis has been confirmed.

T1 A strong relationship can be identified between the ownership background of the companies and the focus of their R&D activities, as well as between the type of R&D activities and the size and industry of the company. Based on the residual values, Fisher's exact tests, and cosine similarity results, the closest correlations can be traced back to the following characteristics:

- "Hungarian majority private" enterprises are more frequently involved in new product development, while "Foreign family" enterprises tend to focus more on process innovation. Among "Multinational" companies, there is a stronger emphasis on developing new technologies.
- Organizations operating in the "Scientific research and development" sector (NACE 72) show a high proportion of basic and applied research, whereas in certain industries (e.g., "Manufacture of electrical equipment", NACE 27), less significant R&D activities are carried out.
- Experimental development is more common in small enterprises, and "None" (i.e., companies without R&D activities) is more prevalent in micro-enterprises.

5.2 Q2 research question, H2 hypothesis and T2 thesis

The research question further explores the analysis of organizational and technological interconnections and introduces the topic of forecasting objectives, which can be compared to technological goals.

Q2 What internal connections can be identified in the technological portfolios of businesses (examining both applied and emerging technologies)? How are the various organizational characteristics (ownership structure, company size, revenue sources, and core technology) related to the forecasting objectives of the businesses?

I have formulated the following hypothesis, which is primarily linked to the part of the research question concerning the technological portfolio.

H2a In the technological portfolios of businesses, traditional technologies dominate, and the use of emerging or disruptive technologies is less common.

The detailed analysis is presented in Section 6.1 of the dissertation, specifically in Subsections 6.1.1 and 6.1.2. For the portfolio analysis, I applied VOSViewer and ARM analysis to uncover significant patterns.

Among the technologies used by the companies, traditional technologies are more dominant; however, in several cases, new technologies also appear. Additionally, emerging and disruptive technologies tend to occur in various combinations with each other.

The hypothesis has been confirmed.

T2a Characteristics of the technological portfolio
In the majority of businesses, traditional technologies (e.g., CNC, machining, CAD/CAM, welding) continue to dominate the portfolio. Although emerging, disruptive solutions (e.g., artificial intelligence, autonomous systems) are present, their prevalence and central role are still limited..

To further answer the question, I have formulated an additional hypothesis that deepens the relationship between organizational and technological characteristics, while also examining the forecasting aspect.

H2b I hypothesize that the forecasting objectives of companies are correlated with their organizational characteristics, and a particularly strong relationship exists in the case of the company's revenue sources and core technology.

A detailed investigation is presented in Section 6.1, with the subsections 6.1.3 to 6.1.6 providing in-depth analyses. The applied statistical tests — residual analysis, Fisher's exact test, and cosine similarity — demonstrate that the sources of revenue and core technologies are indeed associated with the companies' forecasting objectives. Although not all categories show a clear and statistically significant relationship, in most cases at least two different statistical approaches indicate a meaningful connection or pattern. This triangulation strengthens the validity of the findings and provides a more reliable basis for interpreting the links between companies' technological bases and their strategic forecasting aims.

Therefore, my hypothesis has been confirmed.

T2b There is a particularly weak relationship between the ownership structure of the companies and their forecasting objectives. However, a strong correlation exists between the companies' core technology and their revenue sources and their forecasting objectives. The closest positive correlations can be traced back to the following characteristics:

- Among companies using "Manufacturing technology" (core technology), the "Manufacturing parameters analysis" objective is particularly prominent. Additionally, these companies show a willingness to analyse business performance and technological opportunities as forecasting objectives.
- For "Product-based" businesses, the correlation with "Manufacturing parameters analysis" is significant. Moreover, a possible connection with business forecasting objectives is also suggested. In the case of "Know-how" type businesses, a relationship exists with the objective of "Analysing new technological opportunities".

5.3 Q3 research question, H3-H4 hypotheses and T3 thesis

The research question aims to explore how companies apply forecasting in practice, and at what level of methodological rigor — whether it involves analysing technological opportunities, monitoring megatrends, or relying on more rudimentary, ad hoc approaches. The main focus of the study is to uncover the relationships between information-gathering practices, the forecasting techniques used, and the varying degrees of systematicity that characterise different firms.

Q3 What relationships can be observed between companies' development goals, their forecasting objectives, and the criteria they consider in technological decision-making? Additionally, how are the use (or lack) of forecasting methods, the ways of gathering technological information, and the specific forecasting techniques applied interrelated?

For this research question, two separate hypotheses were formulated. The first hypothesis examines the relationships between the companies' stated development goals, their forecasting objectives, and the motivations behind their technological decisions.

H3 There is a detectable relationship between companies' general goals, forecasting objectives, and the criteria considered in technological decision-making. It is assumed that companies aiming for profit maximization are more likely to use business performance analysis and focus on strategic market advantage in their technological choices, whereas companies prioritizing modernization may favour analysing production parameters and aligning technologies with company size.

detailed and comprehensive analysis starts from Section 7.1 of the dissertation, where I examine companies' goals, forecasting objectives, and technological decision criteria. The main results are presented in the tables below.

The findings indicate that there are some minor, but likely non-random, differences between companies' strategic goals and their technological decision considerations (e.g., "Asset preservation" and "Selecting technology suitable for company size"; "Modernization" and "Strategic market advantage"; "Development of new capabilities" and "Impact on other existing technologies"). Overall, some values fall short of the expected strength, yet they still highlight potential directions. The relationships were examined using at least two different methods, and additional patterns were explored with Association Rule Mining (ARM) analysis. In general, no strong overall relationship can be demonstrated between company goals,

forecasting objectives, and technological decision criteria, but certain specific pairings do show significant connections.

The hypothesis has been partially confirmed: There is no general strong relationship, but specific correlations support the hypothesis.

T3 There is a weak statistical relationship between corporate goals, forecasting objectives, and technological decision criteria. However, some specific connections that are practically relevant can be identified, among which the strongest positive associations are as follows:

- Business performance analysis" as a forecasting objective appears strongly linked to several corporate goals, with the most pronounced association observed with the "Profit" goal.
- Companies aiming for "Asset preservation" typically consider "Analysis of production parameters" an important forecasting objective, and for them, "Identifying technology appropriate to company size" also emerges as a relevant decision criterion. Additionally, there is a strong link between "Analysis of production parameters" and "Identifying technology appropriate to company size.
- The "Modernization" corporate goal frequently coincides with the "Strategic market advantage" decision criterion. This decision criterion, in turn, shows one of its strongest connections with the "Analysis of technological opportunities" forecasting objective.

Overall, these results suggest that companies' decisions are shaped by nuanced interconnections between specific goals, forecasting objectives, and decision-making aspects.

The hypothesis formulated for the second part of the research question is as follows. On the one hand, it focuses on examining the methodology of forecasting, analysing the relationship between forecasting objectives and the systematic approach to forecasting. On the other hand, it explores how the modes of information gathering and the application of various techniques are linked to different levels of methodological sophistication.

H4 I hypothesise that there is a significant relationship between forecasting objectives and the use of forecasting methods. Furthermore, I expect that the application of forecasting is closely linked to firms' information-gathering practices and the forecasting techniques they employ. Companies that actively rely on targeted information sources, such as workshops or professional conferences, are more likely to adopt structured forecasting approaches, including megatrend analysis or technology roadmapping.

A detailed examination is presented in Chapter 7.3 of the dissertation, specifically in Subsections 7.3.1–7.3.3.

Overall, a relationship can be observed between the forecasting-related variables and the corresponding answer pairs. Furthermore, it can be concluded that companies apply these methods at different levels of maturity, which provides flexibility in decision-making. Based on the analyses, the hypothesis has been largely confirmed.

T4 The systematic implementation of forecasting activities in companies is closely linked to the specific forecasting techniques they adopt. In addition, there is a moderate association between the level of forecasting objectives and the degree of systematic practice. However, the relationship between how technological information is gathered and the use of forecasting methods is relatively weak. The strongest positive relationships can be attributed to the following patterns:

- Companies that prioritise the "Analysis of technological opportunities" as a forecasting objective tend to apply technological forecasting methods in a more systematic way.
- Companies that "Use technological forecasting" typically rely on specific forecasting techniques ("Megatrend analysis", "Technology roadmapping", "Patent research", "Scientific research trend analysis").
- Among companies that collect information through "Workshops, conferences", "Professional journals", or "Professional networks", a more conscious and systematic forecasting approach is more likely to be found.

Companies apply forecasting methods at varying levels of systematic practice.

5.4 Q4 research question, H5 hypothesis and T5 thesis

The final research question focuses on the relationship between technological forecasting and technology management practices. In addition, it examines the link between these variables and technological competence. Since technological competence comprises both human and technical elements, the question also addresses how these dimensions are reflected in the operations of companies. Finally, it investigates the relationship between ownership structure and the degree of systematic management processes. Accordingly, the research question can be formulated as follows:

Q4 What is the relationship between the use of technological forecasting and the level of systematic technology management? How are these linked to technological competence? Furthermore, what connections can be identified between ownership structure and the practices of knowledge and competence management?

For this research question, I formulated two hypotheses. The first focuses on the systematic nature of forecasting and technology management, and also includes assumptions related to technological competence.

H5a There is a positive relationship between the level of systematic technological forecasting and the systematic nature of technology management among the companies studied. Furthermore, a consistent pattern of association can be identified between forecasting–technology management and the human–technical competence background.

The detailed analysis relating to this is presented in Section 8.1 of the dissertation, particularly in Subsection 8.1.1. In the following, I present the research findings.

First, I examined the relationship between the level of systematic technological forecasting (TF) and the level of systematic technology management (TM). Since the variables were ordinal scale values, I used rank correlation alongside Fisher's exact test.

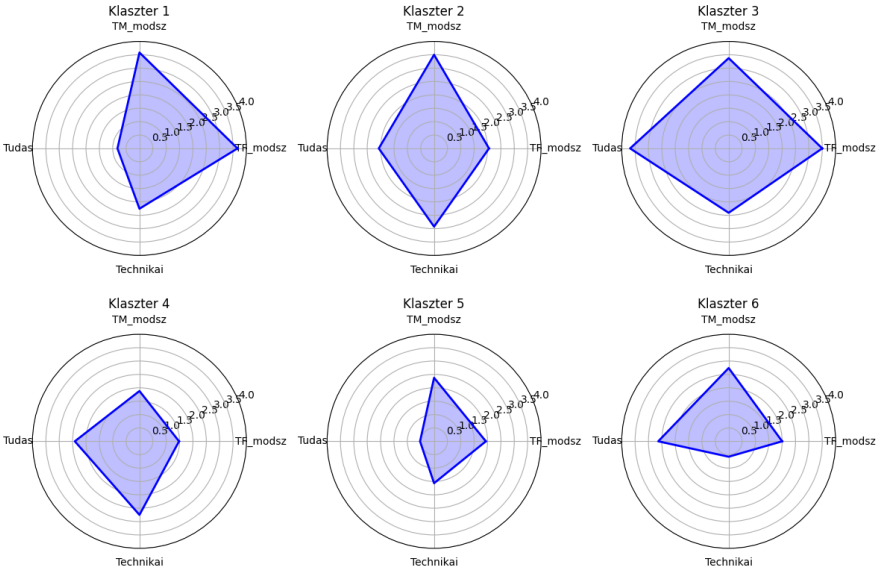
The highest TF category ("4: applied") included 12 companies, of which 7 also reached the highest level of TM systematic practice. This indicates that companies successfully applying technological forecasting tend to integrate it more systematically into their operations.

Subsequently, for the analysis of technological competence, I introduced two variables derived from companies' publicly available business data: technological/technical intensity and human/knowledge intensity. In addition to Fisher's exact test, rank correlation was also applied. According to the results, only seven companies fell into the most favourable category — that is, the range where both human and technological intensity reached the highest level (interval 1–25). Relative to the full sample (n = 102), this represents a rather low proportion, indicating that few companies are able to achieve outstanding performance in both dimensions simultaneously. At the same time, the middle intensity ranges (26–50 and 51–75) show a more balanced distribution.

Overall, the results indicate that the rankings of human and technological intensity do not move in parallel. Given that technological competence has two main components or perspectives, it is evident that some companies achieve success primarily through a strong technical foundation, others through human capital, or through some combination of the two. Using the two components of technological competence alongside technological forecasting and management, I visualised the companies' 'technological effort'. This visualisation allowed me to represent connections that cannot be clearly arranged into value pairs but still follow discernible patterns.

The different levels of intensity can be interpreted along an ‘L-shaped’ distribution, and I manually positioned the companies according to their scores. For example, if a company shows high human but low technological intensity, it suggests that its performance relies mainly on intellectual capital and likely involves lower investment in new technologies (though this can vary by industry). This provided a form of categorisation, which I further validated by conducting a cluster analysis.

To determine the clusters, I used a dendrogram, which indicated the possibility of examining both three and six clusters. The three-cluster solution did not provide sufficient depth to reveal multiple corporate profiles; therefore, I proceeded with the six-cluster analysis. For the visual representation of the corporate profiles, I applied a radar plot, and the evaluation was supplemented with additional cluster characteristics such as company size, ownership structure, and industry classification (NACE code). Based on these, the resulting radar plots illustrated the distinct profiles identified. (2. Figure).



2. Figure The radar plots of the six clusters

Overall, by visualising the dominance patterns of human versus technical intensity—reflecting the companies’ ‘technological efforts’—I was able to map the characteristic patterns within the sample. The main conclusions were derived from the six-cluster analysis. As a result, I demonstrated both systematic and less systematic patterns in the areas of forecasting and technology management, thus confirming the hypothesis.

T5a There is a positive and very strong relationship between the systematic nature of technological forecasting and technology management. The variables introduced in the research—human intensity and technical intensity—characterise technological competence; however, only a weak correlation can be observed between these two factors. This suggests that enhancing a company's technological competence does not necessarily require the simultaneous strengthening of both dimensions. Based on the cluster analysis, six distinct company profiles were identified, some of which reveal characteristic patterns worth highlighting:

- Only a small proportion of the surveyed companies (~8%) demonstrate high levels of systematic practice and high human competence, combined with a moderate level of technical capacity. These are typically medium-sized and large firms with predominantly foreign ownership.
- Another segment of the companies (~12%) shows high TF–TM systematic practice, but low human competence and a moderate level of technical capacity. These are generally medium-sized and large firms, mostly with foreign family ownership.
- A further smaller group (~16%) operates with medium levels of technology management but low levels of forecasting systematic practice, and displays very low human and technical intensity. These characteristics typically describe Hungarian-owned, traditional, low-resource companies of mixed size categories.
- The majority of the surveyed companies (~25%) exhibit low levels of systematic practice but medium levels of knowledge and technical intensity; these are of mixed size and predominantly domestic ownership.

The results of the cluster analysis highlight that acknowledging the differences between the level of advancement in corporate technology forecasting and management and the intensity of technological competence is essential for designing tailored development programmes and targeted support interventions. Accordingly, the research can serve as a concrete compass for aligning corporate practice with policy instruments.

All this indicates that strengthening systematic approaches and technological competence are complementary yet not necessarily co-evolving factors; therefore, development strategies should be designed in a targeted manner and tailored to the specific profile of each company.

In relation to the research question, the second hypothesis addresses assumptions concerning the ownership background of the companies and the level of systematicity embedded in their management processes.

H5b There is a strong relationship between the ownership structure and the systematicity of knowledge and competence management among the enterprises surveyed. I assume that foreign-owned enterprises are more systematic in their approaches than those with Hungarian ownership.

A detailed analysis is presented in Subchapter 8.1.2 of the dissertation. For this investigation, I used the same methods as in the previous analyses — residual analysis, Fisher's exact test, and cosine similarity.

There is a strong relationship between the ownership structure and the systematicity of competence management, and several answer pairs also support this finding. The influence of ownership also shows strong associations in relation to the systematicity of knowledge management.

Overall, the results confirm that the ownership background of the enterprises has a clear impact on the systematic nature of the established management processes — particularly in the fields of competence and knowledge management.

T5b The ownership background significantly influences the systematicity of knowledge and competence management. The strongest positive relationships can be traced back to the following characteristics:

- Among enterprises with a Hungarian background (family-owned or majority private domestic ownership), there is a strong link with competence management practices focused mainly on training-level activities.
- In the case of foreign-owned enterprises, especially those with a family ownership structure, there is a strong relationship with more advanced and systematic competence management.
- Hungarian-owned enterprises typically do not operate systematic knowledge management processes.
- Hungarian-owned enterprises typically do not operate systematic knowledge management processes.

6. CONCLUSIONS AND RECOMMENDATIONS

My research was conducted within the framework of the Cooperative Doctoral Programme (KDP-2020), so the results are expected to provide useful feedback to the companies surveyed. The correlations revealed by statistical and network analysis cannot be generalised to all firms, but the logical relationships and patterns that emerge in the sample provide an opportunity to formulate certain guidelines.

In this research, I did not only examine the individual effects of each area of analysis but also explored how they are interlinked. A novel aspect of the dissertation lies in the investigation of human and technical competencies in relation to the systematicity of technological forecasting

and technology management. This enabled a visual representation of enterprises' technological efforts. The findings contribute to a better understanding for domestic companies to assess and interpret the interconnections within their own technological operations and to make more informed decisions regarding forecasting and management processes. Furthermore, the research provides a foundation for future longitudinal studies, pointing towards the examination of business performance and outlining a direction for the development of a conceptual framework.

In my dissertation, I formulate recommendations based on the research findings, which I briefly summarise below:

- The research contributes to a deeper understanding of corporate practices in technological forecasting and technology management, with a particular focus on the characteristics of technology-oriented micro, small, medium-sized, and large enterprises in Hungary
- For policymakers, the findings highlight that support for technological and competence development should not be handled uniformly. Enterprises with different ownership structures and sizes show varying levels of maturity, thus more targeted, segment-specific forms of support are advisable — especially for micro-enterprises and family-owned businesses.
- For corporate professionals, the study provides guidance for a more conscious approach to technological forecasting and decision-making. It supports the identification of forecasting approaches aligned with strategic objectives, as well as the targeted development of human and technical competence elements. Introducing formalised forecasting practices can also contribute to more structured corporate processes.
- For researchers, the methodological contribution lies in the combination of qualitative and quantitative approaches and the application of methodological triangulation. This supports the interpretation of data sets with small sample sizes and complex patterns, and provides a basis for further studies, such as modelling forecasting maturity levels or competence pairs. It also demonstrates a flexible approach to significance levels.
- Finally, the results of the research lay the groundwork for more targeted industry-academia collaborations, especially in addressing competency gaps related to technological foresight and strategic planning.

I developed additional recommendations based on the informal responses given during the interviews, specifically regarding topics that were not mentioned but were considered important by the company representatives.

The main directions of these responses are as follows:

- The significance of organisational culture and human factors
- Education, vocational training, and knowledge demand
- Technological approaches and decision-making uncertainties

Based on the feedback received, I formulated the following supplementary considerations:

- The human side of technological implementation is harder to plan but cannot be overlooked. It may be beneficial to take into account training and organisational factors during the planning phase.
- Strengthening vocational training and practical knowledge transfer would be important where specific competencies are required to operate new technologies.
- Existing corporate culture, internal working methods, and established processes determine how well a company can adapt to technological changes. Therefore, creating this foundation is crucial in the design and maintenance of processes.
- Collaborations between education and industry can help align expectations and knowledge transfer, particularly in areas where there is a lack of or specific expertise. These partnerships could support the initiation of training programs.

In connection with the topic of the dissertation, I also outlined a framework model, the development of which could be further explored in the next research phase and potentially tested and refined within the context of a case study. The framework model represents a systems-level approach, which would forecast the technological impact from a management perspective. It would map technological information from the external environment – to strategic implications; from driving forces – to market implications; and from management aspects – to value creation implications. A detailed presentation of the framework model can be found in Section 10.3 of the dissertation.

Finally, I propose a study of business performance and present the results achieved so far. Unlike the previous cross-sectional approach, this research direction would be longitudinal. The aim would be to examine the relationships between data collected during the interviews – such as the number of new technologies implemented, the methodological rigor of technology

forecasting, and the methodological rigor of technology management – and the business performance of the companies. Business performance will be assessed using publicly available financial data of the companies, with a focus on revenue and profitability. For this purpose, business data from the past ten years will also be collected. The presentation of the results so far can be found in Section 10.4 of the dissertation.

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