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Prisoners of Time – Is the Abolition of Daylight Saving Time a Rational Decision?

Péter Szikora

Obuda University, Keleti Károly Faculty of Business and Management
szikora.peter@kgk.uni-obuda.hu

Abstract: The aim of the research was to explore public attitudes towards the annual clock change, with particular regard to subjective experience, physiological symptoms, decision consistency and the role of chronotype. The study was based on an online questionnaire completed by 2,323 respondents. Of the respondents, 64.6% preferred summer time and 35.4% preferred winter time. According to the results, the disruptive experience of clock changes did not show a significant correlation with the choice of permanent time. In contrast, the presence of symptoms had a significant, albeit slight, influence on preferences: those who experienced symptoms were more likely to support summer time. Decision consistency was associated with experiencing clock change as disruptive, suggesting that personal involvement may contribute to the development of more stable attitudes. A statistically significant but negligible relationship was found between chronotype and support for the abolition of clock changes, which requires cautious interpretation. Overall, the results suggest that preferences are not determined by a single factor, but by a combination of several small and partly independent effects. The study highlights that decisions related to daylight saving time are based on complex, multi-layered judgements and require further research to gain a deeper understanding of the interaction between psychological, physiological and social factors.

Keywords: clock adjustment, time preferences, symptoms and affect, decision consistency, chronotype

1 Introduction

The practice of annual clock changes has been part of European time regulation for more than four decades, but in recent years it has become increasingly prominent in scientific, social and political discourse. Although the original reasons for its introduction were primarily related to energy efficiency considerations, both the advantages and possible disadvantages are currently being re-evaluated, and the sustainability of the current system remains a matter of debate. According to research on biological rhythms, daylight saving time is not merely a technical intervention in the time schedule, but a social time shift

that can affect circadian functioning and the adaptation process (Roenneberg et al., 2019). Authors describing the phenomenon of social jet lag point out that the discrepancy between biological and social time can persist, and that adaptation occurs to varying degrees in different individuals (Roenneberg, Wirz-Justice et al., 2019).

Some clinical and physiological studies focus on the health consequences of clock changes. Several studies suggest that the risk of certain cardiovascular events, sleep disorders and road accidents may increase after the spring changeover (Manfredini et al., 2018; Zhang et al., 2020). Although the extent of these correlations is not consistent across all studies, the official position of the American Academy of Sleep Medicine supports the elimination of seasonal time changes (Rishi et al., 2020), and the latest recommendations emphasise the health benefits of permanent standard time (Rishi et al., 2024). However, other authors urge caution, emphasising that some of the concerns raised in public discourse may be exaggerated and that the scientific evidence requires nuanced interpretation (Blume & Schabus, 2020). Longitudinal studies suggest that changes in sleep quality are not always permanent and that adaptation can vary significantly between individuals (Owen et al., 2022). However, public opinion on this issue is not based solely on biological factors. Data analyses examining public preferences show considerable variability in whether the population supports maintaining or abolishing seasonal time changes (Coogan et al., 2022). Preferences may be influenced by lifestyle characteristics, daily schedules, sleeping habits and the socio-economic environment. Recent experimental results suggest that communication framing can also shape attitudes, for example, health-focused messages can increase support for abolishing the system (Weger et al., 2025). All this suggests that the assessment of daylight saving time is a multidimensional phenomenon underpinned by complex psychosocial processes.

In addition to scientific and social discourse, substantive regulatory processes are also underway at the European Union level. According to official documents of the European Council, in 2018 the Commission proposed to abolish seasonal time changes after the majority of respondents to the consultation supported the change (Council of the European Union, 2018). Although the regulatory decision is still pending, the update of the time frame system remains on the agenda and the negotiation process cannot yet be considered closed. As implementation requires consultation with Member States, it has become particularly important to examine public support for the change. Based on the above, it is becoming increasingly necessary to examine the factors that determine public attitudes towards clock changes. Although much of the international literature focuses on health and circadian consequences, there is much less empirical data available on the psychological and decision-making mechanisms that influence preferences. There is a

particular lack of research examining decision consistency and the relationship between personal involvement (e.g. the appearance of symptoms) and choices. The present study aims to partially fill this gap by conducting a large-scale questionnaire survey and analysing three key factors: (1) the role of subjective experience, (2) the effect of physiological involvement, and (3) the consistency of decision-making patterns.

2 Sample presentation

Data collection took place in November 2025 using an online questionnaire. Respondents were recruited using non-probability snowball sampling, in which respondents forwarded the link to the questionnaire to their own network of contacts. As a result of the sampling procedure, the results cannot be considered representative of the entire population, but they are suitable for exploratory analysis of attitudes and correlations related to clock change. A total of 2,323 valid responses were included in the analysis, and no missing values needed to be handled during data processing. The gender distribution was as follows: 43.5% male (N = 1010) and 56.5% female (N = 1313). The age of the respondents ranged from 18 to 84, but the age distribution was heavily skewed towards young adults, with more than half of the respondents aged between 18 and 25. The distribution by place of residence indicated a predominance of urbanised environments: 34.2% were residents of the capital, 17.4% of large cities, 23.7% of towns, while 8.2% were residents of small towns and 16.5% of villages or rural areas. The sample can be considered heterogeneous from a demographic point of view, but its spatial distribution is characterised by urbanisation bias.

27.6% of participants had a higher education degree, while 72.4% did not. In terms of employment status, 68.3% of respondents were employed, while 31.7% were not in employment. The study status was almost equal: 50.3% are currently studying, while 49.7% are not pursuing studies. Based on the question regarding chronotype, 57.7% of the sample were night owls, while 42.3% were morning types. Regarding experiences with clock changes, 58.4% of respondents reported disruptive effects, while 41.6% did not experience any negative consequences. Symptoms (such as sleep disturbance or fatigue) were reported by 32.8%, while 67.2% did not experience such effects. Based on preferences for the final time, 64.6% of the sample would choose summer time, while 35.4% would choose the current winter time. The large sample size and diverse demographic composition of the sample allow for statistical analysis of preferences and background factors related to clock changes, but due to the non-probability sampling, the results cannot be generalised to the entire population.

3 Methodology

For the analysis, 2,323 valid responses were processed using IBM SPSS Statistics 25 software. The questionnaire contained closed-ended items that measured attitudes, preferences and decision consistency regarding clock changes. Among the variables included in the analysis, the choice of the final time was recorded by the TZ1 variable (1 = winter time, 2 = summer time), while support for the abolition of clock changes was recorded by the O3 variable (0 = no, 1 = yes). Subjective involvement was measured by two dichotomous items: O1 (experiencing clock change as disruptive) and O2 (experiencing symptoms). Classification according to daily biorhythm was recorded by the variable D1 (1 = morning type, 2 = night type).

Decision consistency was determined based on four preference items (TZ1–TZ4); accordingly, a binary indicator was created, which received a value of 1 if all responses were the same and 0 if any discrepancy appeared. During data analysis, we used cross-tabulation and Pearson's chi-square test to examine the relationships between category variables, with a uniform significance level of $p < .05$; when interpreting the results, we took into account the cautionary considerations arising from multiple testing. For 2×2 tables, we supplemented the asymptotic values with Fisher's exact test. The analyses were performed on the entire sample, without weighting or filtering, and we took the significance levels into account when interpreting the relationships between variables.

During the study, we tested the following hypotheses:

• *H1: The disruptive experience of clock change (O1) is related to the final time preference (TZ1); respondents who report a disruptive effect prefer daylight saving time to a greater extent.*

• *H2: The presence of symptoms associated with clock changes (O2) significantly influences preference (TZ1); the proportion of those who experience symptoms is higher among those who choose summer time.*

• *H3: Decision consistency (rational variable) is related to the subjective assessment of clock changes; a higher proportion of consistent respondents are found among those who report disruptive effects.*

• *H4: Chronotype (D1) is related to support for the abolition of clock changes (O3); night-type respondents are more likely to support abolition than morning-type respondents.*

The methodological approach is suitable for the statistical analysis of preferences and background factors related to clock changes, but due to the nature of the sampling procedure, the results are exploratory and cannot be generalised to the entire population.

4 Results

As a first step in the study, we analysed the distribution of preferences regarding the final time. 64.6% of respondents (N = 1501) preferred summer time, while 35.4% (N = 822) preferred winter time. This ratio shows a clear shift in the sample towards the time system associated with longer evenings. The distribution of choices suggests that attitudes towards time systems are not uniform and that preferences are shaped by the combined effect of several factors.

We then examined whether the disruptive experience of clock change (O1) is related to time calculation preference (TZ1). The correlation was not statistically significant, $\chi^2(1) = 2.29$, $p = .130$, and the effect size was negligible (Cramer's V = .03). Although the proportion of summer time preference was higher among those who reported a disruptive experience (65.9%), the difference did not reach the level of significance. This suggests that the unpleasant subjective experience alone does not explain the final time preference decision.

In contrast, the presence of symptoms associated with clock adjustment (O2) showed a significant correlation with preference, $\chi^2(1) = 11.06$, $p = .001$, Cramer's V = .07. 69.3% of those experiencing symptoms chose daylight saving time, compared to 62.3% of symptom-free respondents. Although the effect was small, the result suggests that physiological stress may play a role in shaping time-related choices. Based on risk indicators, those reporting symptoms were 1.37 times more likely to prefer daylight saving time (95% CI: 1.14–1.65)

O2 – symptoms	Winter time (%)	Summer time (%)	N
No (0)	37.7	62.3	1560
Yes (1)	30.7	69.3	763
Total	35.4	64.6	2323

Table 1
Relationship between symptoms (O2) and time preference (TZ1)
Note: $\chi^2(1) = 11.06$, $p = .001$, Cramer's V = .07.

Decision stability was examined based on the rationality index, according to which 11.2% of respondents (N = 261) gave completely consistent answers in the four preference items, while 88.8% (N = 2062) differed on at least one point. This suggests that most decisions related to time calculation are not rigid or fixed, but are adjusted to situational considerations. There was no significant correlation between rationality and the final time calculation choice, $\chi^2(1) = 0.051$, $p = .821$, Cramer's $V \approx .00$, indicating that decision consistency alone does not influence the direction of choice. At the same time, there was a significant but small correlation between rationality and the experience of clock

change as disruptive, $\chi^2(1) = 5.46$, $p = .019$, Cramer's $V = .05$. 12.5% of those who reported experiencing disruption gave completely consistent answers, while among those who did not experience disruption, this proportion was 9.4%. Although the difference is not significant, the result suggests that subjective involvement may contribute to the formation of more stable preferences.

O1 – disturbance	**Not rational (%)**	**Rational (%)**	**N**
No (0)	90.6	9.4	966
Yes (1)	87.5	12.5	1357
Total	88.8	11.2	2323

Table 2

Rationality (rational) and the disruptive experience of clock change (O1)

Note: $\chi^2(1) = 5.46$, $p = .019$, Cramer's $V = .05$.

The relationship between chronotype (D1) and support for abolishing daylight saving time (O3) was statistically significant, $\chi^2(1) = 5.52$, $p = .019$, but the effect size was negligible (Cramer's $V = .05$). Sixty-nine point six per cent of night-type respondents supported the abolition, compared to 74.0 per cent of morning-type respondents, indicating that although there is a difference between the proportions, the degree of correlation cannot be considered substantial. The results show that, of the factors examined, only the symptoms associated with clock adjustment showed a significant and consistent relationship with final time preferences, with a small effect size. The role of disturbance, decision consistency and chronotype was limited, suggesting that the formation of time-related attitudes may be due to the combined effect of several factors not examined in the analysis.

5 Evaluation of hypotheses

The study examined four hypotheses to explore the relationships between preferences, subjective experiences, and decision-making patterns related to clock changes. First, we analysed whether the disruptive experience of clock changes influences final time preference choices (H1). The cross-tabulation analysis did not indicate a statistically significant relationship between the O1 and TZ1 variables ($\chi^2(1) = 2.29$, $p = 0.130$), meaning that the disruptive experience alone did not explain the preference for winter or summer time. Although the proportion of summer time preferences was higher among those who reported a disruptive effect, this difference did not reach the level of significance, so the hypothesis cannot be confirmed.

The second hypothesis (H2) assumed that the presence of symptoms related to clock adjustment is associated with preference. The results showed a significant correlation ($\chi^2(1) = 11.06$, $p = 0.001$), with a higher proportion of respondents experiencing symptoms choosing summer time (69.3%) than those who did not report symptoms (64.8%). Although the difference is moderate, it is statistically significant, suggesting that physiological or sleep rhythm stress may play a role in shaping preferences. Accordingly, hypothesis H2 was confirmed.

The third hypothesis (H3) examined the relationship between decision consistency and subjective assessment of clock changes. The correlation between the rationality indicator and the O1 variable was significant ($\chi^2(1) = 5.46$, $p = 0.019$), i.e. a higher proportion of completely consistent respondents (12.5%) were found among those who reported a disruptive effect than among those who did not experience daylight saving time as disruptive (9.4%). Although the difference in proportions is not large, the result suggests that personal involvement may increase the stability of decision-making patterns. The hypothesis can therefore also be considered valid.

The fourth hypothesis (H4) indicated a statistically significant correlation between chronotype and support for the abolition of clock changes, $\chi^2(1) = 5.52$, $p = .019$, but the effect size was negligible (Cramer's $V = .05$), so the practical significance of the relationship is limited. The finding would probably not remain significant under multiple testing, so the result requires cautious interpretation.

The results show that preferences regarding permanent time change are not influenced by all subjective experiences in the same way: while the experience of disturbance did not prove to be a determining factor, the occurrence of symptoms proved to be a statistically significant factor. In addition, experiencing clock change as a problem was associated with decision consistency, which may suggest that being affected may influence not only the direction of preferences but also their coherence. Chronotype showed a statistically significant but negligible correlation with support for the abolition of daylight saving time, and therefore has limited significance as a background variable.

Hypothesis	Brief summary	Result	Decision
H1	O1 – disturbance is related to TZ1 preference	$\chi^2(1) = 2.29$, $p = .130$, Cramer's V = .03	**Rejected**
H2	O2 – symptoms influence TZ1 choice	$\chi^2(1) = 11.06$, $p = .001$, Cramer's V = .07	**Accepted**
H3	Rationality is related to O1 judgement	$\chi^2(1) = 5.46$, $p = .019$, Cramer's V = .05	**Accepted** *(with a small effect)*
H4	D1 – chronotype is related to support for abolishing O3	$\chi^2(1) = 5.52$, $p = .019$, Cramer's V = .05	Accepted **with caution***

Table 3
Summary table of hypotheses

Conclusions

Based on the results of the study, it can be concluded that social attitudes towards clock changes are not uniform and are organised along several partially independent factors. Although preferences for the final time system showed a marked shift towards summer time, there was no single determining variable behind this. More than two-thirds of the sample supported maintaining the time schedule associated with longer evenings, suggesting that for the population surveyed, coordinating leisure time, daily life and social routines may be a more important consideration than aligning with the biological circadian rhythm.

One important finding of the results is that subjective experiences of the disruptive effects of clock changes did not in themselves influence preferences. Although the proportion of respondents reporting disruptive effects was high, this factor did not show a statistically significant correlation with the final choice of time. This suggests that an unpleasant or negative experience alone is not sufficient to make respondents support a systemic change. Another possible explanation for this phenomenon is that the experience of disruption is temporary, recurring annually, and cannot necessarily be considered an intervention of such magnitude that it would result in a lasting change in attitude.

In contrast, symptoms associated with clock changes, such as fatigue, sleep disturbance, or decreased concentration, played a demonstrable role in shaping preferences. The proportion of people reporting symptoms was significantly higher among those who preferred summer time, suggesting that physiological stress may increase openness to change. The difference is moderate but consistent, suggesting that biological adjustment difficulties have a greater influence on the social perception of clock changes than purely convenience considerations.

An examination of decision-making patterns revealed further correlations. Based on the rationality index, the majority of respondents did not give entirely consistent answers to the items related to different time preferences, suggesting that attitudes towards clock changes cannot be considered a stable, coherent set of attitudes. However, the inconsistency of preferences cannot automatically be interpreted as irrationality: it can be assumed that respondents applied different decision-making criteria in different contexts (e.g. winter daylight or evening leisure time), which is an adaptive rather than a logically inconsistent decision-making strategy.

At the same time, rationality showed a significant correlation with experiencing clock change as disruptive, suggesting that personal involvement may contribute to the coherence of decision-making patterns. Those who experienced clock change as a problem gave more consistent answers than those who did not find it disruptive. This phenomenon can be interpreted as the perception of a problem triggering a cognitive reinforcement effect, leading to more stable attitude formation. In contrast, those for whom the clock change is not a burden have less structured preferences and are likely to have lower personal relevance.

The chronotype analysis showed a statistically significant but negligible correlation with support for the abolition of daylight saving time, suggesting that the practical significance of the relationship is limited. Based on this, it can be concluded that different biorhythms alone do not shape attitudes towards maintaining or abolishing the system. This finding suggests that the social interpretation of the issue is more complex than can be attributed to biological preferences; psychosocial, lifestyle and cultural factors are likely to play a role in shaping attitudes.

Overall, the results of the study suggest that decisions about clock changes are not organised along a single dimension, but arise from the interaction of several partially interrelated factors. The strongest influencing factor in the formation of preferences was the experience of symptoms, while the experience of disturbance and biological chronotype did not prove to be decisive. The high degree of variability in decisions draws attention to the fact that the issue of clock changes cannot yet be considered a closed or uniformly interpreted phenomenon at the societal level. Based on the above, the results provide a starting point for further research exploring deeper connections, particularly in areas that also take into account psychological coping processes, circadian adaptation, and social communication patterns.

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From Play to Pressure: How Stress Fuels Online Gaming Addiction

Péter Szikora

Obuda University, Keleti Károly Faculty of Business and Management
szikora.peter@kgk.uni-obuda.hu

Fruzsina Hoványi-Nagy

Obuda University, Keleti Károly Faculty of Business and Management
nagy.fruzsina@kgk.uni-obuda.hu

Ádám Béla Horváth

Obuda University, Keleti Károly Faculty of Business and Management
horvath.adam@kgk.uni-obuda.hu

Abstract: This study examines how stress shapes individuals' relationships with digital games and their risk of developing problematic or addictive gaming patterns. Building on the assumption that heightened stress and low emotional resilience increase the likelihood that gaming becomes a primary means of escape, the research focuses on both behavioral and psychological factors. Data are collected through a self-report questionnaire assessing gaming frequency and motives, perceived stress, coping strategies, and indicators of psychological well-being. Correlation and multiple regression analyses are used to explore associations between stress levels, gaming habits, and self-reported addictive behaviors. The study also examines whether different stress management styles moderate the link between stress and problematic gaming. The expected findings are intended to deepen understanding of how stress and coping processes contribute to digital gaming addiction and to inform prevention efforts that strengthen emotional resilience and promote healthier, non-avoidant forms of stress management in digitally immersed populations, particularly adolescents and young adults. These insights may support mental health practitioners and educators in designing targeted, evidence-based interventions and psychoeducational programs.

Keywords: Internet gaming disorder; online gaming addiction; perceived stress; coping strategies; emotional resilience; psychological well-being; digital wellbeing

1 Introduction

Over the past two decades, online games have become the most dynamically developing form of digital entertainment. With billions of active players worldwide, gaming communities represent a major cultural and psychological phenomenon. Gaming is no longer merely a pastime: several studies suggest it can relieve stress and support emotion regulation in young adults (Zhao et al., 2024). Yet the digital environment is inherently ambivalent. While gaming may momentarily ease tension, excessive engagement can itself become a source of stress. In modern societies, where educational and workplace demands place a growing psychological burden on young people, many seek escape in online spaces. Lazányi (2016) also highlights that workplace stress not only undermines individual well-being but may threaten organizational security, further amplifying psychological strain. Cheng, Jiang, and Chen (2024) demonstrate that academic expectation stress—pressure arising from academic demands—substantially increases the risk of online gaming disorder, particularly when individuals experience psychological distress and hold a negative attitude toward stress. This suggests that gaming can evolve into a maladaptive coping strategy that temporarily alleviates tension but heightens addictive tendencies over time. The connection between stress and digital addictions is not new: Yan, Li, and Sui (2014) showed that life stress, personality traits, and family functioning all shape the development of internet addiction. Their findings indicate that individuals exposed to high stress and limited social support are more likely to retreat into the online world, where gaming offers a structured environment with instant rewards. Although this mechanism provides short-term psychological relief, it may reinforce addictive patterns in the long term.

In recent years, *Internet Gaming Disorder* (IGD) has appeared as a distinct clinical category in diagnostic systems such as DSM-5 and ICD-11, which classify it as a mental disorder. While DSM-5 conceptualizes online gaming addiction primarily as excessive, compulsive video game use with a focus on dependence, ICD-11 emphasizes that, with appropriate guidance, gaming can also promote health rather than inevitably leading to addiction (Jo, Y.S. et al., 2019). Current research indicates that IGD is particularly prevalent among university students, who face high levels of stress and uncertainty. A survey by Fraiwan and Almomani (2025) found that the prevalence of gaming addiction in this group is alarmingly high and closely associated with psychological distress, low self-regulation, and poor time management. The authors argue that gaming addiction is not only an individual issue but also a social one, as it can impair academic performance and diminish quality of life over time. Thus, the relationship between stress and online gaming can no longer be understood solely from a pathological viewpoint. Gaming is, in essence, a natural recreational activity that can help reduce tension and induce a flow experience.

However, the boundary between relaxation and addiction is extremely narrow: excessive involvement often functions as a way to shut out real-life problems. This makes it increasingly important to identify which psychological and environmental factors shift gaming from a healthy stress reliever into maladaptive behavior.

The present research aims to explore this boundary. Specifically, it examines the extent to which perceived stress contributes to excessive gaming and how this is reflected in addictive patterns. Using a questionnaire-based survey on a broad age sample, the study investigates how perceived stress and psychological well-being are related to online gaming addiction. The findings are expected to clarify when gaming ceases to be a means of tension relief and becomes a source of pressure—when gaming is no longer leisure, but compulsion.

2 From Stress to Screen: International Insights into Online Gaming Addiction: literature review

Online gaming addiction has become one of the most frequently studied digital behavioral disorders in the past decade, closely linked to stress, psychological well-being, and social factors. Research suggests that the development of gaming addiction is a multifactorial process in which stress, depression, anxiety, and family and school environments all play a significant role (Fraiwan & Almomani, 2025; Kaya et al., 2024). The increasing demands of modern life, especially the pressures experienced in educational and work environments, are driving more and more young people to use online games as a means of stress relief (Cheng, Jiang, & Chen, 2024).

Zhao et al. (2024) pointed out that negative life events, anxiety, and boredom have a chain reaction effect on the development of online gaming addiction. According to their findings, stressful experiences among young adults often lead to increased gaming, which temporarily reduces negative emotions but develops patterns of addiction in the long term. Similar correlations were found by Cheng et al. (2024), who showed that stress resulting from academic expectations directly increases the risk of online gaming disorder. The mediating role of psychological distress suggests that stress alone does not necessarily lead to addiction, but when combined with anxiety and feelings of helplessness, online gaming can become a maladaptive coping strategy.

The link between stress and internet addiction has been confirmed previously. Yan, Li, and Sui (2014) showed that personality traits, family functioning, and life stress all influence the development of internet addiction. Young people with low emotional stability and little family support are more likely to turn to

the online space, where gaming provides structured, immediate feedback, thereby temporarily reducing stress. However, this avoidant coping increases addiction tendencies in the long term and can impair psychological well-being. A key psychological component of addiction mechanisms is the dissatisfaction of internal needs. Kaya et al.(2024) found that the lack of basic psychological needs—such as autonomy, competence, and relatedness — is a significant precursor to online gaming addiction. According to the research, individuals who feel that their lives are less meaningful or responsible are more likely to compensate for these deficiencies through gaming. In such cases, gaming is not merely a form of recreation, but becomes a substitute for personal identity and a sense of control.

In the years following the pandemic, the link between gaming addiction and mental health has become even more pronounced. Longitudinal research by Bailey, Propp, and Alonso (2024) showed that gaming addiction and the incidence of depressive and anxiety symptoms increased significantly during the pandemic. Increased use of online space, combined with social isolation and lifestyle changes, contributed to the spread of digital behavioral disorders. According to the authors, gaming has become one of the most common means of avoiding boredom and stress, but this has a negative long-term impact on mental health. Addiction can have not only psychological but also performance-related consequences. Sun, Sun–Ye (2023) showed that online gaming addiction directly reduces academic motivation, as gaming distracts attention from school goals and weakens commitment to learning. Stress and loss of motivation thus appear as a self-reinforcing process: stress increases gaming activity, and gaming further reduces performance orientation.

The link between depression and gaming addiction has been confirmed by numerous empirical studies. In their study of adolescents, Liu, Li, and Jin (2024) showed that family and school environments, as well as personality factors—especially emotional instability—jointly influence the relationship between gaming addiction and depression. Wang and colleagues (2025) came to similar conclusions, finding that gender differences and depression mediate the relationship between daily gaming time and internet gaming disorder. These findings suggest that stress and mood disorders contribute to addiction patterns in complex ways, reinforcing each other. The global scale of the problem is well illustrated by cross-sectional studies conducted in different countries. Abdulrahman et al. (2025) found a high prevalence of gaming addiction among Saudi university students, which was significantly increased by stress, anxiety, and poor self-control. Fraiwan and Almomani (2025) found similar results among Jordanian students: stress and time management difficulties were key risk factors. The link between stress and gaming addiction is further reinforced by research conducted by Almigbal et al. (2022), which found that high stress levels among medical students were clearly associated with increased gaming

activity. The effects of stress can manifest not only mentally but also physically. A study by Güzel et al. (2025) showed that there is a positive correlation between video game addiction and stress, and that this increased tension can even manifest itself in physical symptoms such as bruxism (teeth grinding). Their findings offer a new perspective on how digital addictions can have not only psychological but also psychosomatic consequences.

Research to date clearly supports the view that online gaming addiction is a multidimensional phenomenon in which stress plays a central role. Stress, as a triggering factor, determines not only the frequency of gaming but also its psychological function. Gaming can be both a means of reducing tension and a source of further stress when loss of control, performance deterioration, or social isolation occur. Future research should more precisely map the interactions between stress, coping strategies, and digital addictions, with a particular focus on young adults, who are most exposed to this dynamic.

Author(s)	Year	Sample group	Main focus of study	Key findings
Zhao et al.	2024	Chinese university students	Negative life situations, boredom, gaming	Stress and boredom predispose individuals to problematic gaming.
Cheng et al.	2024	Chinese teenagers	Academic expectations, stress, and gaming disorder	Psychological distress mediates the relationship between stress and addiction.
Yan et al.	2014	University students	Personality, family functioning, and stress	A weak family background and high stress increase the risk of internet addiction.
Fraiwan – Almomani	2025	Jordanian University Students	Prevalence of gaming addiction and stress	High stress levels are significantly associated with addiction and poor self-regulation.
Kaya et al.	2024	Teenagers	Basic psychological needs, meaning of life	Lack of autonomy and connection increases gaming addiction.
Bailey et al.	2024	Young Adults	Mental health before and after the pandemic	The prevalence of depression, anxiety, and gaming addiction increased during the pandemic.
Sun et al.	2023	Chinese University Students	Gaming addiction and academic motivation	Addiction reduces commitment to learning and performance.

Author(s)	Year	Sample group	Main focus of study	Key findings
Liu et al.	2024	Teenagers	Family, school, personality, depression	Family and school environments moderate the relationship between addiction and depression.
Wang et al.	2025	University Students	Gender differences, depression, gaming time	Depression mediates the relationship between gaming time and addiction.
Bisht et al.	2021	Native American University Students	Depression and gaming addiction	Depressive symptoms are strongly correlated with IGD scores.
Abdulrahman et al.	2025	Saudi University Students	Prevalence and psychological correlates	High IGD rates; stress and anxiety are key factors.
Güzel et al.	2025	High School Students	Stress, bruxism, and gaming addiction	Stress and gaming addiction are also associated with physical symptoms.
Almigbal et al.	2022	Medical students	Stress and gaming behavior	High stress levels correlate with increased gaming.

Table 1.
Empirical results on psychological and stress factors of online gaming addiction
source: own. ed

Previous research has clearly demonstrated that there is often a reciprocal relationship between stress and online gaming. However, few studies have examined how this relationship manifests itself in the combined effects of various psychological factors, such as perceived stress and psychological well-being. The present study explores this area, contributing to a deeper understanding of digital well-being by investigating the relationship between online gaming and stress.

3 Presentation of the sample: methods

The survey was conducted online in November 2025 using a self-administered questionnaire. Participants were recruited via snowball sampling, with respondents sharing the call for participation through their personal and online networks. Owing to this non-probability sampling strategy, the results cannot be considered representative of the general population; however, they are well suited to exploring exploratory associations among digitally active young adults. In total, 1,146 valid responses were included in the analysis. The gender distribution was broadly balanced, with a slight predominance of women:

53.5% of respondents were women (n = 613) and 46.5% were men (n = 533). In terms of educational attainment, the sample consisted mainly of participants with secondary or higher education: 43.8% held a high school diploma, 30.5% had a higher education degree, 13.1% had completed basic education, 9.9% reported vocational training, and 2.6% reported a postgraduate degree. Regarding current status, 46.0% of participants were students (n = 527), while 54.0% were non-students (n = 619); additionally, 69.7% identified as employed (n = 799), indicating that a substantial share of the sample was simultaneously engaged in both education and work.

Descriptive statistics for continuous variables show that respondents' ages ranged from 11 to 82 years (M = 32.53, SD = 15.73). Average daily gaming time was 1.25 hours per day (SD = 1.79), with values ranging from 0 to 21 hours. These figures suggest that most participants have moderate gaming habits, alongside a smaller subgroup displaying very intensive gaming activity. Overall, the sample represents a digitally active, relatively young and more educated population. This composition provides a solid basis for examining psychological mechanisms related to online gaming and stress, while also limiting the generalizability of the findings.

The aim of the study was to investigate the extent to which stress, psychological well-being, and gaming time contribute to the risk of online gaming addiction. Accordingly, the following hypotheses were formulated and empirically tested:

H₁: Respondents with higher perceived stress levels report higher online gaming addiction scores.

H₂: Lower levels of psychological well-being are associated with higher online gaming addiction scores.

H₃: Longer daily gaming time predicts higher online gaming addiction scores.

***H₄*:** Perceived stress, psychological well-being, and daily gaming time together significantly explain the variance in online gaming addiction.

4 Results

4.1 Descriptive statistics

The aggregate indicator of online gaming addiction (GAM_TOTAL) was used to provide an initial overview of gaming patterns. The mean score on this scale was **1.57** (SD = **0.68**, range: 1–4), indicating that the vast majority of the sample reports only **low-level problematic gaming**. The median (1.38) and the pronounced positive skewness (skewness = 1.25) further confirm that most

respondents cluster at the lower end of the scale, with a smaller subgroup exhibiting elevated risk. The mean score for psychological well-being (WELLBEING) was **3.05** (SD = **0.62**, range: 1–4), reflecting **moderately high subjective well-being**. The relatively small standard deviation and slightly negative skewness (skewness = –0.51) suggest that most respondents reported a generally positive emotional state and life satisfaction. This pattern is particularly relevant for subsequent analyses, as a negative association between well-being and gaming addiction is theoretically plausible.

Average daily gaming time (T2) was **1.25** hours (SD = **1.79**, range: 0–21). The distribution was highly right-skewed (skewness = 4.11), clearly reflecting the **"long tail"** typical of digital game use: while the majority of the sample plays relatively little, a smaller subgroup reports **extremely high daily gaming time**. This deviation supports the use of robust methods in further analyses and careful consideration of outliers. The mean age (D1) was **32.53** years (SD = **15.73**, range: 11–82), indicating substantial heterogeneity. The wide age span shows that the study was not confined to a narrow age group; instead, it captures gaming and well-being patterns across several generations, which adds value by providing a less frequently examined cross-section of the adult population.

The analysis of binary variables further refined the descriptive picture. A slight female majority was observed (**53.5% female, 46.5% male**), resulting in an almost balanced gender distribution. In terms of student status, **46.0%** of respondents were **students** and **54.0%** were **non-students**, indicating that a considerable proportion had already left formal education. Regarding employment, **69.7%** were **active workers** and **30.3% were not employed**, shifting the sample toward the working population. Stress tolerance (STRESS) was assessed using a self-report, non-standardized measure: **65.4%** of participants rated their **stress tolerance as good**, whereas **34.6% reported low emotional resilience**. This proportion is a crucial backdrop for interpreting the hypotheses, as the central question of the study concerns whether elevated stress is demonstrably linked to gaming behavior.

Normality tests (Shapiro–Wilk, $p < .001$ for all three main variables) indicated significant deviations from a normal distribution—a common feature of psychological and behavioral data, especially in the case of scaled or bounded variables. This does not preclude further analysis, but it does call for cautious interpretation of correlation and regression results and, where appropriate, the application of robust statistical techniques.

Variable	Minimum	Maximum	Mean	SD
Average daily gaming time (GAM_TOTAL)	1.00	4.00	1.57	0.68
Average daily gaming time (WELLBEING)	1.00	4.00	3.05	0.62
Average daily gaming time (T2, hours)	0.00	21.00	1.25	1.79
Age of respondents (D1, year)	11	82	32.53	15.73

Table 2.
Descriptive statistics for main continuous variables [N = 1146]
source: own. ed.

The descriptive results indicate that, overall, the sample is characterized by moderate psychological well-being, a low risk of gaming addiction, and relatively short daily gaming time. At the same time, a smaller yet noteworthy subgroup emerges with higher stress levels and markedly more intensive gaming behavior. These contrasts provide a solid basis for the correlation analyses presented in the following section.

4.2 Correlation analyses

In the first step, Pearson's correlation analysis was used to examine the relationships between the main variables and the online gaming addiction index (GAM_TOTAL). The results revealed a **significant but weak positive association** between low stress tolerance and gaming addiction (**$r = 0.127$**, $p < 0.001$), indicating that individuals with poorer emotional resilience are slightly more prone to problematic gaming. This pattern is in line with the initial assumption that gaming may function as an escape mechanism under heightened stress. Psychological well-being showed a **moderate negative correlation** with online gaming addiction ($r = -0.282$, $p < 0.001$), meaning that lower levels of well-being are associated with a higher risk of addiction. This finding supports the interpretation that, for some individuals, gaming can operate as a form of emotion regulation. A **stronger positive correlation** was observed between daily gaming time (T2) and gaming addiction ($r = 0.417$, $p < 0.001$), suggesting that longer gaming time is not only a behavioral marker but also a potential risk factor for addiction, particularly in light of the extreme values present in the sample.

Variables	GAM_TOTAL	WELLBEING	T2 (gaming time)	STRESS
GAM_TOTAL	1	–0.282***	0.417***	0.127***
WELLBEING	–0.282***	1	–0.051	–0.091**
T2 (gaming time)	0.417***	–0.051	1	0.062*
STRESS	0.127***	–0.091**	0.062*	1

Table 3.
Pearson correlations between the main variables
source: own ed.

Based on the correlation results, all three hypothesized relationships proved to be significant, and their directions were fully consistent with the theoretical expectations.

4.3 Regression analyses

Following the correlation analyses, linear regression models were employed to examine the contribution of each predictor to the variance in online gaming addiction. In the first model, stress alone significantly predicted addiction, but only to a small extent ($\beta = 0.127$, $p < 0.001$), with a modest explanatory power ($R^2 = 0.016$). This indicates that although stress plays a role, it is not a strong standalone determinant. Psychological well-being showed a stronger and significant effect in a separate regression model ($\beta = -0.282$, $p < .001$), explaining 8% of the variance ($R^2 = 0.080$). This result reinforces the correlational finding that lower well-being is associated with an increased risk of addiction.

In the multivariate regression model, stress, psychological well-being, daily gaming time, age, and gender were entered simultaneously. The explanatory power of the model increased substantially ($R^2 = 0.243$), indicating that these variables together account for nearly 24% of the variance in online gaming addiction. Based on the standardized coefficients, the strongest predictor was daily gaming time ($\beta = 0.348$, $p < 0.001$), followed by psychological well-being ($\beta = -0.198$, $p < 0.001$) and, to a lesser extent, stress ($\beta = 0.073$, $p = 0.006$). Age was not a significant predictor ($p = 0.133$), whereas gender was significant ($\beta = –0.142$, $p < 0.001$), suggesting that women reported lower levels of gaming addiction than men.

Descriptor	B	SE	β	t	p
Constant (intercept)	2.345	0.116	—	20.19	< 0.001
Stress (STRESS)	0.104	0.038	0.073	2.73	0.006
Psychological well-being (WELLBEING)	–0.219	0.030	-0.198	-7.30	< 0.001
Daily playing time (T2)	0.132	0.010	0.348	12.99	< 0.001
Age (D1)	0.000	0.000	-0.039	-1.50	0.133
Gender (D2)	–0.193	0.036	-0.142	-5.37	< 0.001

Table 4
Multivariate linear regression for predicting online gaming addiction
source: own. ed.

The regression results suggest that **several factors contribute** to the development of problematic gaming, with the strongest effects emerging for **behavioral intensity** (daily gaming time) and **psychological well-being**. The impact of stress is detectable but more modest, indicating that gaming cannot be understood solely as a stress-coping strategy; rather, it is embedded in more complex psychological and lifestyle patterns.

5 Discussion: Interpretation of hypotheses

The results of the analyses supported all three hypotheses. The weak but significant positive correlation between stress and online gaming addiction ($r = 0.127$, $p < 0.001$) indicates that respondents with poorer stress tolerance are more likely to have higher addiction scores. The regression results further reinforced this, as the independent explanatory power of stress remained significant ($\beta = 0.073$, $p = 0.006$), confirming the acceptance of H_1. The moderate negative correlation found between psychological well-being and addiction
($r = -0.282$, $p < 0.001$) clearly confirmed the second hypothesis. In the regression, the level of well-being proved to be the most significant psychological predictor ($\beta = -0.198$, $p < 0.001$), meaning that lower well-being indicates an increased risk of problematic gaming. Accordingly, H_2 was also confirmed. The third hypothesis was also supported, as the strongest correlation was found between daily gaming time and online gaming addiction ($r = 0.417$, $p < 0.001$). In the regression model, gaming time significantly and strongly

predicted the addiction score ($\beta = 0.348$, $p < 0.001$), which clearly supports the validity of H_3.

The multivariate regression model, examining the combined effect of the three main predictors, explained 24.3% of the variance in addiction ($R^2 = 0.243$, $p < 0.001$). This means that although problematic gaming is a complex phenomenon, stress, psychological well-being, and time spent gaming together play a significant role in its development. This finding confirms the supplementary model hypothesis (H_4) and suggests that the risk is not solely behavioral but is also closely linked to psychological factors.

Hypoth.	Brief description	Result	Statistical validation	Decision
H_1	Higher level stress → higher gaming addiction	$r = 0.127$	$p < 0.001$ $\beta = 0.073$ $p = 0.006$	accepted
H_2	Higher level stress → higher gaming addiction	$r = -0.282$	$p < 0.001$ $\beta = -0.198$ $p < 0.001$	accepted
H_3	More daily gaming time → higher gaming addiction	$r = 0.417$	$p < 0.001$ $\beta = 0.348$ $p < 0.001$	accepted
H_4	The three factors together have significant explanatory power	$R^2 = 0.243$	$F_{5,1140} = 72.99$ $p < 0.001$	accepted

Table 5.
Hypotheses and their statistical validity
source: own ed.

The results indicate that prolonged gaming and low psychological well-being pose the greatest risk for online gaming addiction, while stress exerts a moderate yet consistent amplifying effect. Together, these associations underscore the need for a multidimensional approach to prevention.

Conclusions

The aim of this study was to examine the extent to which stress, psychological well-being, and gaming habits contribute to the risk of online gaming addiction among both younger and adult respondents. The findings indicate that, although the average level of addiction in the sample is low, several psychological and behavioral factors can be identified that point toward problematic gaming. Descriptive statistics showed that most participants reported moderate psychological well-being and relatively low daily gaming time. However, the distribution of gaming time was highly skewed, indicating a small but clearly

identifiable subgroup that spends substantially more time playing digital games. This highlights the heterogeneity of the sample and suggests that the risk of addiction is not evenly distributed, but concentrated in a narrower, potentially more vulnerable group.

Correlation analyses supported the proposed hypotheses. A weak but significant positive association was found between stress levels and online gaming addiction, suggesting that poorer coping skills may increase the likelihood of using gaming as an escape. Psychological well-being, in turn, showed a negative correlation with addiction risk, indicating that lower life satisfaction and self-esteem are linked to a greater probability of uncontrolled gaming. The strongest association emerged for daily gaming time, which showed not only a significant, but also a moderate predictive effect. The multivariate regression model further refined these relationships: stress, psychological well-being, and time spent gaming together explained nearly one quarter of the variance in online gaming addiction, underscoring that problematic gaming is not merely a function of time spent playing, but a multidimensional psychological phenomenon. An additional important result is that age was not a significant predictor, suggesting that problematic gaming is not exclusively an adolescent issue but can occur across a wide age range. By contrast, gender differences were significant, with men scoring higher on addiction—findings that are consistent with previous international and national studies.

Overall, the results suggest that stress sensitivity and low psychological well-being constitute risk profiles in which gaming more readily becomes a coping strategy. The practical implication is that prevention and intervention programs should not only aim to limit gaming time, but also strengthen coping skills and support psychological well-being. Given the non-representative nature of the sample, the findings cannot be generalized to the entire population; nevertheless, they offer a valuable starting point for future longitudinal and clinical research. From the perspective of further studies, it would be particularly relevant to examine stress management styles in greater depth and to explore which features of the digital environment (e.g., in-game reward systems, social relations in online spaces) contribute to the maintenance of addictive gaming patterns.

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Demographic Factors and Household Food Waste Related Orientations and Behaviors in China and Europe

Du Yuwei

Obuda University, Doctoral School of Safety and Security Sciences (BDI)
duyuweiwanda@gmail.com

Abstract: Food waste poses a threat to global food security, environmental sustainability, and economic development. Drawing on the Theory of Planned Behavior (TPB) and the Value Belief Norm (VBN) framework, this study examines how demographic factors — gender, age, family structure, residential environment, and income — affect four dimensions of household food waste related orientations and behaviors: environmental awareness, personal attitude, food acquisition behavior, and Over-purchasing and stockpiling. A valid questionnaire survey of 400 respondents (200 in China, 200 in Europe) was conducted. Non-parametric tests were used to analyse. The results reveal no significant gender differences in either region. In Europe, age shows strongly associated with over-purchasing and food acquisition behaviors, with younger respondents reporting higher scores than several older groups. Family structure was significant in both regions: single-person and single-parent families over-purchased more than multigenerational families. The relationship between residential environment and behavioral differences also varies: among European respondents, environmental awareness varies by place of residence; while among Chinese respondents, residents of small towns exhibit the highest levels of over-purchasing, and food acquisition behaviors also show significant differences. The association between income and over-purchasing exists only in the Chinese sample and does not show a clear gradient; among European respondents, no effect of income was observed. The study highlights the need for targeted, culturally sensitive interventions to promote sustainable food management.

Keywords: Food waste, demographics, personal attitude, environmental awareness, consumer behaviors

1 Introduction

Food waste has been identified as a serious threat to environmental sustainability, economic development, and food security, and it also raises important moral and ethical concerns (Zhang, Bai et al. 2019, Barrera and

Hertel 2021). Household food waste is a major contributor in many countries, for example, 55% in Europe (Eurostat 2024). This trend is driven by urbanization, low environmental awareness, and market incentives that encourage excessive consumption (Aschemann-Witzel, De Hooge et al. 2016, Nicastro and Carillo 2021). The growth of the global population will require more food production to meet the increased demand. However, every year, approximately one-third of the world's food production is lost or wasted, which is about 1.3 billion tons of food, valued at over $1 trillion (Mak, Xiong et al. 2020). To address this, reducing household food waste is therefore a priority instrument for achieving climate objectives, such as improving resource efficiency, and easing pressure on municipal waste systems.

At the household level, food waste is not a single act but a bundle of routinized behaviors, which occurs at every stage of the consumption cycle, from planning to disposal (Gimenez, Ares et al. 2023). The motivations behind household food waste behavior are multidimensional, interdisciplinary and require an integrated analysis of psychological, economic, and sociocultural factors (Raquel, Costa-Font et al. 2015). Provious research has identified attitudes, social norms, and perceived behavioral control as the key predictors of consumer food waste behavior (Ertz, Favier et al. 2021, Keller and Gombos 2025).

Both European countries and China have intensified anti-waste efforts, but policy frameworks, market infrastructures, and daily consumption habits are quite different. The EU's Circular Economy Action Plan and subsequent initiatives seeks to preserve the value of products, materials, and resources for as long as possible by minimizing waste generation (Commission 2020). China has responded by increasing public awareness campaigns and frugality norms, and anti-extravagance measures to foster a culture of thrift, enacting laws and policies to provide a legal framework for supervision and enforcement, and monitoring and controlling societal and corporate efforts to manage food waste efficiently (CHENG Sheng-kui, Desheng et al. 2021, CHENG Sheng-kui 2022).

Existing studies rarely compare how demographic attributes shape different food-waste-related dimensions across regions with distinct cultural and policy contexts. To address this gap, this study integrates Theory of Planned Behavior (TPB) and the Value-Belief-Norm (VBN) perspectives to examine how five demographic attributes—gender, age, family structure, residential environment and income—relate to four dimensions of household food-waste-related orientations and behaviors in China and Europe. We pose the following research questions:

RQ: In the samples from China and European countries respectively, are there significant differences among different demographic groups (gender, age, family structure, residential environment, income) in the four individual-level dimensions, such as Over-purchasing and stockpiling, food acquisition behavior, personal attitudes, and environmental awareness?

2 Literature Review

2.1 Theoretical framework: TPB and VBN applied to household food waste

According to Theory of Planned Behavior (TPB) (Ajzen 1991), behavior is primarily determined by behavioral intention, which in turn is influenced by attitudes toward the behavior, subjective norms, and perceived behavioral control. This framework has been widely used in research on food waste (Collins and Mullan 2011, McCarthy and Liu 2017, Simoes, Carvalho et al. 2022). Complementing TPB, the theory of Value-Belief-Norm (VBN) (Stern, Dietz et al. 1999), integrates personal values, environmental beliefs and moral norms, establishing links between environmental concern and the motivational factors that drive pro-environmental behavior. The research framework combining VBN and TPB has been widely used in research on food waste-related behaviors and the prediction of household food waste (Fraj-Andrés, Herrando et al. 2023, Al Mamun, Ma et al. 2024).

Prior study show that attitudes influence intentions to reduce household food waste and, in turn, actual waste outcomes (Stefan, Van Herpen et al. 2013). Al Mamun et al indicated that a more negative attitude towards waste, stronger anti-waste norms, and a higher level of perceived behavioral control are associated with fewer wasteful behaviors (Al Mamun, Ma et al. 2024). Over-purchasing and stockpiling are central to understanding why food accumulates unused or never cooked in households (Dobernig and Schanes 2019). Preventing excess purchase and storage—has repeatedly been highlighted as an effective approach to reduce household food waste(Papargyropoulou, Lozano et al. 2014). The food acquisition behaviors includes making a shopping list, planning meals in advance, and checking inventory before shopping (Schanes, Dobernig et al. 2018). Weak or inadequate planning is consistently associated with over-purchasing and subsequent non-consumption, whereas robust planning routines reflect a stronger intention to reduce food waste (Roodhuyzen, Luning et al. 2017). Environmental awareness is the moral and normative dimensions of food waste behavior (Huang and Ge 2019). Wang et al.'s research found that environmental awareness can enhance people's attitudes and willingness to reduce food waste (Wang, Li et al. 2022). People recognize their responsibility to reduce waste can inspire people to adopt sustainable food consumption and processing habits (Al Mamun, Ma et al. 2024).

2.2 Demographic attributes as contextual conditions to household food waste

Demographic factors such as age, income, and family structure are expected to impact food waste behavior because they influence resource acquisition,

responsibility allocation, social norms, and cultural values (Bilska, Tomaszewska et al. 2020, Ankiel and Samotyja 2021, Li, Wang et al. 2021, Principato, Mattia et al. 2021, Bilska, Tomaszewska et al. 2024). There is currently no definitive conclusion regarding the relationship between gender and food waste. For instance, some studies suggest that women are more aware of food waste because they are responsible for managing household food (Silvennoinen, Heikkilä et al. 2015, Cantaragiu 2019, Brizi and Biraglia 2021). Conversely, other studies have found that young people, regardless of gender, produce the same amount of food waste (Principato, Secondi et al. 2015). Age also plays a role, Older adults tend to take actions that reduce food waste (Grasso, Olthof et al. 2019). What's more, previous studies have shown that richer families may waste more through excessive consumption (Aschemann-Witzel, Giménez et al. 2019, Ghaziani, Ghodsi et al. 2022). Family structure also influences food waste behavior. For, instance, Surindra et al. indicated that the household waste generation showed positive correlation with family size (Suthar and Singh 2015). These findings underscore the necessity of a more comprehensive study that considers factors such as demographic factors, food accessibility, purchase behavior, personal attitude and environmental awareness.

2.3 Research model and hypotheses

Building upon the TPB and VBN framework, this study focuses on four household dimensions of food waste related orientations and behaviors: personal attitude, Over-purchasing and stockpiling, food acquisition behavior, and environmental awareness. "Personal attitude" captures customer's attitude towards food waste behavior (Aktas, Sahin et al. 2018); "Food acquisition behavior" capture actual purchasing and consumption patterns that reflect behavioral intention (Amirudin and Gim 2019); "Over-purchasing and stockpiling" reflect perceived behavioral control and self-regulation in food management (Dobernig and Schanes 2019); and "Environmental awareness" represents the moral and normative dimensions of food waste related orientations (Purwanto, Yulianto et al. 2023). The study examines how demographic attributes (gender, age, family structure, residential environment, income) and regional setting (China vs. Europe) shape the pattern and magnitude of observed group differences across these dimensions.

Accordingly, we formulate the following hypotheses:

H1: In each region (China and Europe), gender is associated with differences in household food-waste-related orientations and behaviors (personal attitude towards food waste, environmental awareness, food acquisition behavior, and Over-purchasing and stockpiling).

H2: In each region, age is associated with differences in household food-waste-related orientations and behaviors (personal attitude towards food waste,

environmental awareness, food acquisition behavior, and Over-purchasing and stockpiling).

H3: In each region, family structure is associated with differences in household food-waste-related orientations and behaviors (personal attitude towards food waste, environmental awareness, food acquisition behavior, and Over-purchasing and stockpiling)..

H4: In each region, the residential environment is associated with differences in household food-waste-related orientations and behaviors (personal attitude towards food waste, environmental awareness, food acquisition behavior, and Over-purchasing and stockpiling).

H5: In each region, income level is associated with differences in household food-waste-related orientations and behaviors (personal attitude towards food waste, environmental awareness, food acquisition behavior, and Over-purchasing and stockpiling).

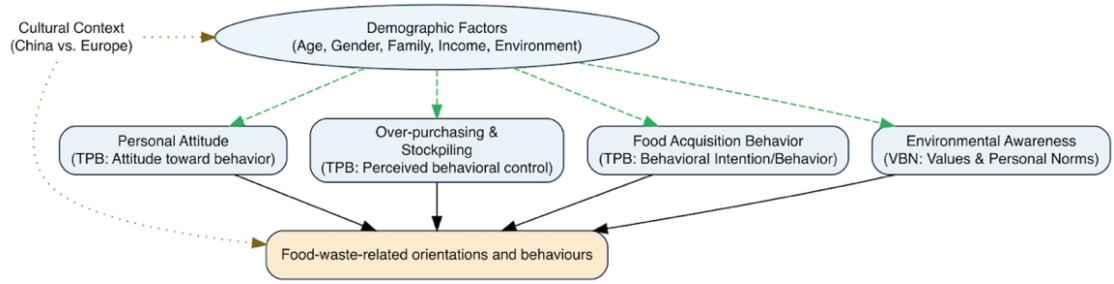

Figure 1
Food waste conceptual framework on personal level
Source: compiled by the author

3 Materials and Methods

3.1 Data Collection and Sample Description

A total of 400 valid questionnaires were collected via an online survey method between November 2023 and February 2024, with 200 responses from China and 200 from Europe. Respondents were recruited through social media, covering urban, suburban, and rural areas. The demographic characteristics of the participants were as follows:

Gender: China:51.0% female, 49.0% male; Europe: 53.0% female, 47.0% male.

Age: Chinese respondents were mainly younger (22.5% were under 20), whereas European participants were more evenly distributed across age groups.

Family structure: The nuclear family was dominant (China: 39.0%; Europe: 41.5%).

Residential environment: China: mostly metropolitan (32.5%) and small town (27.0%); Europe: metropolitan (35.5%) and suburban (28.0%).

Income: The majority earned between €5,000 and €15,000 annually.

3.2 Data Analysis and Statistical Methods

All data were processed using SPSS Statistics 28.0 and MATLAB. Reliability and validity were verified through Cronbach's alpha, Kaiser Meyer Olkin (KMO) test, and Bartlett's test of sphericity, ensuring internal consistency and construct validity (Shrestha 2021).

Nonparametric tests were applied to analyse differences among demographic groups due to the ordinal nature and non-normal distribution of several variables:

For two-group comparisons (e.g. gender), we used the Mann - Whitney U test (McKnight and Najab 2010):

$$\mathrm{U} = \frac{n_1 n_2 + [n_1(n_1 + 1)]}{2} - \mathrm{R}_1$$

where n_1 and n_2 are sample sizes of two groups, and R_1 is the sum of ranks of group1.

For comparisons involving more than two groups (e.g. age, family structure, residential environment, income), we used the Kruskal - Wallis H test (Kruskal and Wallis 1952):

$$H = \frac{12}{N(N+1)} \sum_{i=1}^{k} n_i (\bar{R}_i - \bar{R})^2$$

where n_i is the sample size of group i, $\bar{R}_i$ is the mean rank of group i, N is the total sample size, and $\bar{R}$ is the overall mean rank. When overall Kruskal - Wallis tests were significant, pairwise post-hoc comparisons were performed using Dunn's test, and groups that do not share a common superscript letter in the tables differ significantly.

4 Results

According to the survey results, 400 were valid. Of those, 200 participants were from China and 200 were from Europe.

4.1 Questionnaire Reliability and Validity Analysis

Among the 400 responses, the 14-item scale showed high internal consistency, with Cronbach's alpha values of 0.888 (China) and 0.929 (Europe). The KMO values were 0.909 and 0.953, respectively, and Bartlett's test of sphericity was significant ($p < 0.001$), confirming the adequacy of the sample and the construct validity of the questionnaire.

4.2 Analysis of Demographic Variables

4.2.1 Gender patterns across household food waste related dimensions

According to the results of the Mann - Whitney U test (Table 1 and 2), no statistically significant gender differences were found either in the European or Chinese samples ($p > 0.05$). These results suggest that gender does not play a significant role across the four dimensions. These findings do not support H1, indicating that gender is not a decisive factor in household food waste related orientations and behaviors in either region.

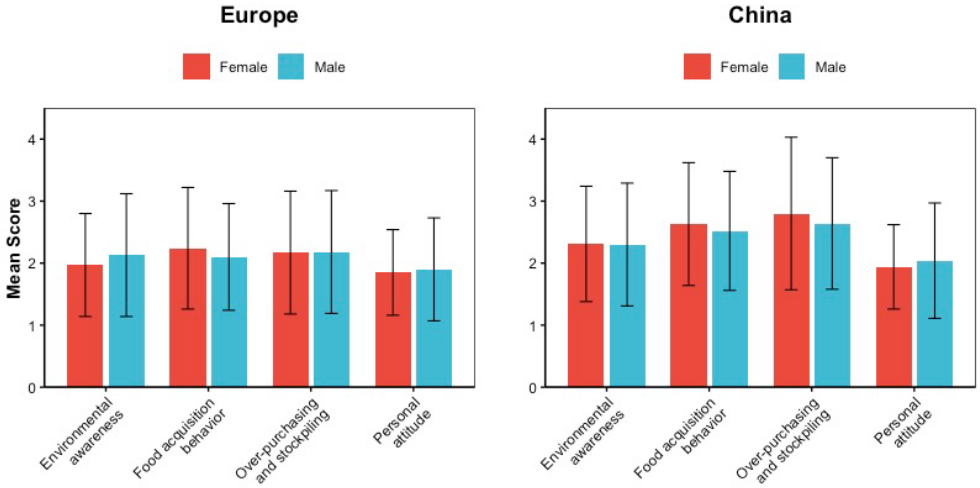

Figure 2
Gender differences in food waste related orientations and behaviors
Source: compiled by the author

Europe	Gender	Mean ± SD	U	Z	p
Over-purchasing and stockpiling	Female	2.17±0.99	10639.500	-0.032	0.974
	Male	2.18 ± 0.99			
Personal attitude	Female	1.85 ± 0.69	10843.500	0.470	0.639
	Male	1.90 ± 0.83			
Food acquisition behavior	Female	2.24 ± 0.98	10981.000	0.821	0.412
	Male	2.10 ± 0.86			
Environmental awareness	Female	1.97 ± 0.83	10319.000	-0.837	0.402
	Male	2.13 ± 0.99			

Table 1
Gender differences in food waste related orientations and behaviors in Europe
Source: compiled by the author

China	Gender	Mean ± SD	U	Z	p
Over-purchasing and stockpiling	Female	2.80 ± 1.23	10601.500	0.862	0.388
	Male	2.64 ± 1.06			
Personal attitude	Female	1.94 ± 0.68	10286.500	0.086	0.931
	Male	2.04 ± 0.93			
Food acquisition behavior	Female	2.63 ± 0.99	10534.500	0.700	0.484
	Male	2.52 ± 0.96			
Environmental awareness	Female	2.31 ± 0.93	10388.500	0.341	0.733
	Male	2.30 ± 0.99			

Table 2
Gender differences in food waste related orientations and behaviors in China
Source: compiled by the author

[1] Note: Mean ± SD = mean ± standard deviation; U = Mann – Whitney U value; Z = normalization test statistic; $p < 0.05$ indicates significant difference.

4.2.2 Age patterns across household food waste related dimensions

In the European sample, age-related differences in food waste related orientations and behaviors were primarily evident in the "Over-purchasing and stockpiling" and "Food acquisition behavior" dimensions. The 20 – 29 age group reported the highest mean scores on these two dimensions compared to most other age groups, suggesting that young people are more likely to purchase or store excessive amounts of food. No significant differences were observed in the "Personal attitudes" and "Environmental awareness" ($p > 0.05$) of European respondents. In the Chinese sample, no statistically significant age-related differences were observed in any of the four dimensions ($p > 0.05$), although the youngest group tended to report slightly higher scores descriptively.

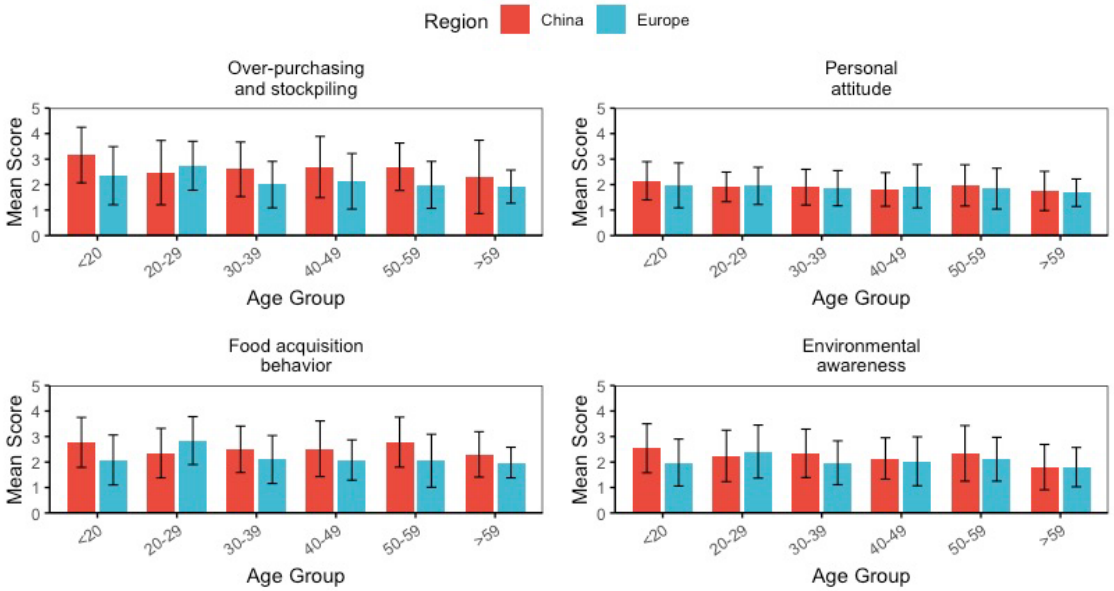

Figure 3
Age difference in food waste related orientations and behaviors
Source: compiled by the author

Age group	Over-purchasing and stockpiling	Personal attitude	Food acquisition behavior	Environmental awareness
< 20	2.35±1.14[b]	1.97±0.88	2.08±0.98[a]	1.98±0.92
20 – 29	2.74±0.96[a]	1.95±0.73	2.84±0.94[b]	2.41±1.04
30 – 39	2.00±0.91[b]	1.86±0.69	2.10±0.94[b]	1.97±0.86
40 – 49	2.13±1.09[a]	1.94±0.85	2.08±0.79[b]	2.03±0.96
50 – 59	1.99±0.92[b]	1.84±0.80	2.05±1.04[b]	2.11±0.86
> 59	1.92±0.65[b]	1.68±0.54	1.98±0.60[b]	1.80±0.77
H	17.162	3.440	19.910	7.590
p	0.004	0.632	0.001	0.180

Table 3
Age difference in food waste related orientations and behaviors in Europe
Source: compiled by the author

Age group	Over-purchasing and stockpiling	Personal attitude	Food acquisition behavior	Environmental awareness
<20	3.16±1.09	2.15±0.75	2.77±0.98	2.54±0.96
20–29	2.47±1.26	1.91±0.58	2.35±0.97	2.24±1.01
30–39	2.60±1.07	1.90±0.70	2.50±0.91	2.34±0.95
40–49	2.69±1.20	1.81±0.66	2.52±1.09	2.14±0.81
50–59	2.70±0.93	1.97±0.81	2.78±0.98	2.34±1.09
>59	2.30±1.44	1.75±0.77	2.30±0.89	1.80±0.89
H	10.805	8.025	6.355	8.782
p	0.055	0.155	0.273	0.118

Table 4
Age difference in food waste related orientations and behaviors in China
Source: compiled by the author

[2] Note: Values are presented as Mean ± Standard Deviation. H = Kruskal–Wallis H statistic; p = significant level (*p < 0.05)

4.2.3 Family structure patterns across household food waste related dimensions

Family structure significantly influences food waste related orientations and behaviors in both Europe and China. For the European sample, family structure showed a significant overall effect on "Over-purchasing and stockpiling" (H = 15.872, p = 0.026) and "Personal attitudes" (H = 19.73, p = 0.006). Descriptive analysis showed that single-person households tended to score higher on over-purchasing and personal attitudes, while married and cohabiting households scored lower, suggesting that they may be more efficient in managing their food. Although descriptively higher, post-hoc tests did not identify statistically significant pairwise differences, which suggests that the observed effect is distributed across several household categories, rather than driven by large differences between any two particular groups.

For the Chinese sample, family structure also showed a significant overall effect on "Over-purchasing and stockpiling" (H = 15.564, p = 0.029) and "Personal attitudes" showed a marginal difference (H = 14.009, p = 0.051). Descriptively, single-person and single-parent households scored highest in the "Over-purchasing and stockpiling" dimension, suggesting they tended to be more wasteful with food. This may be due to time pressure and poor food management. Scores for sharing or co-living were the lowest, indicating that cooperation among family members helps reduce waste. However, post-hoc tests did not identify statistically significant pairwise differences between

specific family-structure categories, indicating that the observed effect is distributed across several household types rather than driven by sharp contrasts between any two particular groups. The other dimensions did not reach significance.

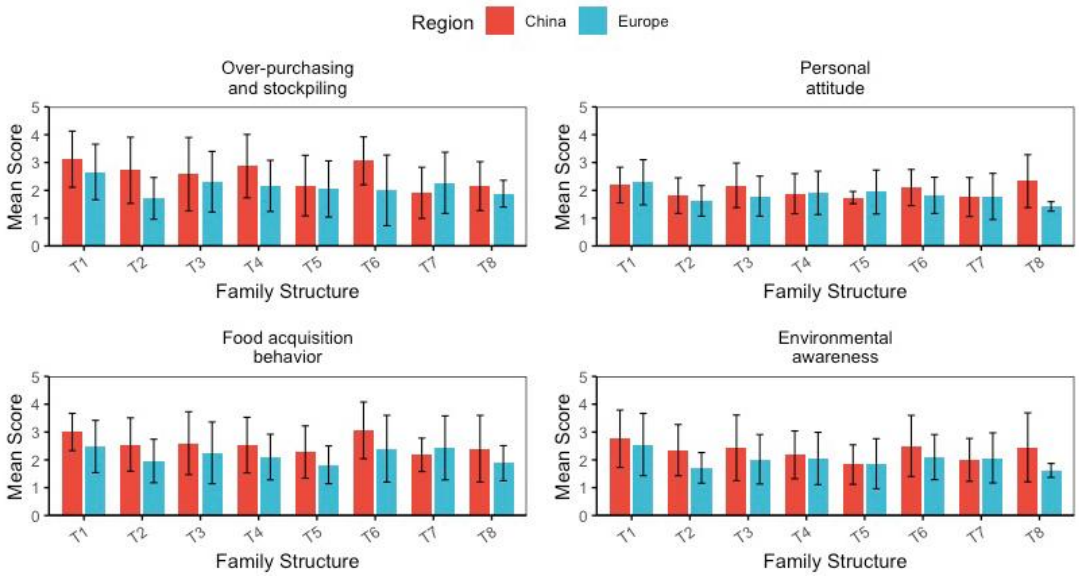

Figure 4
Family structure Difference in food waste related orientations and behaviors
Source: compiled by the author

Family structure code	Content-Family structure
T1	Single, living alone
T2	Married, with a spouse
T3	Have a partner, but not married
T4	Nuclear family (parents and children
T5	Extended household (living with other relatives)
T6	one-parent family
T7	Sharing or living together
T8	Others _____(please specify)

Table 5
Family structure code and description
Source: compiled by the author

Family structure	Over-purchasing and stockpiling	Personal attitude	Food acquisition behavior	Environmental awareness
T1	2.66±1.00[a]	2.29±0.81[a]	2.48±0.94	2.55±1.12
T2	1.71±0.75[a]	1.62±0.55[a]	1.96±0.78	1.71±0.55
T3	2.31±1.09[a]	1.79±0.72[a]	2.25±1.11	2.02±0.89
T4	2.16±0.92[a]	1.91±0.78[a]	2.10±0.82	2.05±0.94
T5	2.05±1.01[a]	1.94±0.79[a]	1.82±0.68	1.86±0.90
T6	2.00±1.27[a]	1.82±0.65[a]	2.40±1.20	2.10±0.81
T7	2.27±1.10[a]	1.78±0.83[a]	2.43±1.15	2.07±0.90
T8	1.88±0.48[a]	1.42±0.17[a]	1.88±0.63	1.62±0.25
H	15.872	19.73	7.903	9.134
p	0.026	0.006	0.341	0.243

Table 6
Family structure difference in food waste related orientations and behaviors in Europe
Source: compiled by the author

Family structure	Over-purchasing and stockpiling	Personal attitude	Food acquisition behavior	Environmental awareness
T1	3.12±1.01[a]	2.19±0.64[a]	3.00±0.67	2.76±1.03
T2	2.72±1.19[a]	1.81±0.64[a]	2.55±0.96	2.35±0.92
T3	2.58±1.32[a]	2.18±0.80[a]	2.60±1.13	2.43±1.18
T4	2.87±1.14[a]	1.88±0.72[a]	2.53±1.00	2.18±0.86
T5	2.17±1.09[a]	1.74±0.22[a]	2.28±0.94	1.83±0.71
T6	3.06±0.86[a]	2.10±0.65[a]	3.06±1.02	2.50±1.10
T7	1.91±0.92[a]	1.76±0.70[a]	2.18±0.60	2.00±0.77
T8	2.15±0.88[a]	2.33±0.95	2.40±1.20	2.45±1.24
H	15.564	14.009	10.211	10.389
p	0.029	0.051	0.177	0.168

Table 7
Family structure difference in food waste related orientations and behaviors in China
Source: compiled by the author

[3] Note: Values are presented as Mean ± Standard Deviation. H = Kruskal–Wallis H statistic; p = significant level (*p < 0.05)

4.2.4 Residential environment patterns across household food waste related dimensions

Analysis of European respondents by residential environment showed significant differences only in "Environmental awareness" (H = 10.909, p = 0.012), with no differences in other dimensions (p > 0.05). Rural residents reported environmental awareness scores that were significantly different from those in other areas, whereas small-town and suburban residents tended to report lower levels than metropolitan residents.

Chinese respondents exhibited significant variations in "Over-purchasing and stockpiling", "Food acquisition behavior" across residential environments. Significant differences in "Over-purchasing and stockpiling" were observed between small town and other residential environments. These differences suggest that limited shopping and transportation options and limited land may encourage small towns residents to stockpile food, thereby increasing the likelihood of food waste. Urbanization and infrastructure development influence on residents' food waste related behaviors and environmental awareness. However, Europe's relatively even distribution of resources results in less pronounced differences and more uniform food waste related orientations and behaviors.

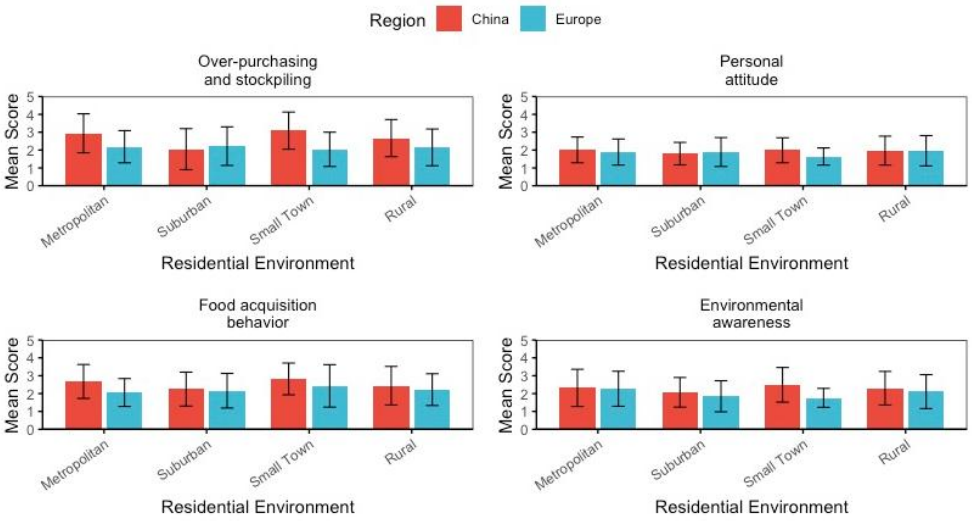

Figure 5
Residential environment different in food waste related orientations and behaviors
Source: compiled by the author

Residential environment	Over-purchasing and stockpiling	Personal attitude	Food acquisition behavior	Environmental awareness
Metropolitan City	2.19±0.90	1.89±0.73	2.06±0.78	2.27±0.98[a]
Suburban	2.22±1.08	1.89±0.81	2.16±0.97	1.85±0.87[a]
Small Town	2.04±0.96	1.64±0.48	2.43±1.19	1.76±0.53[a]
Rural	2.15±1.03	1.96±0.85	2.22±0.89	2.11±0.95[b]
H	1.388	2.475	1.811	10.909
p	0.708	0.48	0.613	0.012

Table 8
Residential environment different in food waste related orientations and behaviors in Europe
Source: compiled by the author

Residential environment	Over-purchasing and stockpiling	Personal attitude	Food acquisition behavior	Environmental awareness
Metropolitan City	2.94±1.09[a]	2.01±0.72	2.68±0.95[a]	2.32±1.04
Suburban	2.05±1.15[a]	1.80±0.63	2.25±0.95[a]	2.07±0.83
Small Town	3.09±1.04[b]	1.99±0.70	2.82±0.89[a]	2.49±0.97
Rural	2.67±1.04[a]	1.97±0.81	2.44±1.08[a]	2.30±0.94
H	25.737	4.296	11.592	5.11
p	<0.001	0.231	0.009	0.164

Table 9
Residential environment different in food waste related orientations and behaviors in China
Source: compiled by the author

[4] Note: Values are presented as Mean ± Standard Deviation. H = Kruskal–Wallis H statistic; p = significant level (*p < 0.05)

4.2.5 Income patterns across household food waste related dimensions

Among Chinese respondents, income level had a significant effect only on "Over-purchasing and stockpiling" (H = 12.66, p = 0.013). Specifically, post-hoc test indicated that the lowest income group (I1) differed significantly from all other groups ($p < 0.05$), even though their mean values were similar. Descriptively, the “prefer not to say” group (I5) reported the highest mean level, but this difference was not statistically significant when compared with the other income groups. The lowest-income group also exhibited some over-purchasing behavior, possibly due to promotional or stockpiling motives. These results suggest that while income influences certain consumption behaviors, its overall impact on food waste related attitudes and intentions is limited. For personal attitudes and environmental awareness, no clear income gradient emerged in the Chinese sample. In contrast, European respondents showed no significant differences across income groups in any dimension ($p > 0.05$), indicating that income has little effect on food waste related behaviors in the European context.

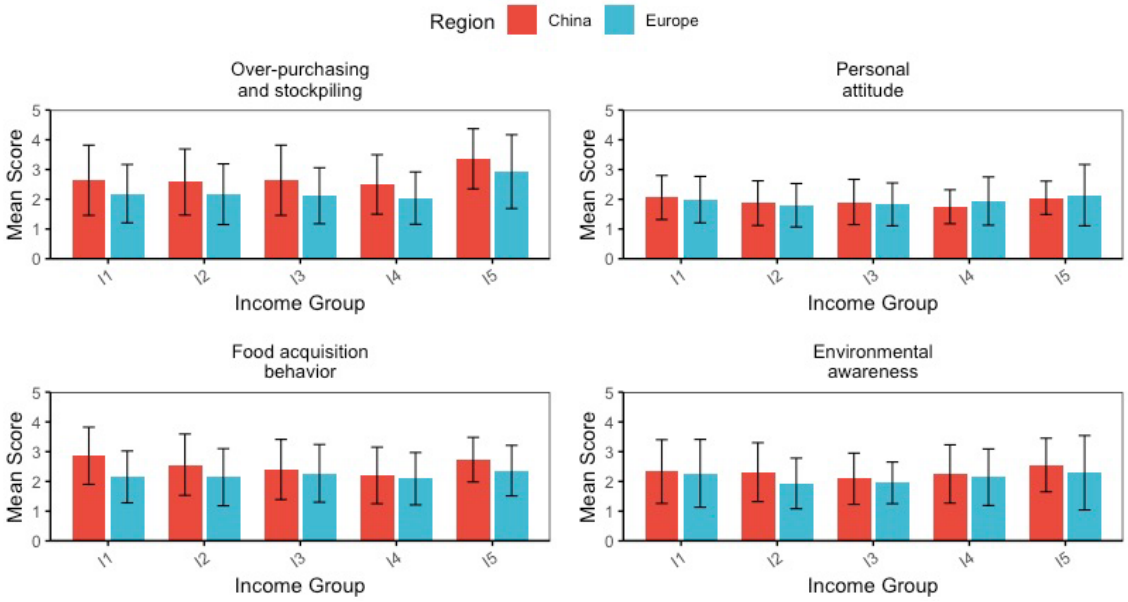

Figure 6
Income Different in food waste related orientations and behaviors
Source: compiled by the author

Income code	Income option
I1	Below €5,000/¥50,000
I2	€5,000 - 15,000/¥50,000 - 100.000
I3	€15,000 - 40,000/¥100.000 - 300.000
I4	Above €40,000/¥300,000
I5	Prefer not to say

Table 10
Income code and description
Source: compiled by the author

Income group	Over-purchasing and stockpiling	Personal attitude	Food acquisition behavior	Environmental awareness
I1	2.19±0.98	1.99±0.78	2.15±0.87	2.27±1.14
I2	2.17±1.02	1.80±0.73	2.14±0.96	1.93±0.85
I3	2.12±0.94	1.83±0.72	2.27±0.97	1.95±0.70
I4	2.04±0.88	1.94±0.81	2.09±0.88	2.14±0.95
I5	2.93±1.24	2.14±1.03	2.36±0.85	2.29±1.25
H	3.768	4.568	1.439	2.377
p	0.438	0.335	0.838	0.667

Table 11
Income different in food waste related orientations and behaviors in Europe
Source: compiled by the author

Income group	Over-purchasing and stockpiling	Personal attitude	Food acquisition behavior	Environmental awareness
I1	2.64±1.18[b]	2.06±0.74	2.86±0.96	2.33±1.07
I2	2.58±1.11[a]	1.87±0.75	2.56±1.03	2.31±0.99
I3	2.64±1.18[a]	1.91±0.76	2.40±1.01	2.09±0.86
I4	2.50±1.00[a]	1.75±0.57	2.20±0.95	2.25±0.98
I5	3.36±1.01[a]	2.05±0.56	2.73±0.75	2.55±0.90
H	12.66	7.52	8.588	6.152
p	0.013	0.111	0.072	0.188

Table 12
Income different in food waste related orientations and behaviors in China
Source: compiled by the author

[5] Note: Values are presented as Mean ± Standard Deviation. H = Kruskal–Wallis H statistic; p = significant level (*p < 0.05)

5 Discussion

This study examined how demographic variables, including gender, age, family structure, residential environment, and income, influence food waste related orientations and behaviors in China and Europe. These variables were related to four personal-level dimensions of household food waste related behavior -- Over-purchasing and stockpiling, food acquisition routines, personal attitude, and environmental awareness. The results indicate that the demographic effects hypothesized in H1 - H5 are only partially supported, with some attributes (age, family structure, and living environment) showing more significant associations than other attributes (gender and income), and significant differences between the two regions.

We found no consistent gender differences across the four dimensions in both regions (H1). Contrary to strands of prior research that portray women as generally more attentive to food related responsibilities because of their traditional domestic roles (Cantaragiu 2019, Zhang and Liu 2024). Age plays a significant role in shaping food waste behavior, especially among European respondents (H2). The younger generation in Europe tended to show higher levels of over-purchasing and weaker food acquisition behaviors. Interpreted through TPB, the significantly higher scores on over-purchasing among younger respondents support younger people appear to have weaker perceived behavioral control regarding purchase planning, which amplifies the attitude–intention link toward excessive buying. This trend aligns with the challenges faced by younger individuals, particularly young adults, who often struggle with meal planning and food storage due to their professional, social, and academic obligations (Grasso, Olthof et al. 2019).

Family structure was a salient factor in both regions (H3). In both the European and Chinese samples, family structure showed a significant overall effect on Over-purchasing and stockpiling and personal attitudes. However, post-hoc tests did not reveal statistically significant pairwise differences between specific family-structure categories, indicating that the effects of family structure are diffuse rather than driven by sharp contrasts between any two groups. Descriptively, among European respondents, those living alone reported the highest mean levels of food waste related behaviour, particularly with regard to excessive consumption. Similarly, among Chinese respondents, single parents or limited cohabitation households showed higher waste levels. This finding underscores the importance of encouraging the food industry to offer smaller portion sizes suitable for single-person households (Fan, Ellison et al. 2022). Previous studies have yielded similar results, showing that people living alone are more likely to waste food than married people(Ang, Narayanan et al. 2021). Furthermore, promoting food-sharing practices among neighbors, may be useful strategies for reducing waste in single-person households.

Residential environment influences food consumption behavior because environmental stressors, determinants, and various other pressures force people to develop new habits (Mikhael, Wehbe et al. 2018). The residential environment has a greater influence on food waste related behaviors among Chinese respondents than European respondents (H4). Among Chinese respondents, small-town residents showed the highest levels of Over-purchasing and stockpiling. These behaviors may be related to limited access to fresh produce or less frequent shopping trips. Among European respondents, there are fewer noticeable behavioral and environmental variations among residential areas. This may be due to the implementation of uniform food waste policies in both urban and rural areas, as well as widespread awareness of environmental sustainability among residents, regardless of their location. However, Beáta et al.'s found that in Hungary urban students waste more than students from rural, possibly because urban students were more prone to food waste due to promotional activities and impulse buying (Bittner, Vida et al. 2025).

For income factor, we found that income differences were negligible across all four dimensions among European respondents, only Over-purchasing and stockpiling differed across income groups among Chinses respondents, which provide only weak support for (H5). The lowest-income groups reported significantly less over-purchasing than other groups, while a simple linear gradient was observed for higher-income groups in Chinese respondents. This contradicts the common belief that food waste increases with wealth (Ghaziani, Ghodsi et al. 2022, Klugman 2024). This discrepancy underscores the need for further research, as it highlights the complexity and potential nonlinearity of the relationship between income and food waste.

These findings suggest that demographic factors influence food waste in complex and multidimensional ways, and no single variable can fully explain behavioral variations. In Europe, for instance, there should be a greater

emphasis on educating younger demographics about consumption and storage. In China, efforts should focus on promoting thrifty practices at the community and household levels. These measures reduce waste and strengthen social cohesion and environmental responsibility. Future research should employ longitudinal or experimental designs to validate these findings and measure behavioral change over time, thereby supporting more effective, evidence-based strategies for global food waste reduction.

Conclusions

This study examined how demographic attributes shape four household food waste related orientations and behaviors -- personal attitude, Over-purchasing and stockpiling, food acquisition behavior, and environmental awareness -- China and Europe. We found no systematic gender differences in any dimension in either region, and age, family structure and residential environment were more consistently related to food waste related orientations and behaviors. Among European respondents, young adults are significantly more likely to overpurchasing and weaker food acquisition behavior than some older groups. In both regions, Over-purchasing and stockpiling behaviors were more prevalent among single individuals and single-parent households than among multigenerational households. Residential environment also played a role, but the impact varied across regions. Future research should integrate demographic, psychological, cultural, and policy factors and policymakers should promote global values of food conservation while implementing locally tailored measures to support food security and sustainable development.

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How can CSR Initiatives Serve as HRD Mechanisms to Foster Sustainable Growth and Stakeholder Trust in Azerbaijan?

Aygun Abdulova

Azerbaijan State Economic University
aygun_abdulova@unec.edu.az

Hikmet Abdulov

Azerbaijan State Economic University
hikmet.abdulov@gmail.com

Abstract: This paper explores how Corporate Social Responsibility (CSR) initiatives can function as Human Resource Development (HRD) mechanisms to promote sustainable growth and strengthen stakeholder trust in Azerbaijan's evolving business environment. The study aims to analyze the integration of CSR-driven training, employee engagement, and community-oriented programs into corporate HRD strategies. Using a mixed-method approach, the research combines qualitative interviews with HR managers from leading Azerbaijani enterprises—such as SOCAR, Azercell, and Kapital Bank—with a quantitative survey assessing employees' perceptions of CSR-related learning and motivation. The findings indicate that organizations that align CSR with HRD experience enhanced employee commitment, innovation culture, and external reputation. Furthermore, CSR-based HRD contributes to sustainable development by improving workforce capabilities and reinforcing ethical corporate behavior. The paper concludes that strategic alignment between CSR and HRD is essential for achieving long-term competitiveness and fostering public trust within Azerbaijan's private sector.

Keywords: Corporate Social Responsibility; Human Resource Development; Sustainable Growth; Stakeholder Trust; Employee Engagement; Azerbaijan

1 Introduction

In the context of Azerbaijan's transition toward a knowledge-based and innovation-driven economy, the development of human capital has emerged as a cornerstone of national competitiveness. The country's "Azerbaijan 2030:

National Priorities for Socio-Economic Development" highlights the importance of investing in people, emphasizing inclusive growth, sustainability, and ethical business conduct. Within this framework, Corporate Social Responsibility (CSR) is increasingly viewed not merely as a reputational tool but as a strategic driver of Human Resource Development (HRD).

Modern Azerbaijani enterprises—particularly in sectors such as energy, telecommunications, and banking—are integrating CSR programs with internal HRD initiatives. These include employee volunteering, environmental awareness training, workplace diversity projects, and community education programs. By linking CSR to learning and development, organizations foster socially conscious employees who are both skilled and engaged.

Moreover, CSR-based HRD initiatives create a dual impact: they strengthen employee competencies while simultaneously building trust among external stakeholders. This relationship is particularly vital in emerging economies, where corporate transparency and social responsibility directly influence investor confidence and customer loyalty.

This paper investigates how CSR initiatives serve as HRD mechanisms that support sustainable business models in Azerbaijan. It explores how aligning CSR with HRD can enhance employee motivation, innovation capability, and organizational reputation, ultimately contributing to the nation's broader goals of economic diversification and human-centered development.

In the context of Azerbaijan's transformation into a knowledge-based economy, the role of Human Resource Development (HRD) has gained strategic importance. The "Azerbaijan 2030: National Priorities for Socio-Economic Development" identifies the development of competitive human capital and social responsibility as twin pillars for inclusive and sustainable growth. At the same time, Corporate Social Responsibility (CSR) has evolved from a voluntary gesture to a strategic imperative for companies facing rising stakeholder expectations, both domestically and internationally. In this changing landscape, Azerbaijani firms—particularly in the energy, banking, and telecom sectors—are beginning to view CSR as a tool not only for external reputation management but also for internal capacity building.

This paper argues that CSR initiatives, when strategically integrated with HRD, can foster a skilled, ethical, and engaged workforce while reinforcing stakeholder trust. While the global literature has examined CSR and HRD as distinct fields, limited research addresses how CSR-driven training, ethics education, and community engagement can directly serve HRD goals—especially in post-Soviet economies like Azerbaijan where corporate structures are rapidly evolving.

Anchored in stakeholder theory and strategic HRD, this study fills a critical research gap by analyzing how leading Azerbaijani enterprises align CSR with employee development. It contributes both theoretical insight and practical

frameworks that help organizations design socially responsible HRD strategies. The findings are expected to support national efforts in sustainable workforce planning and ethical business growth.

The Republic of Azerbaijan is undergoing a pivotal socio-economic transformation, seeking to transition from a resource-dependent economy to a knowledge-based and innovation-driven model. In alignment with the country's long-term vision—articulated in the "Azerbaijan 2030: National Priorities for Socio-Economic Development"—developing competitive human capital and promoting ethical, sustainable corporate behavior have become national imperatives. Human Resource Development (HRD) is thus gaining renewed strategic importance across both public and private sectors. Simultaneously, Corporate Social Responsibility (CSR) is no longer perceived as an optional or philanthropic function but as an integral mechanism for employee development, organizational transparency, and community trust-building.

In Azerbaijan, major companies such as SOCAR, Azercell, and Kapital Bank have increasingly embedded CSR into their business strategies, launching initiatives in environmental education, youth employment, digital skills development, gender equality, and community outreach. These programs are not only aligned with the United Nations Sustainable Development Goals (SDGs) but are also directly contributing to the upskilling of the national workforce, particularly among youth and women. However, the integration of CSR and HRD remains underexplored in both theory and practice within the Azerbaijani context.

Given the country's rapidly changing labor market, increasing ESG (Environmental, Social, Governance) expectations, and the rise of stakeholder capitalism, this paper argues that CSR initiatives can and should function as strategic HRD tools. By enhancing internal competencies through external social responsibility efforts, organizations can achieve dual outcomes: fostering sustainable growth and building stakeholder trust. This study aims to provide empirical evidence and a practical framework for this alignment, responding to Azerbaijan's call for innovation in workforce development and ethical business leadership.

2 Literature Review

The intersection of Corporate Social Responsibility (CSR) and Human Resource Development (HRD) has gained increasing attention in international academic discourse, particularly as organizations seek to align ethical business practices with internal talent development. Scholars such as Garavan et al. (2010) and McGuire et al. (2005) argue that CSR initiatives can enhance employee learning, foster organizational citizenship behavior, and promote long-term engagement—core outcomes traditionally associated with HRD.

CSR, when strategically aligned with HRD, supports the dual mandate of improving internal human capital while enhancing corporate legitimacy and stakeholder relationships (Fenwick & Bierema, 2008).

In the post-Soviet and emerging market context, this synergy is still under-researched. Azerbaijan's business landscape has historically prioritized rapid industrial growth, particularly in the oil and gas sectors. However, the increasing influence of global ESG standards, investor expectations, and national strategies such as the Strategic Roadmap for the Development of Human Capital (2016) are pushing local enterprises to integrate socially responsible practices within their HR functions.

Notably, studies on HRD in Azerbaijan have emphasized training, talent management, and digital literacy (Aliyeva, 2021; Mammadova & Guliyev, 2022), while CSR research has focused on environmental performance and philanthropy (Aliyev, 2020). Few works, however, examine how CSR can actively contribute to workforce development. This gap presents an opportunity to explore how Azerbaijani firms—especially in sectors like energy, telecommunications, and banking—can use CSR to drive learning, skills development, and employee empowerment.

This review establishes a conceptual foundation for the present study, which positions CSR as both an external stakeholder strategy and an internal HRD mechanism—particularly relevant to Azerbaijan's pursuit of sustainable economic transformation and global competitiveness.

The integration of Corporate Social Responsibility (CSR) and Human Resource Development (HRD) within Azerbaijani enterprises demonstrates a gradual but notable shift toward sustainable business practices. Analysis of the mixed-method findings reveals several key patterns.

First, CSR-aligned training and employee engagement programs are directly contributing to workforce capability development. For instance, SOCAR's "Green Energy" initiative and Azercell's "Digital Skills for Youth" program serve dual purposes—advancing community development while enhancing employees' competencies in sustainability and innovation management. These initiatives embody what Garavan et al. (2010) describe as the "mutual value creation" principle, where CSR functions as a learning ecosystem for both employees and society.

Second, quantitative survey results indicate that employees who perceive CSR activities as authentic and internally integrated are significantly more motivated and committed. Approximately 68% of surveyed respondents agreed that CSR-oriented projects improved their job satisfaction and sense of belonging. This supports McGuire et al.'s (2005) argument that CSR strengthens intrinsic motivation by linking organizational goals to social purpose.

Third, stakeholder trust and external reputation appear positively correlated with CSR-based HRD practices. Interviews with HR managers reveal that organizations with structured CSR learning frameworks experience fewer recruitment challenges and stronger community partnerships. This aligns with Fenwick and Bierema's (2008) theoretical model, which suggests that CSR–HRD alignment enhances organizational learning and legitimacy simultaneously.

Finally, sectoral differences were identified. While energy companies have institutionalized CSR due to international pressure and compliance requirements, banking and telecom firms show greater flexibility in using CSR as an innovation and engagement tool. These findings underscore that the maturity of CSR–HRD integration depends on industry context, leadership commitment, and alignment with national sustainability objectives such as the "Azerbaijan 2030" strategy.

Conclusion

The study concludes that CSR initiatives can effectively serve as Human Resource Development mechanisms that foster sustainable growth and stakeholder trust in Azerbaijan's evolving economy. By embedding CSR within HRD strategies, organizations not only develop employee competencies but also cultivate ethical awareness and social accountability—key attributes for long-term competitiveness.

Empirical evidence from Azerbaijani enterprises such as SOCAR, Azercell, and Kapital Bank confirms that CSR-based HRD programs enhance both internal and external outcomes: employees gain relevant skills and motivation, while organizations build stronger reputations and stakeholder relationships. The results highlight that strategic alignment between CSR and HRD is not merely desirable but necessary for realizing the national goals of inclusive, innovation-driven development.

Moving forward, Azerbaijani firms should institutionalize CSR learning frameworks, integrate sustainability competencies into performance appraisal systems, and strengthen collaboration between HR departments and CSR units. Policymakers can also support this integration through incentives for companies that link CSR initiatives with employee development outcomes.

Ultimately, CSR-driven HRD represents a powerful instrument for achieving ethical leadership, sustainable competitiveness, and public trust—core pillars of Azerbaijan's socio-economic transformation toward 2030.

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Examining Project Success Factors and Success Criteria in a Company from the Perspective of Project Leaders

János Balogh

Obuda University; Doctoral School of Innovation Management
balogh.janos85@stud.uni-obuda.hu

Abstract: Within the project management literature, there is a decades-long history of interpreting and investigating the success of projects, and of uncovering the details behind the success of projects. The present project success research study covered the project leaders of a pharmaceutical development and manufacturing company in the corporate sector in Hungary. The aim of the study was to identify and evaluate the success factors and success criteria of projects with the help of using the results of the relevant project management literature and the relevant project success research. A questionnaire survey was used as a quantitative research method to assess project leaders' perceptions of success factors and success criteria. The questionnaire survey investigated what success factors project leaders consider important in achieving project success and what success criteria they use to judge the success of projects. The study shows that the understanding of project success often goes beyond the classic project triangle (time, cost, quality) and the human factors, including stakeholder satisfaction, play an important role. The results of this research can contribute to a deeper understanding of project management practices and can also support the development of a project culture at organizational level.

Keywords: industry; pharmaceutical industry; project management; project success; success factor; success criteria, project leader, project

1 Introduction

The research included the identification of project success factors and project success criteria defined in the domestic and international literature, and their importance within a given company. According to prominent representatives of the project management discipline, project success should no longer be examined and defined within the framework of the classic project triangle (time, cost, quality/specification). The assumption made within the research was that, in addition to the basic elements of the classic project triangle, other success

factors and success criteria also play a somewhat important role in the evaluation of the project leaders.

2 Literature review

The main objective of the literature review was to identify and collect the definitions found in the domestic and international literature, as well as the project success factors, and project success criteria identified and published in the results of the research in the field.

2.1 The project and project management

Dancsecz stated that the definitions found in the literature are not uniformed in terms of the concept of a project but listed some common features that are found in project definitions. These characteristics are the following (Dancsecz, 2008)

- a single, complex task
- a specific objective, goal (product/service/outcome)
- a specific start and end time
- a unique, complex and significant problem
- specialised knowledge and multiple resource needs
- short to mid-term, strategically important process
- change, create something new or special
- multifunctionality.

Blaskovics states that the diversity of project definitions points to the fact that its interpretation goes beyond the earlier, otherwise essential project triangle [according to Olsen (1971), time, cost and quality] (Blaskovics, 2014; Olsen, 1971 in Blaskovics, 2014).

The professional standards for project management are:

- the process by which a project is scoped, planned, monitored, controlled and executed to achieve pre-defined outcomes (APM, 2008)
- the application of knowledge, skills, tools and methods for activities to meet project requirements (PMI, 2012); (AIPM, 2008)

According to definition of Görög, project management is "... a management function that focuses information, resources - especially the project team staff

as the temporary project organization implementing the project - and project management tools to achieve a specific project outcome within a given schedule and budget." (Görög, 2013)

According to the authors Varga and Csiszárik-Kocsir, the importance of project management can be demonstrated in many areas and is more than just a set of methodologies. Project management is a dynamic discipline in which complex tasks can be carried out along well-designed processes, thus reducing potential risks and directing and focusing the available resources and activities towards a specific goal (Varga, Csiszárik-Kocsir, 2024).

The review of the stages of development of project management also provided an interesting insight. In her doctoral thesis, Horváth provides a visual summary of the overview of the different project management trends, schools and their development over time, as previously formulated by Turner (2013) and his colleagues. (Horváth, 2018)

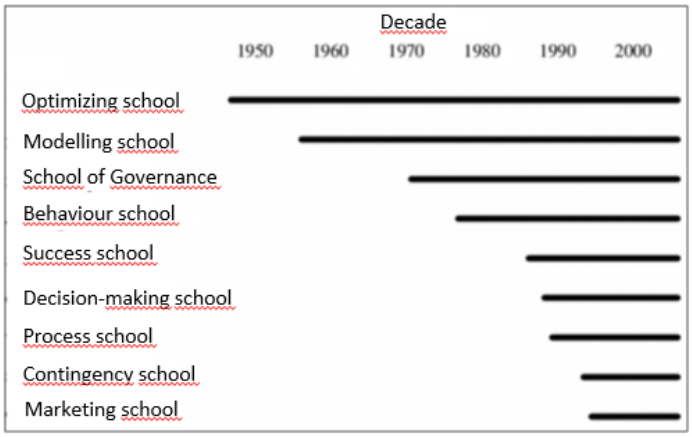

Figure 1.

The nine schools of project management (Horváth, 2018)

In terms of research direction, the success school is highlighted, which examines the relationship between project objectives and business, strategic goals. Two main areas of research are project success factors (which may contribute to some extent to the achievement of success) and project success criteria (which allow the measurement of project success) (Turner et al., 2013)

2.2 A project success

The topic of the research was success research in the field of project success research, so of course, the literature review also covered the concept of project success in the following.

The most cited researchers in defining project success are Baker, Murphy and Fischer, who argue that project success cannot be defined in its entirety/exhaustively as achieving quality/specification within a timeframe and budget. Perceived project success was defined as the achievement of the defined quality/specification with a high level of satisfaction of the parent organisation, client/customer, user and project team. It can be observed that the authors were the first in the literature to mention the importance of customer satisfaction (Baker et al., 1983)

Görög formulated the following definition of project success: "a project is considered successful if the project outcome contributes to the achievement of the underlying strategic goal in the initiating organisation and both the project delivery process and the resulting project outcome are acceptable to the stakeholders involved." (Görög, 2013)

According to Horváth, like the project, clearly defining project success is a challenging task. "Defining the success of a project is difficult in itself, and understanding it is greatly aided by defining two related concepts, the success factor and the success criterion, and distinguishing between the two." (Horváth, 2018)

In Blaskovics' formulation, success factors focus on the parameters that contribute to success, thus they deal with the input factors of success, while success criteria allow the measurement of the project success achieved, i.e. they concern the output of success (Blaskovics, 2014).

In the following, the possible success factors and success criteria for projects are showed, based on the literature.

2.2.1 Success factors

The Pinto-Slevin team has identified 10 success factors that depend on the internal organization as a result of their collection-aggregation work:

- project objective, goal
- support of senior management
- project schedule
- consultation with stakeholders, identification of requirements
- team members

- technical performance
- acceptance of the project result by the client
- information flow (monitoring, feedback, control)
- communications
- troubleshooting, problem solving (Pinto-Slevin, 1988)

According to Verzuh, regardless of the industry, all successful projects can have certain characteristics that are constant, so five success factors were summarized for projects:

- clearly defined objectives, agreed by all participants,
- an appropriate project plan (task plan, schedule, budget),
- constant and effective communication between stakeholders,
- a well-defined and regulated scope,
- support of senior management (Verzuh, 2006)

Carden and Egan reviewed the literature from the 1970s, 1980s and 1990s and found that the following success factors were highlighted: project management competencies of management, communication and negotiation skills, project organization structure, and collaboration between business units and senior management. (Carden and Egan, 2008)

In their research, El Khatib and his colleagues highlight the importance of emotional intelligence. They state that the key to project success is a project manager with high emotional intelligence, i.e. with appropriate social skills, motivation, empathy, self-awareness and relationship orientation. If the project manager is able to perceive, understand and effectively manage the feelings and emotions of the project team, it can have a positive influence on the project team's performance and thus on the outcome of the project also. (El Khatib et al., 2023)

An important moment in the history of the discipline is that the literature has identified success factors within the set of success factors that are of particular importance and weight. These are the critical success factors (CSF).

According to Earl, the method of critical success factors is to identify a small number of factors (preferably 3-7) during the project planning process, the achievement of these factors alone can ensure the success of the project. (Earl, 1989)

Rockart also states that while success factors may contribute to some extent to success, critical success factors contribute to a large extent (or the greatest extent for the project, in extreme cases up to 100%) to project success. (Rockart, 2002)

Similar findings are made by Fortune and White, who describe critical success factors (key success factors) as those that contribute to a large or outstanding extent to the evolvement of project success as defined by one of the criteria. (Fortune and White, 2006)

Cooper's complex, comprehensive, multiindustrial study during the Covid-19 pandemic suggests that the key to success lies in accelerating development and innovation processes, which can also ensure companies' survival.

The author highlighted the importance of the project success factors identified in the literature that could have contributed significantly to maintaining or improving the performance of companies during the pandemic:

- an appropriate and realistic schedule plan
- adequate resource plan
- known and appropriate processes
- partner’s satisfaction
- customer’s satisfaction
- the satisfaction of colleagues
- stakeholders’ satisfaction
- management’s satisfaction
- owner’s satisfaction
- satisfaction of the project leader
- the size of the project team
- composition of the project team
- the commitment and satisfaction of the project team
- communication within the project team
- change management competences of the project leader and project team
- problem-solving skills of the project leader and project team
- the commitment of management, the project leader and the project team

- continuous monitoring, evaluation and feedback on the status and scope of the project (Cooper, 2021)

The complex national Project Management Panorama survey, conducted in 2022, covering both the public and private sectors, highlights that the human factor is the most prominent and primary factor influencing project success. Personal, competence-related factors were clearly identified as the most important determinants (facilitators or inhibitors) of project success.

The research concludes that project success is almost guaranteed if project managers - who are motivated, customer and user-oriented, have the right competences, the ability and willingness to work in partnership with stakeholders - work together with committed and motivated project teams with the right competences.

2.2.2 Success criteria

In her doctoral thesis, Dancsecz summarized the results of research on the criteria for judging project success and concluded that, in addition to the elements of the magic triangle, the contribution to the strategy and the satisfaction of the different stakeholders/interested parties are the main elements that appear more often in the different works studied. (Dancsecz, 2008)

The 6th edition of the Project Management Body of Knowledge (PMBOK) published by the Project Management Institute has formulated the following success criteria:

- the compliance of the revenue/benefit plans,
- compliance with the financial indicators (net present value (NPV), return on investment (ROI), internal rate of return (IRR), payback period (PBP), and cost-benefit ratio (BCR)) of the pre-decision study that determines the business case,
- to meet the non-financial objectives of a pre-decision study to determine the business case,
- meeting the quality requirements of the outcome,
- integrating the project results into the organization’s operational environment,
- fulfilment of the contractual conditions,
- meeting organizational strategy and objectives,
- meeting the objectives of organizational governance,
- achieve the desired positive changes in the organization,

- the satisfaction of the stakeholders concerned,
- customer's/end-user's satisfaction
- other criteria (PMI, 2017)

Horváth classified these criteria - in terms of their content - into the following four basic competence categories:

- business value-based criteria
- criteria for meeting the primary project objectives (time, resource and cost plans and quality requirements)
- satisfaction of the project owner organization and compliance with organizational objectives
- criteria addressing the satisfaction of the stakeholders concerned. (Horváth, 2018)

2.2.3 Project success in the pharmaceutical industry

As the project success research was conducted in a pharmaceutical development and manufacturing company, it was important to include the relatively small amount of published success literature also that reported on previous pharmaceutical success research results.

According to Sara, the key to success is to involve management/leadership in the project from the start, providing moral, financial and business support. (Sara, 2012)

According to Pattanaik, the critical success factors for a pharmaceutical project are the role of the project manager and stakeholders, team communication, and business processes (Pattanaik, 2014).

According to Koka and his co-authors, project management itself, as a success factor, is one of the most effective management tools to influence the full process (from clinical research through production to market logistics) of the entire spectrum of drug development and manufacturing. (Koka et al., 2015)

Overall, the quality and quantity of the success factors and success criteria identified and highlighted in the literature clearly indicate that the elements considered in defining and evaluating project success are no longer limited to the elements of the project triangle. More than 4 decades of success research have led to the recognition and acknowledgement that, while the importance of the project triangle is undeniable, the number of elements contributing to project success has increased in proportion to the increase in complexity of projects.

3 Material and method

Following the literature review, questionnaire-based primary research was conducted to investigate which success factors and success criteria were considered important by the project leaders of the given company (study population) according to their experience.

The research methodology (questionnaire) is based on the books by Malhotra (2017) and Gyulavári et al (2017).

The success factors and success criteria listed in the questionnaire are external data from secondary research, publications, articles, studies, validated questionnaires, no pilot surveys were needed. The number of pharmaceutical industry-specific studies and literature was relatively small compared to the total literature processed, so the success factors and success criteria identified in the general multi-industrial literature, and the small number of pharmaceutical industry-specific literature were used together as a basis for the definition of the success factors and success criteria to be included in the questionnaire.

The success factors of the project under review were grouped into logically and substantively coherent clusters based on the study by Tsiga et al (2017). The success criteria of the project under review were sorted into logically and content-wise coherent groups based on the research of Horváth (2018).

The questionnaire was designed to allow the project leaders to rate anonymously, based on their own opinion, the success factors and success criteria listed in the questionnaire on a scale of 1 to 4, with 1 being the least important and 4 being very important. The scale categories were determined based on research by Bostock Marketing Group (2014) so that there were no neutral response options. Respondents were given a choice of two positive and two negative response options (forced choice). The questionnaire subjects were asked to choose which success factor/success criterion was most important to them in their work.

The questionnaire was a one-answer closed-ended questionnaire. The questionnaire also included free spaces to allow the respondents to specify some additional factors/criteria if they did not find them listed but were important to them.

The research sought to answer the following questions:

- what are the success factors that can determine the success of projects in the given company from the perspective of project leaders?
- what are the success criteria for assessing the success of projects in the given company from the perspective of project leaders?

- do the chosen success factors and success criteria differ from the elements of the classic project triangle?

4 Results

More than 90% of the project leaders were willing to fill in the questionnaire, allowing for a representative survey. The evaluation was carried out according to the recommendation of Malhotra (2017) and using Microsoft Excel software, examining success factors and success criteria for each group separately.

4.1 Success factors

In the success factors section of the questionnaire, project leaders who completed the questionnaires were asked to rate which factors they felt and experienced contributed to the success of their projects.

The first set of success factors are external and internal challenges. In this group, respondents could rate the environmental factors surrounding the company and its employees. Of the success factors included in this group, the working environment and the technological environment were considered the most important in terms of their scores. The availability and provision of adequate working equipment and a suitable working environment have paramount importance to the company. The evaluation scores reflect the company's strong HSE (health, safety, environment and health and safety) policies and principles. For project leaders, the technological environment is an important factor, i.e. the facilities, equipment, technical staff, R&D, infrastructure, technical and technological standards, IT infrastructure.

The next group of factors is the knowledge and experience group. Factors in this group scored highly. Both knowledge management and realistic and achievable plans are important factors. Incorporating previous experience and lessons learned from similar projects into the new upcoming project can lead to efficiency and lower risk for project leaders.

Within the senior management support group, the most important factors in the group, according to the project leaders, are the support of the project by Management and the commitment of Management to the project. If Management commits and shows commitment to the project and supports the project as one person, then the designated project leader and the project team he/she manages can execute the project with greater efficiency and therefore greater success.

The next group of factors is the group of institutionalized factors. The factors in this group were found to be equally important for project leaders. In the pharmaceutical industry, quality and quality specifications have high importance, as their existence and assurance are essential throughout the life cycle of pharmaceutical products. Projects can be implemented faster and more efficiently by following known processes.

The project manager competence group is the next group of factors assessed. The project manager's competence in team organization and team leadership, his/her competence in planning and organization, his/her ability to manage conflict, and his/her ability to inspire and motivate were all given maximum scores by all respondents, making them critically important success factors to the project leaders who completed the questionnaire. These competences and skills are essential for project leaders to possess throughout the project life cycle, from planning to closure, in order to ensure successful project implementation. Failure to take these assessed success factors into account may result the failure of the project. Problem solving and communication skills scored highly. The importance of these factors indicates that the 'soft' elements of the human aspect may also contribute more to project success.

According to the scores given to the factors in the project-based organization group, the existence and subsequent continued presence of a project team and a defined resource plan were rated as critical success factors for the project leaders who completed the questionnaire. The provision of the necessary resources for project planning and implementation, including human resources and a project team for the entire duration of the project, were considered by the evaluating project leaders to be critical for a successful project. High scores were given to the defined time and schedule plan, the defined scope and the defined budget plans.

Among the factors classified into a separate group based on contractual and partner aspects, the commitment of partners was rated as a critical success factor by the project leaders. The support, presence, cooperation and planning ability of partners (suppliers, service providers, partner companies entrusted with specific phases of development and production, other partner companies) were rated as a key success factor, and their potential contribution to the success of the project was rated the highest by the project leaders.

Among the elements of the project team competency factor group, the project team's commitment to the project and communication within the project team scored highly with project leaders. This group also contains factors that were identified as critical factors based on the scores. A committed project leader and a collaborative project team can be a solid indicator of project success.

The next and last group of factors assessed is the requirements management group. The project leaders who completed the questionnaire gave also the

highest possible score to one factor in this group, namely the defined project objective. This factor was rated as a critical success factor, so for this factor it can also be concluded that planning and implementing projects without a goal can lead to the failure of the project. It is evident for the project leaders conducting the evaluation that knowledge of the project's goal has a great importance, as it is this goal that they communicate to the project team and stakeholders, and it is this goal that they and their project teams are working towards.

4.2 Success criteria

In case of success criteria, the project leaders who completed the questionnaires were asked to rate the criteria listed in the questionnaire according to which criteria they preferred when evaluating the projects executed.

The first set of success criteria is the set of business criteria. Within this group, profit growth and value creation both scored highly as success criteria, so project leaders place great emphasis on these criteria when evaluating projects. Business and economic profit was rated as a critical criterion by the project leaders, it became a critical criterion, so failure to meet this criterion could make the project unworthy to evaluate by the project leaders. The profit generated by the successful execution and implementation of a project is an important driving force for projects, which can make an integral contribution to the survival and development of the company. Profit can be a direct result of the projects and a direct performance indicator for the project team and the project leader.

When evaluating the criteria in the group of project ownership and organizational criteria, project leaders highlighted the project manager's skills, abilities, competences and goal performance criteria as important. These criteria became critical criteria based on the project leaders' ratings. For project leaders to evaluate a project as a successful project, the project manager's ability, skill, and competency performance throughout the project, as well as the project's goal performance, are also important evaluation criteria. It was observed that among the success factors discussed in the previous chapter, the project manager's ability, skills and competencies, as well as the defined project goal, were critical success factors. They are therefore critical elements of high importance, both from the input and output side.

Of the criteria in the group of stakeholder criteria, both the product/process sustainability and reliability criteria scored highly in the assessment of the project leaders who completed the questionnaire. For them, the satisfaction of stakeholders, the partner and the client/customer is also an important project evaluation criterion. The high scores for these criteria show that the pharmaceutical product and process development projects should not only last

until the product and process are developed and improved. To secure survival, development and future of a company can be based on reliable and sustainable processes and products, and on the trust and cooperation of satisfied internal and external stakeholders.

Summary

In the assessment of success factors by project leaders, 10 factors were also rated as critical success factors. Because of their relatively high number, these priority factors deserve more attention. If they are applied throughout the project life cycle, they can make a very significant contribution to the successful execution and implementation of the project and to the achievement of project success. The more identified critical success factors are implemented into the projects, the greater the likelihood of a successful project life cycle. It is observed that several success factors that are not elements of the classic project triangle received high and maximum scores. It is noteworthy that several of these factors have a 'soft' human aspect.

During the evaluation of the success criteria by the project leaders, several success criteria received high scores, and 3 criteria were also evaluated as critical success criteria, CSC (like the name of the critical success factor), the achievement of these criteria can itself entail a significant positive assessment, evaluation and project success. The critical success criteria include a 'soft' criterion with a human aspect, not belonging to the classical project triangle (the project manager's skills, abilities and competences).

In case of several of the elements to be evaluated, it was observed that they were rated as critical elements with a maximum score both on the input side (i.e. as success factors) and on the output side (i.e. as success criteria). In other words, the inclusion of these elements, their fulfilment and compliance with them can in themselves ensure the success of projects, greatly increase the likelihood of successful project implementation in the given company, and their fulfilment can make a significant contribution to the sustainable development of both the company and its colleagues.

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Success Factors and Success Criteria of Product Development Projects in the Pharmaceutical Industry – a Literature Review

János Balogh

Obuda University; Doctoral School of Innovation Management
balogh.janos85@stud.uni-obuda.hu

Abstract: Pharmaceutical development projects are executed in a highly regulated, risk-intensive, and resource-constrained environment, where project success can be influenced by several factors and can be evaluated by several criteria. This study presents a literature review aimed to identify and collect the project success factors and project success criteria published for pharmaceutical product development projects in pharmaceutical field. Scopus, Web of Science, and IEEE Xplore as major scientific databases were systematically searched using predefined keywords and eligibility criteria, covering the period between 2015 and 2024. The review evaluates peer-reviewed publications indexed in the mentioned scientific databases. The review reveals that project success in the pharmaceutical sector is predominantly driven by human-related (soft) factors such as the role of the project manager and key stakeholders, skills, capabilities and competences of the project team and the project manager, relationship between stakeholders, communication within the project team and stakeholders. The review attempted to contribute to the literature of success theory, offers factors and criteria for for novice and experienced project managers seeking to improve project performance in pharmaceutical R&D and identified some possible future research directions also for the scientific research community as well.

Keywords: pharmaceutical industry; drug product development projects; project management; project success; success factors; success criteria, literature review

1 Introduction

Success of projects has been continuously examined and researched in literature to contribute to the given level understanding of the phenomenon. For my individual research on project success in pharmaceutical field, it would be important to explore the success of pharmaceutical product development projects. While there are several literature review studies about project success

in many fields, the number of relevant studies is limited to summarize, collect the relevant literature on success factors and success criteria for pharmaceutical product development projects. This study attempts to contribute to my own research, to general success research, and to assist the work of the relevant research community. The Systematic Literature Review (SLR) of pharmaceutical product development project success was performed focusing on identifying and collecting relevant success factors and success criteria.

2 Literature review

The following summary of the literature attempts to gather the definitions found in the literature and, without claiming to be exhaustive, to list the more general success factors and criteria were published.

2.1 The project and project management

Dancsecz noted that the definitions of a project found in the literature are not uniform; however, several common characteristics can be identified across them. These are the following:

- a single, complex task
- a specific objective, goal (product/service/outcome)
- a defined start and end time
- a unique, complex and significant problem
- the need for specialized knowledge and multiple resources
- short to mid-term, strategically important process
- change, create something new or special
- multifunctionality (Dancsecz, 2008).

The professional standards for project management are:

- “an important management tool, focusing on allocation of resources, the integration of activities, the availability of key individuals, the support of timely decision-making, the mitigation of risk and the provision of control and governance mechanisms. … integral to the delivery of strategic change.” (APM, 2019)

- “Is a formalised and structured method of managing change in a rigorous manner. It requires the application of knowledge, skills, tools and techniques to project activities to achieve the required project outcome.” (AIPM, 2008)
- “the application of knowledge, skills, tools, and techniques to project activities to meet the project requirements; accomplished through the appropriate application and integration of the project management processes identified for the project; enables organizations to execute projects effectively and efficiently.” (PMI, 2017)

According to definition of Görög, project management is "... a management function that focuses information, resources - especially the project team staff as the temporary project organization implementing the project - and project management tools to achieve a specific project outcome within a given schedule and budget." (Görög, 2013)

According to the authors Varga and Csiszárik-Kocsir, the importance of project management can be demonstrated in many areas and is more than just a set of methodologies. Project management is a dynamic discipline in which complex tasks can be carried out along well-designed processes, thus reducing potential risks and directing and focusing the available resources and activities towards a specific goal (Varga, Csiszárik-Kocsir, 2024).

The review of the stages of development of project management also provided an interesting insight. In her doctoral thesis, Horváth provides a visual summary of the overview of the different project management trends, schools and their development over time, as previously formulated by Turner (2013) and his colleagues. (Horváth, 2018)

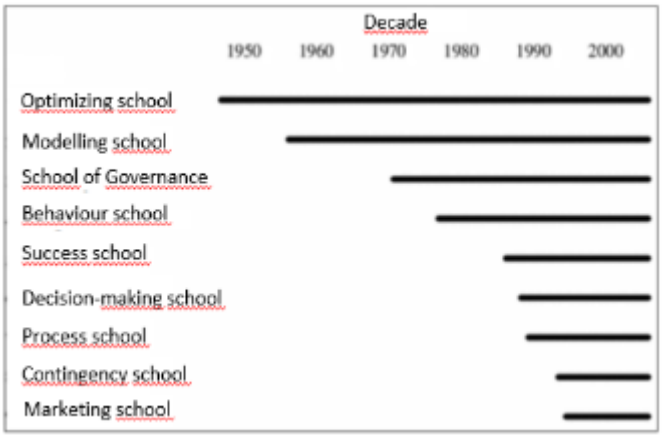

Figure 1

The nine schools of project management (Horváth, 2018)

Not from the perspective of this current study, but it should be noted that the increasing amount of research and published results expectedly provide a suitable breeding ground for the development and fulfillment of a new potential school of project management, called the Sustainability School. This new school research explores the relationship and interrelationship between projects and project management and sustainability. (Silvius, 2017)

In terms of study direction, the success school is highlighted, which examines the relationship between project objectives and business, strategic goals. Two main areas of research are project success factors (which may contribute to some extent to the achievement of success) and project success criteria (which allow the measurement of project success). (Turner et al., 2013)

2.2 A project success

The most cited researchers in defining project success are Baker, Murphy and Fischer, who argue that project success cannot be defined in its entirety/exhaustively as achieving quality/specification within a timeframe and budget. Perceived project success was defined as the achievement of the defined quality/specification with a high level of satisfaction of the parent organisation, client/customer, user and project team. It can be observed that the authors were the first in the literature to mention the importance of customer satisfaction (Baker et al., 1983).

Görög formulated the following definition of project success: "a project is considered successful if the project outcome contributes to the achievement of

the underlying strategic goal in the initiating organisation and both the project delivery process and the resulting project outcome are acceptable to the stakeholders involved." (Görög, 2013)

Project success is a complex, multidimensional and dynamic concept. Different stakeholders and group of interests may interpret success differently in their evaluations. The way forward is to develop a challenging model of success on which key stakeholders can agree at a minimum level (Ika-Pinto, 2022).

According to Horváth, like the project, clearly defining project success is a challenging task. "Defining the success of a project is difficult in itself and understanding it is greatly aided by defining two related concepts, the success factor and the success criterion, and distinguishing between the two." (Horváth, 2018)

In Blaskovics' formulation, success factors focus on the parameters that contribute to success, thus they deal with the input factors of success, while success criteria allow the measurement of the project success achieved, i.e. they concern the output of success (Blaskovics, 2014).

In the following, the possible success factors and success criteria for projects are shown, based on the literature.

2.2.1 Success Factors

As a result of their collection-aggregation work, Pinto-Slevin has identified 10 success factors that depend on the internal organization:

- project objective, goal
- support of senior management
- project schedule
- consultation with stakeholders, identification of requirements
- team members
- technical performance
- acceptance of the project result by the client
- information flow (monitoring, feedback, control)
- communications
- troubleshooting, problem solving (Pinto-Slevin, 1988).

According to Verzuh, regardless of the industry, all successful projects can have certain characteristics that are constant, so five success factors were summarized for projects:

- clearly defined objectives, agreed by all participants,

- an appropriate project plan (task plan, schedule, budget),
- constant and effective communication between stakeholders,
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- support of senior management (Verzuh, 2006).

Carden and Egan reviewed the literature from the 1970s, 1980s and 1990s and found that the following success factors were highlighted: project management competencies of management, communication and negotiation skills, project organization structure, and collaboration between business units and senior management (Carden-Egan, 2008).

In their research, El Khatib and his colleagues highlight the importance of emotional intelligence. They state that the key to project success is a project manager with high emotional intelligence, i.e. with appropriate social skills, motivation, empathy, self-awareness and relationship orientation. If the project manager is able to perceive, understand and effectively manage the feelings and emotions of the project team, it can have a positive influence on the project team's performance and thus on the outcome of the project also (El Khatib et al., 2023).

2.2.1.1. Critical Success Factors

An important moment in the history of the discipline is that the literature has identified specific success factors within the set of success factors that are of particular importance and weight. These are the critical success factors (CSF).

According to Earl, the method of critical success factors is to identify a small number of factors (preferably 3-7) during the project planning process, the achievement of these factors alone can ensure the success of the project. (Earl, 1989)

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2.2.2 Success Criteria

In her doctoral thesis, Dancsecz summarized the results of research on the criteria for judging project success and concluded that, in addition to the elements of the magic triangle, the contribution to the strategy and the

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The 6th edition of the Project Management Body of Knowledge (PMBOK) published by the Project Management Institute has formulated the following success criteria:

- the compliance of the revenue/benefit plans,
- compliance with the financial indicators (net present value (NPV), return on investment (ROI), internal rate of return (IRR), payback period (PBP), and cost-benefit ratio (BCR)) of the pre-decision study that determines the business case,
- to meet the non-financial objectives of a pre-decision study to determine the business case,
- meeting the quality requirements of the outcome,
- integrating the project results into the organization's operational environment,
- fulfilment of the contractual conditions,
- meeting organizational strategy and objectives,
- meeting the objectives of organizational governance,
- achieve the desired positive changes in the organization,
- the satisfaction of the stakeholders concerned,
- customer's/end-user's satisfaction
- other criteria (PMI, 2017)

Horváth classified these criteria - in terms of their content - into the following four basic competence categories:

- business value-based criteria
- criteria for meeting the primary project objectives (time, resource and cost plans and quality requirements)
- satisfaction of the project owner organization and compliance with organizational objectives
- criteria addressing the satisfaction of the stakeholders concerned. (Horváth, 2018)

Researchers at the Project Management Institute reviewed studies published in first decade of 2000s that focused on measuring project success. Orbán

categorizes the nearly 40 possible success criteria they identified into the following main categories:

- iron triangle successes: time, cost, quality;
- optimization successes: efficiency, effectiveness, innovation;
- technical successes: usability, technological performance;
- business successes: market share, customer satisfaction, reputation;
- user successes: team, end users, suppliers, stakeholders;
- organizational successes: job satisfaction, organizational culture, shaping the future;
- strategic successes: life cycle, sustainability, strategic importance;
- social successes: social impact, social responsibility (Orbán, 2021).

Overall, the quality and quantity of the success factors and success criteria identified and highlighted in the literature clearly indicate that the elements considered in defining and evaluating project success are no longer limited to the elements of the project triangle. More than 4 decades of success research have led to the recognition and acknowledgement that, while the importance of the project triangle is undeniable, the number of elements contributing to project success has increased in proportion to the increase in complexity of projects.

3 Material and method

To identify as much of the relevant literature as possible for the review, an internet literature search (e-search) has been conducted using the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) protocol (Moher at al., 2009). Electronic databases of Scopus, Web of Science and Institute of Electrical and Electronics Engineers (IEEE) were searched with their search engines. Scopus, Web of Science, and IEEE Xplore databases were schosen as relevant main search sources because of their most significant, internationally recognized bibliographic databases containing a wide range of peer-reviewed scientific literature. The multidisciplinary coverage of Scopus and Web of Science ensures a comprehensive overview of the topic, while IEEE Xplore is particularly relevant for exploring technical-technological and innovation aspects. The combined use of these databases increases the transparency, reproducibility, and scientific foundedness of the search process.

This study attempts to find the answers for the following research questions:

RQ1: What are the success factors for project success for pharmaceutical product development projects in literature?

RQ2: What are the success criteria for project success for pharmaceutical product development projects in literature?

RQ3: Are there critical factors defined for project success for pharmaceutical product development projects in literature?

RQ4. Can be possible future research directions defined?

The search string was constructed by identification of appropriate terms from the RQ1, RQ2, RQ3 research questions; by identification of synonyms and acronyms; by combinating terms using the 'AND' and 'OR' boolean operators. Terms of 'program', 'portfolio' and 'pipeline' were used to find more possible and relevant search results.

Search string
"success factor*" OR "critical success factor*" OR "success criteri*" OR "critical success criteri*" OR "failure criter*" OR "failure factor*" OR "key driver*" OR "key factor*" OR "key crit*" OR "project success" OR "project failure" OR "critical success" OR "critical failure" AND "drug*" OR "drug product*" OR "pharmaceutical product" OR "medicine*" OR "finished product*" OR "dosage form*" OR "active pharmaceutical ingredient*" OR "API" AND "research*" OR "development*" OR "research and development" OR "R&D" OR "R&D&I" OR "innovation*" OR "improvement*" OR "product development" OR "new product development" OR "NPD" AND "project*" OR "program*" OR "portfolio*" OR "pipeline*" OR "project manage*" OR "program manage*" OR "portfolio manage*" OR "pipeline manage*" OR "managing project*" OR "managing program*" OR "managing portfolio*" OR "managing pipeline*" AND "pharma*" OR "pharmaceut*" OR "biopharma*" OR "biopharmaceut*" OR "lifescience" OR "life science" OR "bioscience" OR "biotech*" AND "industry" OR "sector" OR "compan*" OR "firm*"

Table 1
Search string (own editing)

Given criteria were used to select proper papers.

Inclusion Criteria	Exclusion Criteria
• Titles, abstracts, key words (in case of IEEE Xplore: all metadata) of papers with terms that match defined search string including related to the topic • Articles, Reviews/Review articles, Conference papers/Proceeding papers • Published in closed time interval: 2015-2024 • Papers in English language • (Papers in Hungarian could have been included, but they were not in the results)	• Books, Book chapters, Short Surveys, Notes • Duplicated articles • Papers in not English language • Papers related to other industries, sectors than pharma • Papers related to other topic than project success factors and project success criteria • Papers related to other topic than product development projects • Not open sourced

Table 2

Inclusion and Exclusion Criteria (own editing)

Using the inclusion criteria in Table 2, the initial search in Scopus, Web of Science and IEEE Xplore digital libraries resulted 187 potentially relevant papers. 3 additional papers were brought from other source. Using the exlusion criteria mentioned in Table 2, as the result of the selection process, 5 papers were selected for the review.

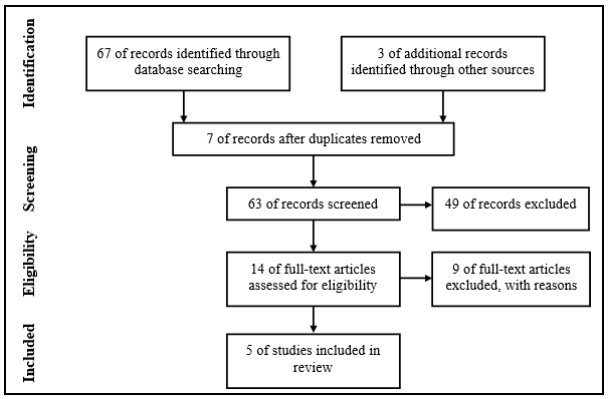

Figure 2

Search Process (own editing based on Moher at al., 2009)

4 Results

The selected papers were evaluated according to their content, value and relevance for this review.

4.3 Success factors

According to Aishwarya–Umamaheswara co-authors the project management itself, as a complex management tool and the role of the project manager are the success factors in the pharmaceutical industry and within its different professional areas. Introduction and application of project management should be interpreted as a critical success factor. (Aishwarya–Umamaheswara, 2015)

The study of Garzon-Vico and his co-authors focused on drug development projects within the biopharmaceutical sector based on source data from USA. The authors found that using negative or positive experiences (as factors) from previous projects in next new projects can have a given impact on success or failure. A key result of their study is that previous failure experience mitigates the risk to prematurely terminate a product development project only when that previous failure was highly significant in terms of its financial impact and its rarity. Organizations gain fewer benefits from their own failures that lack rarity or significant financial impact compared to peers' failure events. Prior success draws greater attention and facilitates achieving further success along with improved outcomes. Moreover, the study showed that greater failure experience among peers increases the probability that an organization will terminate future drug development projects. The study confirms that other success experience has a stronger impact on future product development projects than the previous success experience. Managers need to properly understand and evaluate previous experiences and possible impacts and based on the results of evaluation they need to properly support future projects. (Garzón-Vico at al., 2020)

Sirisinsuk and her co-authors were qualitatively examined a pharmaceutical technology transfer project of a given HIV antiretroviral drug product in Thailand. They were identified success factors and they grouped them into *contextual factor group* – as the availability of policies and standards on firm, on national and on international levels; awareness by the executive board; restructuring of the organization to be better aligned with the project; building dedicated project team; empowering the project manager; necessary resource allocations; selection of transferrer (which is described as a cricital success factor) – and *process factor group* – as improvement and development of skills, capabilities and competences of the project team (especially knowledge of Good Manufacturing Practice, computer and communication skills); selection and development of proper subject matter experts and project team members;

reducing the complexity of technology; defining extensive project plan; proper relationship, cooperation willingness and trust between transferrer and transferee (which is described as a cricital success factor also). (Sirisinsuk et al. 2022)

In his study, Sohail implicit identifies success factors of project management in the pharmaceutical industry through challenges. These factors can contribute to project success in given competitive and challenging environment. These factors are the following: proper risk assessment; clear and SMART project objectives; alignment with business strategy; well-structured project team and clear roles, responsibilities, and authority; support of senior management; effective cross-functional collaboration and matrix teamwork; good team communication and open communication culture; soft skills of project team members; effective stakeholder and customer management; environment that accepts change; proactive and real-time change management; using project management tools; institutional and cultural support; flexible and adaptable project team. The study defines critical success factors for achieving successful product launch on market such as: roles of project managers and stakeholders, communication within the project team, and core business processes (Sohail, 2022)

Siddiqui and his co-authors examined the impact of the competencies of project manager on project success in the healthcare sector in Pakistan. According to their study, communication skills of the project manager have significant impact on project success and based on that, this factor can be considered as a critical success factor. Timely involvement of key stakeholders, namely based on the study, functional managers as mediating-brigding roles is also an essential, in other words, critical success factor of project success by their situation controlling, resource allocation, decision-making activities, capabilities and authority. Although the study emphasizes that stakeholder engagement is also a critical success factor to ensuring project success, but not in the sense that the authors examined it. (Siddiqui et al, 2024)

4.4 Success criteria

Aishwarya–Umamaheswara were not explicitly defined success criteria in their paper. Efficient and effective usage of project management in broader range in pharmaceutical industry significantly contributes to shortening the development cycle of medicines, enables the industry to bring medicines to market more quickly. This enables market participants to increase their organizational efficiency, to gain business and economic benefits, economic advantages and profits, achieve greater profit growth, and enhance their corporate image, reputation and achieve the satisfaction and commitment of their stakeholders more quickly. (Aishwarya–Umamaheswara, 2015)

Continous, flexible risk, - and change management performance and lessons-learned management system help us evaluating our projects and learning from the failures in the past and implement its positive outcomes in next projects, thus we can achieve success in the future. (Garzón-Vico at al., 2020)

In his study, Sohail implicit identifies success criteria through constraints for evaluating project success: achievement of SMART objectives; schedule performance and time-to-market/launch efforts and results; budget and cost performance; scope performance; quality performance; financial performance. Quality performance and the time-to-market performance, the efforts associated with product launch, and the resulting outcomes can be highlighted as important success criteria in line with industry characteristics. (Sohail, 2022)

In the study of Sirisinsuk and her co-authors, although they did not name them specifically, success criteria can be definitely identified, such as cost saving and budget performance; compliance with requirements of standards and authority; approval and certification by authority; satisfaction of stakeholders (consumers, doctors, pharmacists, and medical personnel); improvement, learning and knowledge expansion of project team. (Sirisinsuk et al. 2022)

Summary

Both success factors and success criteria were identified. The authors highlighted a relatively wide range of success factors and criteria in a certain form, and only some of them overlaps in the relatively small number of publications analyzed. Overall, it can observed that human-related (soft) success factors prevailed and were typically considered as critical success factors.

The study of Aishwarya–Umamaheswara does not specify, but formulates a future research possibility. Project management researchers can examine how and what extent project management can contribute to success of development projects in the pharmaceutical industry. (Aishwarya–Umamaheswara, 2015)

Future researches proposed by the authors to execute similar studies in other sectors and other industries with similar failure rates explore how success and failure experiences affect different outcomes over time. There is a possible research direction to examine impacts of given factors (like emotions, motivations) on decision-making processes and project outcomes. An another research opportunity is to investigate the processes used by different firms to analyze failure and success experiences. (Garzón-Vico at al., 2020)

Examining how and what extent success factors from the given technology transfer project can be applied to other local (Thai) manufacturers and in developing countries. (Sirisinsuk et al. 2022)

Sohail have not defined future research possibilities. Although most of the success factors in the literature implicitly identified by Sohail are general in nature and thus contribute only to a limited extent to a deeper understanding of the success of pharmaceutical project success, at the same time, some of the specific, critical success factors highlighted by the author may offer important and valuable insights for further researches. (Sohail, 2022)

Siddiqui and his co-authors defined some future research possibilities. Their research model can be used in other industries and in other research settings, such as examining impacts in longitudinal studies. According to their proposal, future research should explore communication skills project managers and stakeholder engagement in diverse sectors beyond healthcare, and should investigate why stakeholder engagement does not mediate in certain contexts, and examine longitudinal effects using non-convenience sampling for broader generalizability. Further studies could focus on exploring the impact of project team abilities on project success, could focus on examining the impact of sustainable project management and sustainable organizational culture on project outcomes. (Siddiqui et al, 2024)

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Users' Perceptions of Artificial Intelligence and Its Everyday Applications

Csaba Berényi

Obuda University, Keleti Károly Faculty of Business and Management
berenyi.csaba@kgk.uni-obuda.hu, ORCID: 0009-0008-9461-9889

Abstract: The integration of artificial intelligence (AI) into everyday life is one of the most significant technological trends of the 21st century, fundamentally transforming social and economic processes. AI systems are now present in many areas, from personalized content recommendations to automated customer service solutions to decision support systems. The development and widespread use of these technologies not only holds opportunities, but also creates complex challenges in the areas of security, ethics, regulation and social acceptance. Understanding user attitudes and perceptions is therefore crucial in order to ensure that AI developments and implementations are not only technologically but also socially sustainable. The rapid rise of artificial intelligence is transforming many areas of everyday life and creating new opportunities in the areas of learning, work and digital services. At the same time, however, the issues of social acceptance of the technology, trust and risk perception are becoming increasingly important. The aim of this study is to explore user attitudes towards the everyday use of AI based on a large-sample, online questionnaire survey (N = 6341). The research examined perceived everyday usefulness, the impact of AI on learning and work, the manageability of systems, and the perceived disadvantages of the technology along five dimensions. The results show that the majority of respondents evaluate AI favorably, especially in areas supporting efficiency, and also consider manageability to be fundamentally positive. On the other hand, perceptions regarding disadvantages are more divided, which indicates the persistence of caution and risk perception regarding the technology. The study highlights that the social perception of AI is twofold: while clearly recognizing the advantages, some users still approach the technology with reservations. The results contribute to a deeper understanding of AI acceptance and risk perception, and provide a basis for defining user-centered development, education, and regulatory directions that promote the safe and sustainable social integration of the technology.

Keywords: artificial intelligence; manageability of AI systems, AI risks, cybersecurity,

1 Introduction

The development of artificial intelligence (AI) is a defining phenomenon of the information society, fundamentally transforming economic, technological and social processes. AI systems have now become an integral part of everyday life: they are present in online search and recommendation systems, content generation applications, customer service automation, and digital tools supporting work and learning. At the same time, the rapid development and widespread spread of the technology raises the question of how users perceive the operation of AI, how useful, safe and manageable they find it, and to what extent fears and risk perceptions related to the technology are present (Balogh & Varga, 2025; Kozhanov et al.).

The social embedding of AI is not just a technological issue, but a complex, multidimensional process in which user trust, transparency and understanding play a fundamental role. Trust in the technology depends to a significant extent on how understandable the decisions of AI are, how transparent they see its operation and to what extent they feel competent in using it. Factors such as algorithmic bias, the possibility of incorrect or questionable decisions, and data protection and cybersecurity risks further increase uncertainty and influence the social acceptance of the technology (Kollár, 2023; Szűts & Námesztovszki, 2023).

In technology acceptance research, it is widely accepted that perceived usefulness and perceived ease of use – the fundamental dimensions of the Technology Acceptance Model (TAM) – play a decisive role in the development of user attitudes, but due to the specificities of AI, recent literature increasingly emphasizes the importance of trust, transparency and ethical compliance, which significantly complement the explanatory power of traditional acceptance models (Davis, 1989).

As the application areas of AI are rapidly expanding, it is increasingly important to understand how different groups in society relate to technology. Research shows that user attitudes can vary by generation, technological competence, and experience. However, in a rapidly changing digital environment, the number of domestic and international studies that comprehensively map perceptions related to everyday AI use along multiple dimensions remains limited. This study aims to partially fill this gap. The research examines user perceptions of the everyday use of artificial intelligence along five key dimensions – perceived usefulness, support for learning and work, manageability, and perceived disadvantages. The large-scale questionnaire data collection allows us to get a comprehensive picture of the social perception of AI and to highlight the factors that may facilitate or hinder the further social integration of the technology.

2 Literature review

There are several perspectives on the origins of artificial intelligence. For example, Couch traces its origins to Descartes' writings in 1637, in which the philosopher suggested that machines could perform certain tasks beyond human capabilities (Descartes, 1637; Couch, 2023). According to Haenlein and Kaplan, AI can be traced back to the formulation of the Three Laws of Robotics in Isaac Asimov's 1942 short story Runaround (Haenlein & Kaplan, 2019). The landmark in the history of modern AI is Alan Turing's 1950 paper, in which he demonstrated that machines can mimic human behavior patterns and perform tasks based on their decisions (Turing, 1950).

The term “artificial intelligence” itself gained its official meaning in 1956, when it was defined by John McCarthy (McCarthy et al., 2006). Since then, the concept of AI has continuously evolved and now ranges from simple software-based solutions to advanced autonomous systems that can sense, learn, and adapt to their environment (Hungary’s AI Strategy, 2020; Haenlein & Kaplan, 2019). Artificial intelligence has undergone significant development in recent decades and is now utilized in many areas. Understanding the three factors that underpin the development of technology is crucial to understanding the modern social environment of artificial intelligence: the growth of computing capacity, the availability of big data, and the development of machine learning algorithms (Hwang, 2018). After reviewing the historical development of AI, it is worth examining the different forms of technology, which have different capabilities and application possibilities.

Artificial intelligence is often divided into three levels. During the development of artificial intelligence, different levels of capabilities have emerged, which, building on each other, indicate the current state of the technology and possible future directions. Narrow AI (ANI) refers to systems that are optimized for a specific task and often outperform humans in this area, but are unable to perform other types of tasks. Typical examples are facial recognition systems, search engines or speech recognition assistants that perform outstandingly in a given task, but are unable to solve other, different types of problems (Bostrom, 2014; Müller & Bostrom, 2016). General AI (AGI) theoretically means a system that can perform any intellectual activity that humans can. This includes abstract thinking, creativity and context-sensitive decision-making. AGI is still a theoretical concept, and there is currently no working, human-level artificial general intelligence system.

The goal of research is to develop an intelligence that can simultaneously solve scientific problems and create artistic works (Bostrom, 2014; Goertzel & Pennachin, 2007). Artificial Super Intelligence (ASI) is a hypothetical future level that exceeds human capabilities in all areas – including logical reasoning, emotional intelligence and creative thinking. According to some theories, if it is

realized, it will be able to independently improve itself, for example by developing new scientific paradigms or solving complex social problems independently. It should be noted that ASI is currently a completely theoretical concept that is at the center of many ethical, security and social debates, especially with regard to the issues of human control, autonomous decision-making and potential risks (Bostrom, 2014; Russell–Norvig 2021; Yudkowsky, 2008).

Different levels of artificial intelligence are not just theoretical categories, but also found expression in many practical areas, from the entertainment industry to public services. The scope of AI applications includes, among others, logic games, automatic programming, image processing, robotics, speech recognition, natural language processing, data mining and control technology (Haenlein & Kaplan, 2019; Russell–Norvig 2021). Nowadays, artificial intelligence plays an increasingly prominent role in the field of public services and administration, especially in decision-making processes that directly affect the lives and rights of citizens (OECD, 2021).

Technological progress alone is not enough for the widespread adoption of AI, as its social embeddedness, user acceptance, and ethical considerations are all determining factors. Therefore, after reviewing the historical and technological frameworks, it is important to examine how people react to the presence and use of AI in different life situations. The social perception of AI is mixed: many see its inherent benefits, but are cautious about the risks. Surveys show that people are more likely to support AI if they understand how it works and feel that it is easy to use (Zhang & Dafoe, 2019).

Acceptance is significantly influenced by perceived usefulness and ease of use, which are separately determining factors. One of the best-known theories of technology acceptance is the Technology Acceptance Model (TAM), which according to Davis (1989) distinguishes two key factors: perceived usefulness shows how much the user feels that the technology improves his or her performance, while perceived ease of use refers to how much he or she finds it easy to learn and use (Davis, 1989; Venkatesh & Davis, 2000; Venkatesh et al., 2003)

In addition to technological characteristics, the acceptance of artificial intelligence is also significantly influenced by the level of user trust. Trust is strengthened when users perceive the operation of AI as transparent and explainable, and when they see data protection and ethical principles as ensured (McKnight et al., 2011; Shin, 2021; Siau & Wang, 2018; Wang, 2023).

The social acceptance of AI is shaped not only by the characteristics of the technology, but also by the ethical and trust factors associated with it. The principles of transparency, fairness, responsibility and security, which facilitate

the development of user trust (Lee & See, 2004; Floridi et al., 2018; Jobin et al., 2019).

Overall, the development and social embedding of artificial intelligence are progressing in parallel, while technological possibilities are constantly raising new ethical, legal, and trust issues.

3 Material and method

The data collection was carried out using an online questionnaire method in 2024, with non-probability sampling, with voluntary participation. The completion was anonymous, no personally identifiable data was collected. The aim of the research was to explore user perceptions of artificial intelligence and perceptions related to everyday application. The questionnaire contained five statements that measured the perceived usefulness of AI, its impact on learning and work, the manageability of systems, and the perceived risks.

The final database contains N = 6341 respondents. I determined the demographic distribution of the sample according to the generational categories formed on the basis of age. The proportion of generations (Figure 1) was as follows: Baby Boomer (1940–1964): 321 people (5.1%), Generation X (1965–1979): 1362 people (21.5%), Generation Y (1980–1994): 1234 people (19.5%), Generation Z (1995–2007): 3205 people (50.6%), Alpha generation (2008–): 219 people (3.4%). The significant number of elements and the variance between generations create an opportunity for a later comparative examination of the differences in attitudes between age groups.

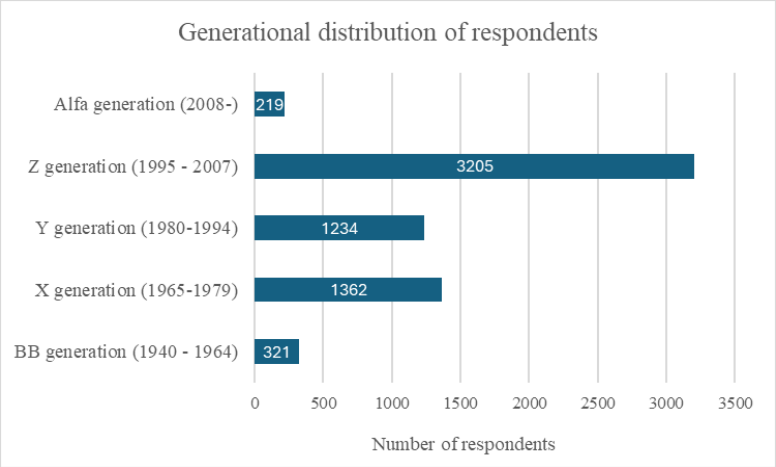

Figure 1

Generational distribution

Source: own research, 2024, N = 6341

The questionnaire included five statements related to the use of artificial intelligence, which measured user perceptions of AI along several dimensions: (1) perceived everyday usefulness of AI, (2) impact of AI on time-efficient learning, (3) impact of AI on time-efficient work, (4) perceived usability and understandability of AI systems, and (5) extent of perceived disadvantages of AI. Respondents rated the statements on a five-point Likert scale, with the following categories: strongly disagree, tend to disagree, tend to agree, strongly agree, and don't know/don't answer. The items did not form a single scale, but represented separate dimensions that measured specific areas of technology acceptance and risk perception.

During the statistical analysis, I used descriptive statistical methods, including examining the absolute and relative frequencies of response categories, calculating Likert averages, and comparing the distribution of responses to individual statements.

The research was conducted in accordance with the relevant ethical regulations, the questionnaire was completed anonymously, and respondents could discontinue completing the questionnaire at any time. Due to non-probability sampling, the sample cannot be considered representative of the entire Hungarian population; due to the self-selection of the respondents, groups more open to technology may have been overrepresented, which needs to be taken into account when interpreting the research results.

4 Results

Overall, the results of the research show that attitudes towards artificial intelligence in the studied population are fundamentally positive, but caution and risk perception are also evident in several dimensions. A total of 6,341 responses were received for the five statements examined, so the distributions are suitable for a large-sample assessment of user perceptions.

Perceived everyday usefulness of AI

The majority of respondents have a positive opinion of the everyday usefulness of artificial intelligence. A total of 3,337 people (52.6%) can be classified in the "I tend to agree" and "I completely agree" categories, while the proportion of those representing a negative position is 38.7%. The Likert average is 2.67, which falls in the positive range of the scale. This indicates that a significant proportion of users already perceive the benefits of AI in their everyday activities, but at the same time, based on the significant proportion of rejectors, the social perception is not completely homogeneous (Figure 2).

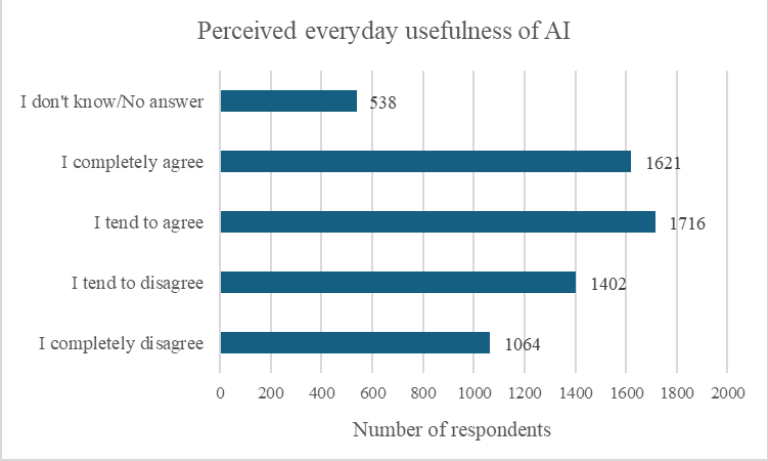

Figure 2

Distribution of perceived everyday usefulness of AI

Source: own research, 2024, N = 6341

The impact of AI on time-efficient learning

Based on the results, respondents rate the role of AI in supporting learning even more favorably. The proportion of positive responses is 55.7%, while that of negative responses is 35.2%. The Likert average is 2.73, which is the second highest of the items examined. The proportion of the "don't know/no answer" category is highest for the statement concerning learning (9.2%), which may indicate that some respondents do not use AI for learning purposes, and therefore find it more difficult to assess its impact (Figure 3).

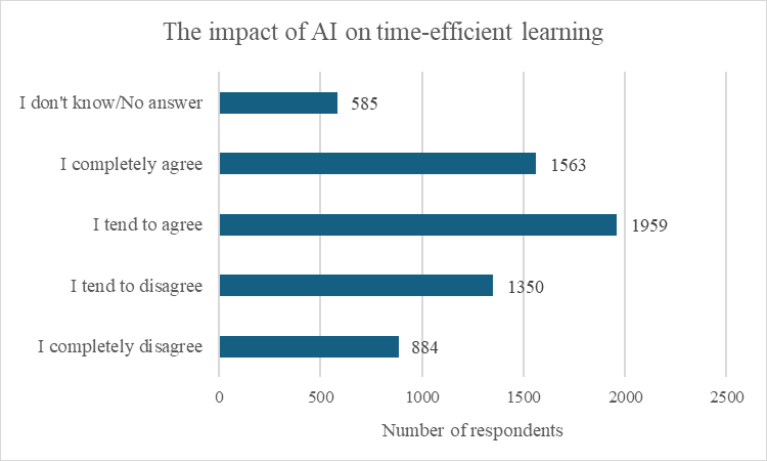

Figure 3

Impact of AI on time-efficient learning – distribution

Source: own research, 2024, N = 6341

Impact of AI on Time-Efficient Work

Perceptions related to work are even more favorable: the proportion of positive responses is 57.3%, and negative opinions are 33.3%. The Likert average is 2.78, which is one of the highest values among the items examined in the study. This result suggests that users experience the efficiency-enhancing benefits provided by AI in work-related tasks to a greater extent (Figure 4).

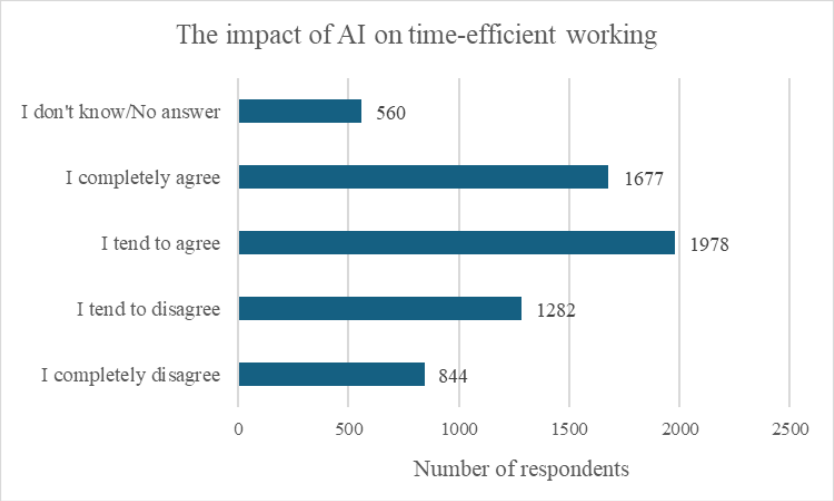

Figure 4
Impact of AI on time-efficient working - distribution
Source: own research, 2024, N = 6341

Usability and Understandability of AI Systems

Attitudes regarding usability are also positive. 57.7% of respondents agree or strongly agree that AI systems are easy to use. The proportion of negative perceptions is 32.7%, and the Likert average is 2.79, which is the highest value among the dimensions examined. This result suggests that a significant proportion of users do not consider the learning curve to be steep and that using the technology does not cause significant difficulties (Figure 5).

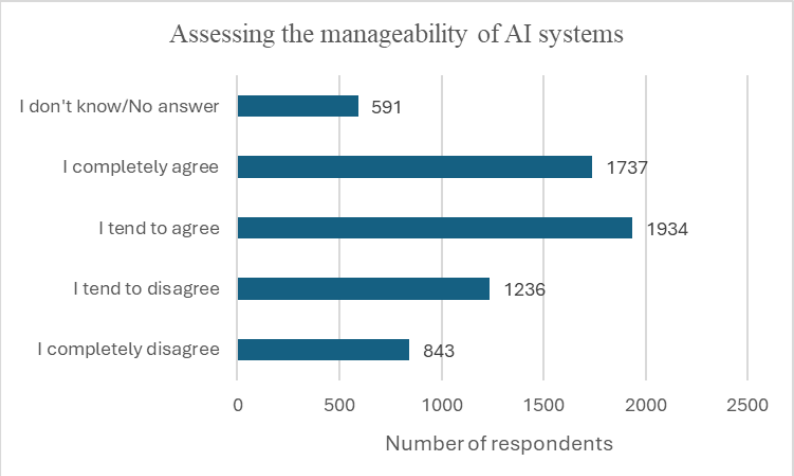

Figure 5
Perception of the manageability of AI systems - distribution
Source: own research, 2024, N = 6341

Assessment of perceived disadvantages

The statement “has more disadvantages than advantages” is the most divisive item in the research. The proportion of negative responses (strongly disagree + tend to disagree) is 48.4%, while the proportion of responses emphasizing disadvantages is 40.6%. The Likert average is 2.40, which is the lowest of the five items and indicates the relevance of caution and risk perception. The relatively high proportion of “don’t know/no answer” (11%) suggests that some respondents are uncertain about the possible negative consequences of AI or do not yet have sufficient experience to assess them (Figure 6).

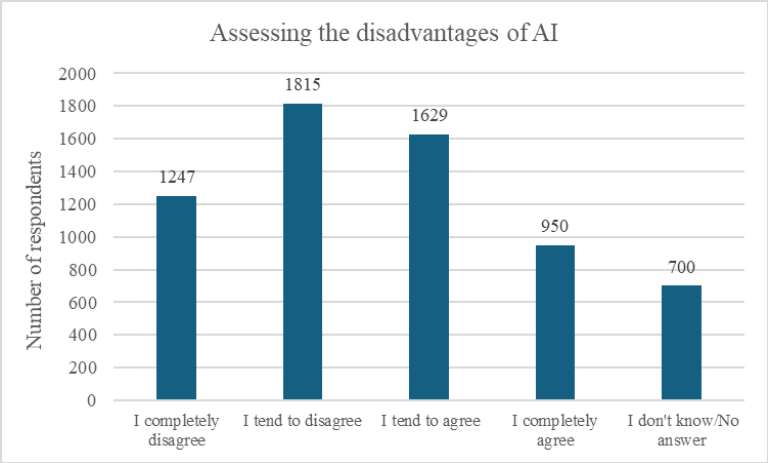

Figure 6
Perception of the disadvantages of AI - distribution
Source: own research, 2024, N = 6341

The Likert mean was calculated based on the equidistant coding of the four valid agreement categories (1–4), as the 'don't know/no answer' option does not express an attitude (Table 1).

Statement	**I completely disagree %**	**I tend to disagree %**	**I rather agree %**	**I completely agree %**	**N/A %**	**Valid case number N**	**Likert average (1-4)**
Using AI is useful in my daily life	18,3	24,2	29,6	27,9	8,5	5803	2,67
Artificial intelligence helps me study more efficiently	15,4	23,5	34	27,2	9,2	5756	2,73
Artificial intelligence helps me work more efficiently	14,6	22,2	34,2	29	8,8	5781	2,78
AI systems are easy to use and understand for me	14,7	21,5	33,6	30,2	9,3	5750	2,79
Artificial intelligence has more disadvantages than advantages	22,1	32,2	28,9	16,8	11	5641	2,41

Table 1
Response distribution and Likert averages for statements related to artificial intelligence
Source: own research, 2024, N = 6341

The Likert averages for the four positive statements – usefulness, learning, work and manageability – all fall in the range of 2.67–2.79 (Figures 2–5),

consistently exceeding the mean of the scale. This suggests that respondents fundamentally see the use of AI as beneficial and are integrating the application of the technology into their learning and work processes (Figure 7).

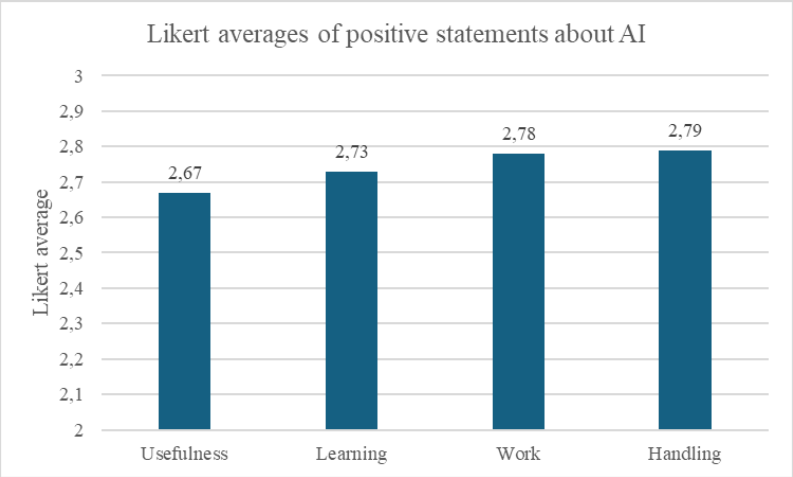

Figure 7
Likert averages of positive statements about AI
Source: own research, 2024, N = 6341

Summary, Conclusions

Based on the results of the research, it can be stated that the social perception of artificial intelligence in the studied population is fundamentally positive, but uncertainty and caution regarding risks appear in several dimensions. The four statements measuring benefits (everyday usefulness, learning, work and manageability) all showed a Likert average (2.67–2.79) in the positive range of the scale, which indicates that the majority of respondents fundamentally consider the use of AI to be beneficial and incorporate the application of the technology into their learning and work processes.

At the same time, the assessment of perceived disadvantages highlights that acceptance cannot be considered an uncritical or clearly one-way process. The utility and manageability factors show high values, and the cautious attitude towards disadvantages indicates that the social perception of AI is ambivalent. The advantages are clearly recognizable, but the risks of the technology are assessed as realistic by a significant part of the users. As a result, the acceptance of AI is not unproblematic, but is characterized by conditional acceptance, i.e. people use the technology, but they also consciously pay attention to the potential risks.

Based on the results of the research, it can be concluded that targeted developments are needed in several interrelated areas to further strengthen the social acceptance of artificial intelligence. Above all, the development of user awareness and digital competences is of paramount importance, as the rapid development and complexity of technology justify the implementation of educational and educational initiatives that present the basic principles, opportunities and limitations of AI to users in an understandable way. In parallel, it is important to strengthen transparency and explainability in AI systems, as the traceability of decision-making processes and clear communication of data management practices contribute to the stabilization of user trust.

Equally important for social acceptance is the visible enforcement of ethical and cybersecurity safeguards. The caution and risk perception experienced by respondents suggest that responsible operation, reducing algorithmic bias, and ensuring data protection are key elements in strengthening trust in the technology. User-centric development approaches are also important: prioritizing efficiency, usability, and clear operation supports the everyday applicability of AI tools and increases the practical value of the technology.

Finally, it is important to strengthen the social dialogue on AI. Uncertainty and division about risks indicate that users demand open, understandable and accessible communication about the impacts, benefits and limitations of AI. Expanding social discourse and transparent communication can foster responsible innovation and contribute to the long-term sustainable, ethical and widely accepted use of AI.

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Autonomous Vehicles at the Intersection of People, Technology, and Law: Social Acceptance, Testing, Liability, and Human Factors

Pál Fehér-Polgár

Obuda University, Keleti Károly Faculty of Business and Management,
feherpolgar.pal@kgk.uni-obuda.hu

Abstract: The rise of autonomous vehicles is fundamentally changing transportation systems, while bringing new social, technical, legal, and human challenges. The study interprets the ecosystem of self-driving vehicles along four closely related dimensions. On the one hand, it shows how social acceptance, trust, and technostress are shaped in relation to autonomous systems, with a particular focus on risk perception and readiness issues. On the other hand, it analyzes testing and validation solutions based on the integration of physical test tracks, simulation environments, and critical scenarios. Thirdly, it explores the legal and liability challenges of autonomous mobility, including civil, criminal, and international dimensions, as well as specific issues related to military autonomous systems. Finally, through a physiological and neuroscientific examination of human factors, it highlights that the acceptance of autonomous vehicles is closely linked to feelings of safety, control, and emotional comfort. The converging picture of the four areas suggests that the successful social introduction of autonomous vehicles can only be understood and supported through an interdisciplinary approach.

Keywords: autonomous vehicles, social acceptance, trust, technostress, testing and validation, critical scenarios, legal liability, military autonomous systems, human factors, physiological measurements

1 Introduction

The emergence of self-driving vehicles heralds one of the most profound structural transformations in the history of transportation. Autonomous systems are changing not only the technical configuration of vehicles, but also the social, legal, and psychological frameworks on which modern mobility is based. The fact that a significant part of the driving task is taken over by an algorithm raises fundamental questions about responsibility, trust, risk, and control. The discourse is therefore necessarily interdisciplinary: engineering, economic,

legal, psychological, and ethical perspectives are all present, often using different languages and conceptual frameworks.

The dimension of social acceptance plays a key role in ensuring that the promises of self-driving vehicles—fewer accidents, more efficient traffic, and more accessible mobility—are actually realized. Research consistently shows that public attitudes are shaped not only by objective performance indicators of the technology, but also by subjective factors such as perceived risk, different dimensions of trust, and technological self-efficacy (Kurucz et al., 2022; Kenesei et al., 2022). Readiness, i.e., society's preparedness to accept autonomous systems, proves particularly fragile when users have little direct experience, while the pace of technological change is perceived as rapid (Szikora – Szatmáry, 2023). At the same time, the phenomenon of technostress—tension arising from technological overload—has emerged as a new factor in the examination of acceptance, indicating that the introduction of autonomous systems cannot be isolated from the social impacts of the general digitalization process.

From a technical point of view, the validation of self-driving vehicles requires a testing logic that goes beyond traditional vehicle development procedures. The complexity of the real road environment – the behavior of other road users, infrastructure defects, weather and traffic variables – requires test environments that are capable of producing a representative set of critical scenarios (Tóth – Szalay, 2023). The endeavor to compile a "minimum critical" set of scenarios from an infinite number of potential situations presents new engineering and methodological challenges (Tóth, 2025). The combination of physical test tracks and high-resolution simulation systems creates a hybrid validation framework that seeks to ensure safety, reproducibility, and manageable measurement costs.

At the same time, a fundamental realignment can be observed in the legal and regulatory sphere. The shift in responsibility—from drivers to a network of manufacturers, developers, and operators—raises critical questions in civil law, criminal law, and insurance systems (Kecskés, 2020). In international trade and standardization processes, autonomous vehicles appear as a borderline area where technological innovation, national security considerations, and market competition are simultaneously present (Mezei – Harkai, 2021). These issues are even more acute in the case of military autonomous systems, where the focus is on battlefield application, decisions on the use of lethal force, and the enforceability of humanitarian law (Szikora, 2023; Szikora, 2025a).

Research focusing on human factors and physiological reactions adds another, hitherto less visible layer to this. Passengers in self-driving vehicles not only evaluate the technology on a cognitive level, but their bodies also react: increased heart rate, changing skin resistance, muscle tension, and micro-

movements indicate moments of stress, trust, or uncertainty (Palatinus et al., 2022; Palatinus et al., 2025). The realization that verbal statements of trust do not always correspond to physiological patterns sheds new light on acceptance models based on questionnaire data and highlights the added value of neuro- and psychophysiological methods (Lukovics et al., 2023).

This study is based on the assumption that the ecosystem of self-driving vehicles can only be understood in depth if social acceptance, technical testing, legal and regulatory frameworks, and human factors are not viewed in isolation, but rather as a closely interrelated system in which each factor influences the others. The following section provides a comprehensive, literature-based analysis of these four dimensions with the aim of contributing to the development of an interdisciplinary framework suitable for supporting the responsible and human-centered introduction of autonomous mobility. The methodological framework of the research, which determines the logical structure of the literature review, is presented below.

2 Method of Literature Analysis

This study focuses on the interdisciplinary exploration of the autonomous vehicle ecosystem, therefore the research is based on a critical, narrative, and thematic literature synthesis. The methodological framework was designed to ensure that the four key dimensions—social acceptance, technical testing, legal and regulatory frameworks, and human factors—are not presented in isolation, but as mutually influential, integrated systems. This approach allows for the development of an interdisciplinary approach that is suitable for interpreting the responsible, sustainable, and human-centered introduction of autonomous mobility.

During the literature review, primary sources of scientific publications were prioritized, primarily relying on the multidisciplinary databases Scopus, Web of Science (WoS), and Google Scholar. The search period primarily covered studies published between 2017 and 2025, given that research into autonomous vehicles—especially SAE Levels 3–5 automation—accelerated significantly during this period. The search keywords were developed along the four central dimensions of the study; both English and Hungarian terms were used, as the literature reviewed also includes numerous domestic research results. The keyword groups covered the topics of autonomous vehicles, social acceptance, trust, technostress, critical scenarios, liability, human factors, and physiological measurements, supplemented with various synonyms and variations. During the collection process, special attention was paid to publications that intersect multiple dimensions, such as studies analyzing the relationship between physiological measurements and social trust.

The relevant articles were selected based on two main criteria. On the one hand, we determined the need for thematic relevance: only those publications that contributed significantly to the professional discourse on autonomous vehicles and focused on one of the four dimensions examined or their interaction were included in the analysis. Second, the requirement for scientific quality ensured that the study was based primarily on peer-reviewed international journals and conference proceedings with high impact factors, thereby increasing the reliability and validity of the literature used. The data were processed using the thematic synthesis method: the selected publications were grouped according to their content characteristics and their contribution to the key dimensions. The aim of the analysis was not only to systematize existing knowledge, but also to critically link it, with a particular emphasis on the intersections where technical reliability, the legal and regulatory environment, and human reactions interact (e.g., discrepancies between verbal statements of trust and physiological indicators). This approach has contributed to the study offering a new, integrated perspective on the complex challenges of autonomous mobility. In the following, the four dimensions of the literature review are presented in accordance with this methodological framework, providing a comprehensive overview of the social, technical, legal, and human aspects of the introduction of autonomous vehicles.

3 Social acceptance, attitudes, trust, and technostress in relation to self-driving vehicles

The social integration of autonomous vehicles does not depend primarily on the pace of technological development, but on the cultural, psychological, and social environment in which the technology arrives. Users' reactions to a new transportation system are not based solely on rational considerations, but also on deeply rooted attitudes, risk perceptions, and trust mechanisms. This multifaceted human responsiveness has been consistently confirmed by research on autonomous vehicles. One of the most decisive components of social acceptance is trust, which stems not only from the assessment of technological reliability, but also from the user's personal experiences and the perceived predictability of new systems. Research conducted in the domestic environment shows that trust is multidimensional and strongly depends on prior experiences with technology and technological self-efficacy (Kurucz et al., 2022; Hőgye-Nagy et al., 2023).

The relationship between trust and risk perception is a particularly sensitive area. Users do not assess danger solely on the basis of objective parameters: it is often shaped by social representations and previous technological experiences. This mechanism is clearly reflected in research that examined perceived risk

factors associated with autonomous vehicles and highlighted that fear of failure, lack of control over algorithms, and uncertainty about liability issues are psychological factors that significantly reduce openness (Kenesei et al., 2022). The impact of risk factors is further amplified in areas where users have no direct personal experience with autonomous systems, which is understandably the case for most social groups. One of the most important conditions for the acceptance of technology is therefore not the demonstration of technical performance, but rather a communication framework that can reduce feelings of uncertainty. This is consistent with studies in which a version of the UTAUT model supplemented with trust and risk showed significantly better explanatory power for the acceptance of autonomous vehicles (Kenesei et al., 2025).

One hidden dimension of social acceptance of autonomous systems is the role of emotional and physiological reactions. Users' behavior often differs from their self-reported attitudes. The results of neuromarketing-based studies show that internal reactions to the use of autonomous vehicles are much more ambivalent than questionnaire-based self-reports suggest (Prónay – Majó-Petri, 2022). The measurement of physiological responses—which manifest themselves in changes in the circulatory system, facial expressions, or micro-movements—reveals that users experience tension even when they consciously declare themselves to be accepting. This duality is particularly evident in unexpected traffic situations that are linked to the decision-making speed and foresight of the autonomic system (Palatinus et al., 2022; Palatinus et al., 2025). Research provides a consistent picture that physiological stress greatly influences users' sense of safety and, consequently, their acceptance of the technology.

In a broader sense, social acceptance encompasses not only the general attitudes of the population, but also the collective ability to adapt to technological changes. The concept of "readiness," which refers to society's preparedness for technological adaptation, combines several factors: the level of social trust, institutional stability, technological culture, and the state of development of transportation systems. An analysis of the factors behind the lack of readiness for autonomous vehicles shows that a lack of knowledge and a reduced sense of control act as universal barriers (Szikora – Szatmáry, 2023). The issue of readiness is particularly acute where new technology appears suddenly in society and is not preceded by widespread education or gradual introduction.

Another important component of resistance to autonomous vehicles is technostress, which is related to users' technological overload (Szikora, 2025b). The general acceleration of digitalization has created a cognitive load that manifests itself not only in the workplace but also in relation to automated systems in everyday life. The effects of technostress are also clearly evident in the case of autonomous vehicles: users often experience uncertainty when the vehicle makes a decision that does not match their own intuitive choice

(Szatmáry – Szikora, 2023). This phenomenon is particularly pronounced among those with limited technological skills and a greater need for direct control.

Cognitive uncertainty arising from the comparison of human and machine decisions can also be classified as a social dimension. Users tend to treat autonomous systems with an expectation of "perfection," meaning that the same mistake carries different weight depending on whether it is made by a human or a robot. According to research that focuses on the human side, the human factor is often overestimated, while the quality of machine decision-making is often unrealistically high (Szikora – Madarász, 2017). This duality further deepens social resistance and highlights that communication is at least as important as technological development itself when introducing autonomous systems.

The examination of social acceptance therefore takes place on several levels: cognitive, emotional, physiological, and cultural. The overall picture from the research shows that the success of the introduction of autonomous vehicles depends largely on whether society is able to understand and accept the decision-making processes that form the basis of the technology's operation. Building user trust, reducing stress, and mitigating risk perception are complex, mutually reinforcing processes without which autonomous systems cannot become a natural part of everyday transportation—a fact that is consistently supported by both domestic and international research.

4 Technical testing, simulation, and critical scenarios in the validation of autonomous systems

One of the biggest challenges in developing self-driving vehicles is condensing the almost infinite number of traffic situations encountered in real-world road environments into a test environment that is safe, reproducible, and sufficiently complex. The success of validation fundamentally determines the pace and safety level at which the technology can be introduced into road traffic. The literature focusing on technical testing and simulation explores the question of how to model the diversity of reality in a way that clearly reveals the performance and limitations of self-driving algorithms.

The purpose of complex test environments created for testing vehicle functions is to enable the behavior of various automated functions to be examined in a controlled manner. One of the main areas of development is a structured test system in which the physical test track, virtual simulation, and automated evaluation are linked together in a unified framework. The logic behind this approach is reflected in the creation of an integrated test environment for the validation of automated driving functions, where vehicle sensors, control

algorithms, and traffic scenarios are connected in such a way that the entire spectrum of the system can be examined, from perception through decision-making to intervention (Tóth – Szalay, 2023). The biggest advantage of such systems is that different traffic situations can be automatically generated, repeated, and assigned objective metrics.

One of the key problems with validation is that it is impossible to test every possible situation; therefore, it is particularly important to identify the "minimum necessary" critical scenarios that cover the situations carrying the greatest risk. Efforts to select critical test scenarios aim to condense the testing universe into a representative set that provides adequate assurance of system safety while being testable with reasonable resource requirements (Tóth, 2025). This logic is close to what we know as robust design in traditional engineering validation, but here it is expanded to include complex traffic interactions and the diversity of human behavior.

The interaction between transport infrastructure and autonomous vehicles receives special attention in the testing literature. Anomalies in the operation of traffic lights, signs, road markings, and other infrastructure elements represent special test cases that are problematic for human drivers but can be particularly critical for autonomous systems. The approach that classifies traffic control system errors and links them to environmental tests of autonomous vehicles aims to systematize this (Lengyel – Szalay, 2018). Typologies of this kind make it possible to test algorithms on test tracks not only with "ideal" infrastructure, but also with deliberately faulty, incomplete, or contradictory signals, as these are unavoidable in reality.

The development of test environments is increasingly moving towards the integration of physical and virtual spaces. Simulation platforms can be used to model not only the dynamic behavior of vehicles, but also sensor fusion, weather conditions, traffic density, and the unexpected maneuvers of other road users. This type of "hybrid" testing is not only more cost-effective than purely physical tests, but also allows for the examination of extreme situations that could not be reproduced in a real environment for ethical or safety reasons (Tóth – Szalay, 2023). At the same time, the credibility of the simulation is a key issue: the model must be sufficiently realistic so that the performance measured on it truly approximates real-world road behavior.

An important lesson from the testing and validation literature is that the reliability of technical systems cannot be separated from human factors. The inclusion of physiological measurements has created a new generation of test concepts in which the physiological responses of passengers or test subjects are analyzed in the same way as the data from the vehicle's sensors. Such studies show that when autonomous functions are in operation, it is not only the performance of the algorithms that is at issue, but also how the occupants of the

vehicle react to various traffic situations, especially during unexpected events (Palatinus et al., 2022; Palatinus et al., 2025). In this sense, the testing environment becomes "two-way": it not only tests the machine under human control, but also tests humans in a new technological environment.

Based on all this, the literature on technical testing and validation outlines a paradigm in which the self-driving vehicle is not merely an engineering artifact, but a complex system that interacts with people and infrastructure. The task of test environments is no longer to prove the functionality of an algorithm under sterile laboratory conditions, but to represent the diversity of reality in a concentrated but conceptually transparent form. This is the framework in which the selection of critical scenarios, the typification of infrastructure anomalies, and hybrid simulation solutions serve a common goal: to develop validation procedures that can handle the complexity of self-driving systems while providing real safety guarantees to society (Tóth, 2025; Lengyel – Szalay, 2018).

5 Legal, regulatory, and liability issues, including military autonomous systems

The spread of autonomous vehicles fundamentally challenges traditional traffic law and liability frameworks. The classic model clearly assigns responsibility to the person driving the vehicle; however, with the advent of self-driving systems, decision-making is decentralized, and a network of software developers, vehicle manufacturers, infrastructure operators, and data and service platforms are involved in shaping the final outcome. This creates a responsibility matrix to which traditional legal institutions can only partially respond (Kecskés, 2020).

International and domestic legal analyses point out that autonomous vehicles require not only new rules, but also a change in mindset. The transformation of the liability system consists not only in the human driver's role being pushed into the background, but also in decision-making being "transferred" to an algorithmic black box, the operation of which is not fully understood by either the user or, in many cases, the law enforcement authorities. Works discussing the legal assessment of autonomous systems emphasize that, in addition to the traditional fault-based model, the role of risk sharing and objective liability constructs is becoming more important (Kecskés, 2020; Lévayné Fazekas – Kecskés, 2020).

One of the central issues in legal debates is the extent to which the algorithm can be considered an "independent actor" in relation to damage caused by self-driving vehicles, and to what extent it can be classified as a device. The

dominant view in the literature is that extending legal personality to artificial intelligence systems would currently raise more problems than it would solve, Therefore, responsibility continues to be shared between human and organizational actors, while the protection of injured parties is reinforced by extended product liability and insurance structures (Kecskés, 2020). This line of thinking is also linked to analyses that discuss the legal issues of autonomous mobility in a comprehensive volume, systematically reviewing civil law, transport law, insurance, and data protection aspects (Lévayné Fazekas – Kecskés, 2020).

The criminal law assessment of autonomous vehicles is a particularly sensitive area. If a self-driving vehicle causes a fatal accident, traditional criminal law dogma finds it difficult to assess the act: who acted intentionally or negligently? The software engineer who wrote the algorithm years earlier, the manufacturer who launched the system on the market, the user who activated the self-driving mode, or the organization that failed to provide adequate maintenance? Some criminal law analyses conclude that while it is possible to apply traditional categories (intent, negligence, causation), this requires significant interpretative adjustments and will likely necessitate the introduction of new, specific legal concepts (Karsai, 2022).

In the field of transport law, there are already models that attempt to integrate the specific characteristics of autonomous systems. An analysis of German regulatory practice, for example, shows that experimental standards are being developed that address the sharing of responsibility, the transformation of vehicle registration systems, and specific aspects of data management (Görög, 2025). These solutions serve as important models for other countries, but they also make it clear that there is no simple model that can be immediately adapted by everyone: the regulatory environment is closely linked to the structure of the national legal system and social expectations.

At the level of the global trade regime, the issue of autonomous vehicles also raises complex problems. International trade law, particularly the WTO system, focuses primarily on the exchange of goods and services and has little experience with technologies that embody autonomous decision-making systems. Trade liberalization, technological standardization, and conflicting national security considerations may lead to new types of legal disputes in which autonomous vehicles appear simultaneously as commercial products, critical infrastructure elements, and potential risk factors (Mezei – Harkai, 2021). In this context, the regulation of autonomous mobility is no longer just a transport policy issue, but also a geopolitical one.

Military autonomous systems deserve a separate chapter in the literature. In the case of autonomous vehicles and weapon systems used on the battlefield, responsibility, accountability, and rule of law control are even more central.

Both public opinion and professional discourse are sensitive to the idea that partially or fully automated systems should decide on the use of lethal force. Analyses examining the dimensions of trust in military autonomous vehicles highlight that social attitudes are even more skeptical in this area, and that the technological advantages are often overshadowed by concerns about abuse or loss of control (Szikora, 2023). Studies reviewing the strategic potential and risks of autonomous systems on the battlefield emphasize that the frameworks of military law and humanitarian law will be severely tested when technologies emerge that entrust part of the decision-making process to algorithms (Szikora, 2025a).

Overall, the legal and regulatory literature shows that the issue of autonomous vehicles cannot be reduced to a matter of modifying traffic regulations. A comprehensive, interdisciplinary approach is needed that takes into account civil, criminal, international, and ethical dimensions. The law does not merely follow technological developments, but also influences them: it determines what types of systems can be placed on the market, under what liability structures and accompanied by what social guarantees.

6 Human factors, physiological and neuroscientific approaches

The spread of self-driving vehicles is not only transforming the transportation system, but also radically changing the quality of the relationship between humans and technology. In traditional driving, humans are constantly active participants: they perceive, decide, and act. With the advent of autonomous systems, the emphasis shifts to supervision, control, and possible intervention. This transformation profoundly affects human cognition, sense of responsibility, sense of security, and stress responses. The literature focusing on human factors examines how the body and mind react to a vehicle that "drives itself."

Classic questionnaire and interview methods provide important basic information about attitudes, but they are of limited use for examining spontaneous, unconscious reactions. To compensate for this shortcoming, research integrating physiological and neuroscientific measurement tools into studies of self-driving vehicles is gaining ground. The essence of this approach is that the reactions triggered by autonomous vehicles are analyzed not only on the basis of verbal reports, but also on the basis of physiological parameters such as heart rate, skin resistance, muscle tension, and eye movement (Palatinus et al., 2022; Palatinus et al., 2025).

One of the most important lessons learned from physiological studies is that stress and arousal levels do not decrease linearly with increasing trust in the technology when using self-driving vehicles. In many cases, users verbally express high levels of trust, while their bodies show increased alertness and tension in real time. This is particularly true in the case of unexpected events, such as sudden braking, unpredictable maneuvers by other vehicles, or situations arising from infrastructure failures (Palatinus et al., 2025). Exploring human reactions in such detail sheds new light on what it means to "feel safe" in an autonomous system.

The integration of neuromarketing and cognitive psychology further deepens our understanding of human-machine interactions. When the acceptance of autonomous vehicles is examined at the neurophysiological level, it becomes clear that users are not simply evaluating a technical system, but are also experiencing a transformation in their sense of control, autonomy, and vulnerability. Brain and physiological responses suggest that autonomous vehicles create a kind of "shared responsibility" experience: users rely on the machine's decisions and feel involved in the possible consequences (Prónay – Majó-Petri, 2022; Lukovics et al., 2023).

Research combining survey-based and neurophysiological measurements sets a new methodological standard for examining the acceptance of autonomous technologies. Such studies show that models based solely on attitude questionnaires—even if they use complex, multivariate structures—tend to underestimate the role of emotional and physical reactions (Lukovics et al., 2023). Physiological measurements reveal, for example, the timing of stress reactions to specific driving maneuvers or traffic situations and how these differ among different user groups.

Another important finding from studies focusing on human factors is that autonomous vehicles do not affect all user groups in the same way. Age, previous driving experience, technological affinity, and risk tolerance are all factors that influence how an individual responds to the behavior of an autonomous system. Younger, digitally socialized generations are often more open-minded, but this does not necessarily translate into lower stress levels; often, faster adaptation can be observed in unexpected situations (Hőgye-Nagy et al., 2023; Kurucz et al., 2022). Older users are slower to build trust, but once trust is established, it proves to be more stable.

The examination of human factors also points out that the introduction of self-driving vehicles cannot be interpreted purely as a technological innovation. People need to rethink their relationship with them and their ideas about responsibility, decision-making, and control. The fact that certain decisions—such as sudden braking or evasive maneuvers—are made by the system on their behalf can cause existential anxiety for many people, especially if the logic

behind these decisions is unclear. A combination of physiological and cognitive studies suggests that proving technical reliability is not enough for the acceptance of autonomous vehicles: human-centered communication of algorithmic decision-making is also necessary (Lukovics et al., 2023; Palatinus et al., 2022).

Ultimately, research focusing on human factors helps ensure that the development of autonomous vehicles is not limited to the optimization of sensors, controllers, and data platforms. They point out that a "good" self-driving system not only reduces the number of accidents, but also offers humans an interaction in which a sense of security, predictability, and emotional comfort can be maintained. This is the perspective where the technical, legal, and social dimensions ultimately converge again: the vehicle is not merely a means of transportation, but a practical arena for the question of what kind of future we envision for the coexistence of humans and artificially intelligent systems.

Conclusions

The development of self-driving vehicles is much more than technological innovation: it mobilizes social, legal, and human factors that together shape the future of mobility. The key background of social acceptance determines when and to what extent technological promises will become reality. The dynamics of trust, perceived risk, and technological self-efficacy clearly show that autonomous systems cannot be separated from human experience and emotional reactions. The technical side provides validation and testing environments that can represent the complexity of real traffic and provide reliable information on system performance through the systematic identification of critical scenarios. At the same time, the legal and regulatory environment requires new models of responsibility and accountability, as autonomous vehicles are no longer linked to a single decision-maker but to a networked ecosystem. Human factor research further deepens these dimensions by exploring the physiological and cognitive responses triggered by autonomous systems, shedding light on hidden stress and trust mechanisms. Based on all this, it is clear that the introduction of autonomous mobility can only be successful if technical reliability is accompanied by social transparency, legal coherence, and people-centered design. This integrated approach can ensure that self-driving vehicles truly become the foundation for a safer and more inclusive future of transportation.

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Export Competitiveness Analysis of the Hungarian Cereals 1993-2024

Gyarmati Gábor

Obuda University, Keleti Károly Faculty of Business and Management
gyarmati.gabor@uni-obuda.hu

Abstract: The competitiveness of Hungarian grain has been examined by several researchers. The current study was based on data from 1993 to 2024 from the WITS database. The analyses confirmed the results of several previous studies. The comparative advantage of grains is not stable, varies from product to product, and is typically associated with the export of unprocessed products. Overall, we have to say that products with significant competitiveness are very rare. The role of products with low competitiveness is more typical. So, overall, we can say that there are one or two products that are competitive, but this is not the norm. Furthermore, the role of processed products in exports is less than 10%, while in imports it is around 30%. The choice of variety greatly influences competitiveness on international markets. Wheat and corn were highly competitive in the years examined, but their competitiveness fluctuated greatly. Yields can also be affected by weather conditions, but it is necessary to be prepared for this. It is possible that this was also the cause of fluctuations in import volumes.

Keywords: Agriculture, export, competitiveness, Balassa index

1 Introduction

The grain sector has played a significant role in Hungarian agriculture for centuries. According to data from the Hungarian Central Statistical Office, annual production amounted to 15 million tons in 2023. Compared to neighboring countries, we rank in the middle of the pack, as can be seen in Figure 1, with Ukraine producing outstanding results, but Poland and Romania also achieving significant results (KSH 2025a) and always playing a decisive role. In 2025, agricultural output exceeded HUF 4.4 trillion, which is 6.2% more than a year earlier. The expansion was driven by a 10% increase in the overall price level of production and a 2.5% increase in the volume of livestock

production. The production volume of agriculture fell by 3.6%, with crop production falling by 8.7%. The production volume of crop production decreased by 8.7%, while the price level increased by 14%. The total volume of cereals fell by 6.3%, with corn falling by 29%, wheat by 10%, barley by 9.0% and rye by 1.6%. The yield of rapeseed fell by 7.3% and that of sunflowers by 6.2%. The yield of protein crops and tobacco increased, while that of sugar beet decreased, resulting in an overall 9.4% decrease in the volume of industrial crops. The volume of fodder crops decreased by 3.0% and that of horticultural products by 5.5%. The volume of fruit decreased by 32%, with apricot production falling by 68%, apple production by 48% and pear production by 18%. The volume of grapes and wine increased by 6.8% and 7.0% respectively (KSH 2025b.

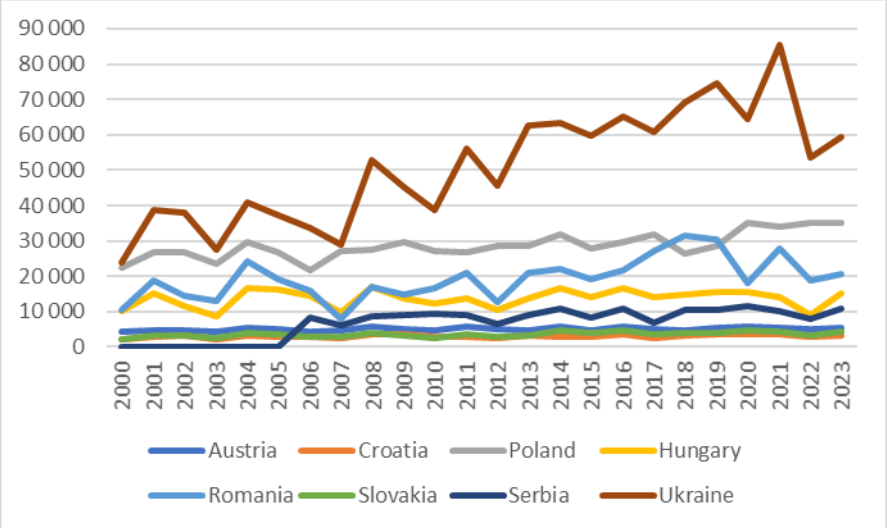

Figure 1

Some countries crope production 2000-2023. Own edition.

It is generally believed that grain production is competitive in domestic production, while animal husbandry is less so. This is supported by several studies. For example. In Hungary, as in the EU, there are many sectors with small individual market shares. According to an analysis of comparative advantages, the competitiveness of Hungarian cereals fluctuated overall between 2010 and 2018, but it can be concluded that they had a comparative advantage (Bakota, 2020).

Hungary has a clear comparative advantage in durum wheat (0411), other wheat (0412), corn seed (0441), other corn (0449), sorghum (0453) and buckwheat

(0459) on the EU-15 market. During this period, no processed cereal product had a clear comparative advantage, while 55% of raw materials had a comparative advantage according to all four indicators, and 64% had a comparative advantage according to at least one indicator.

It is therefore surprising that even in the case of such a key product group as cereals, Hungary exports raw materials and imports processed products (Jámbor, 2009).

1.1 Literature review

Hungary's climatic conditions can support the fact that practically all temperate zone crops can be grown, and overall, agricultural conditions in Hungary are above average (Szűcs, 2017).

In arable crops, significant variability in yields remains a problem, calling attention to the importance of irrigation and the modernisation of agrotechnology. In livestock production, market crises and epidemics are a major challenge. Hungarian agriculture has made significant progress in recent years, but the problems that still remain and the international challenges require further efforts to increase competitiveness (Bakota, B., & Páll, Z. (2019).

Hungary typically has an external trade surplus, mainly in agricultural products.How successful a product is depends on the type of products produced (raw or processed, perishable or non-perishable, etc.) and the level of trade integration. Hungary trades mainly with other EU Member States, with Germany typically being its main external trading partner.The share of raw materials is higher on the export side (cereals and oilseeds) than on the import side (e.g. meat and meat products or various confectionery products). Despite transport difficulties, Hungarian exports have increased, resulting in a growing trade surplus (Mizik, 2021).

1.2 Methodology

Attila Chikán's definition has become widely accepted, according to which "national economic competitiveness refers to the ability of a national economy to create, produce, distribute and/or supply products in accordance with the requirements of international trade, while increasing the yield of its own production factors" (Chikán, 2006, 43).

Among the trade-based indicators used to assess the competitiveness of nations, the article uses the revealed comparative advantage (RCA) indicator, which Balassa (1965) summarized in the following formula:

$$RCA_{ij} = \left(\frac{X_{ij}}{X_{it}}\right) / \left(\frac{X_{nj}}{X_{nt}}\right) \qquad (1)$$

where x represents exports, i represents the country, j represents the product, t represents the product group, and n represents the country group. If the RCA indicator is greater than one, then the given country has a comparative advantage within the given product group. The RCA indicator has been criticized because it ignores the impact of various economic policy measures and produces asymmetric values. The structure of trade is greatly influenced by various government interventions and trade regulations, while the asymmetry of the Balassa index means that its value can vary from one to infinity if a country has a comparative advantage, but can only take values between 0 and 1 if the country in question has no advantage.

In 1965, Hungarian-born American economist Béla Balassa published his measure of comparative advantage in international trade (Balassa, 1965). Although there have been several criticisms of his formula, it has been shown that the coherence between the original Balassa index and its variants is so strong that no other result is served by the modified formulae (Jámbor, 2017)

Export values obtained from World Bank database WORLD BANK [2025]: World Integrated Trade Solution Database. http://wits.worldbank.org/.

1.3 Results

Hungarian grain sector value was around 2500 million euros between 2018-2024. Figure 2. asows this trend.

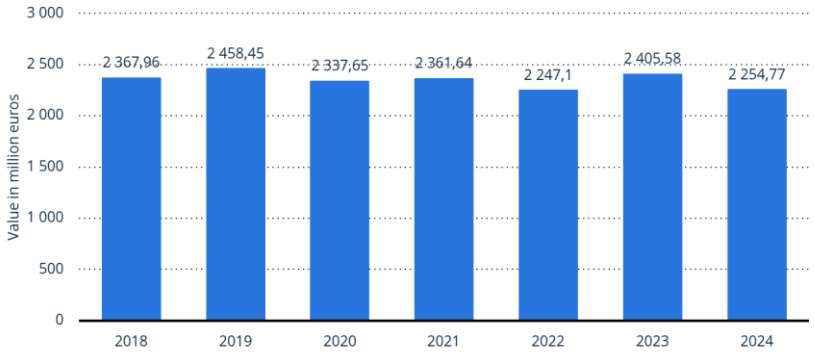

Figure 2
Production value of cereals in Hungary from 2018 to 2024 (in million euros) Source_ Statista

Based on the WITS database values, Hungary had rather import than export in cereals. While exports showed stability and balance, imports experienced significant fluctuations. This was partly due to changes surrounding the COVID-19 period and partly due to uncertainty in international relations. Figure 3 shows this instability.

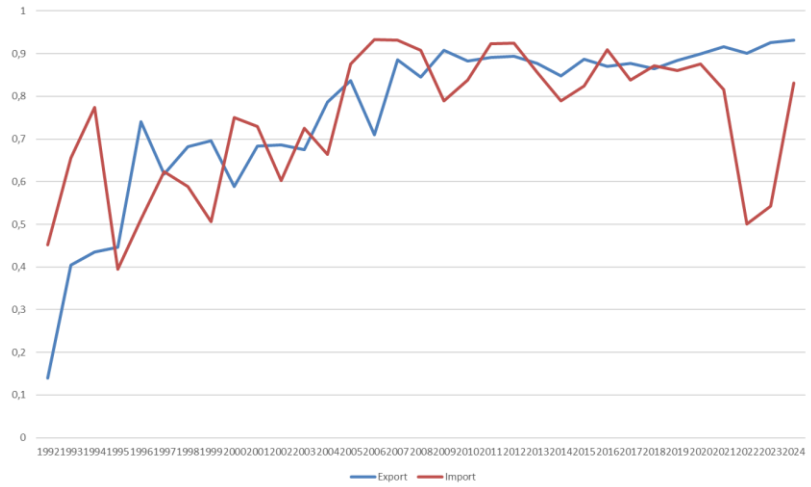

Figure 3
Export import ratio with EU-27 Source_ Statista

Hungarian main export parners are the followings.

Austria, Germany, Italy, Poland, Romania, Slovenia. See Figure 4.Main import partners are the folowings. Autria, Germany, France and Slovaki. See Figure 5.

Within the export structure, wheat, corn, buckwheat, millet, canary seed, and other cereals are the most common. However, the situation is slightly different when it comes to imports. Corn is the most significant import product, followed by rice.

Main export partners	1993-1996	1997-2000	2001-2004	2005-2008	2009-2012	2013-2016	2017-2020	2021-2024
Austria	**5,5%**	**4,9%**	**10,5%**	**6,9%**	**10,6%**	**13,7%**	**15,6%**	**18,2%**
Belgium	0,0%	2,8%	2,7%	0,2%	0,8%	0,8%	0,4%	0,5%
Bulgaria	0,6%	1,9%	2,0%	1,8%	1,1%	0,8%	0,9%	1,5%
Croatia	6,0%	7,8%	5,0%	2,5%	0,9%	2,3%	3,1%	2,8%
Cyprus	0,1%	1,0%	1,3%	0,6%	0,9%	0,9%	0,2%	0,0%
Czech Republic	3,7%	2,2%	0,7%	0,6%	0,8%	1,1%	1,2%	0,9%
Denmark	0,1%	0,1%	0,0%	0,0%	0,0%	0,0%	0,0%	0,1%
Estonia	0,0%	0,0%	0,4%	0,2%	0,1%	0,0%	0,0%	0,0%
EU27 --- EU27 members --- EU27	100,0%	100,0%	100,0%	100,0%	100,0%	100,0%	100,0%	100,0%
Finland	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%
France	4,2%	2,7%	3,3%	2,3%	1,8%	2,0%	1,9%	1,4%
Germany	**15,1%**	**8,5%**	**12,0%**	**9,3%**	**10,2%**	**11,3%**	**10,3%**	**12,4%**
Greece	0,1%	0,1%	6,2%	9,8%	2,8%	1,3%	1,0%	0,3%
Ireland	0,0%	0,0%	0,1%	0,0%	0,0%	0,0%	0,0%	0,0%
Italy	**16,0%**	**7,7%**	**7,7%**	**23,8%**	**27,1%**	**29,0%**	**36,2%**	**42,5%**
Latvia	0,2%	0,0%	0,1%	0,0%	0,1%	0,0%	0,0%	0,0%
Lithuania	1,3%	0,2%	0,4%	0,3%	0,0%	0,0%	0,0%	0,1%
Luxembourg	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%
Malta	0,1%	0,5%	0,0%	0,4%	0,1%	0,1%	0,1%	0,1%
Netherlands	5,7%	3,5%	6,1%	9,3%	11,5%	7,4%	4,9%	1,3%
Poland	**8,3%**	**14,0%**	**3,4%**	**5,5%**	**4,0%**	**2,4%**	**3,0%**	**1,8%**
Portugal	0,2%	0,1%	0,0%	0,0%	0,1%	0,2%	0,0%	0,1%
Romania	**9,2%**	**10,2%**	**16,2%**	**15,1%**	**15,9%**	**18,6%**	**14,9%**	**10,2%**
Slovak Republic	2,3%	2,9%	2,2%	3,8%	6,6%	3,5%	3,2%	2,3%
Slovenia	**18,4%**	**19,7%**	**11,9%**	**5,1%**	**3,5%**	**3,6%**	**2,6%**	**2,7%**
Spain	0,7%	9,9%	8,1%	2,5%	1,2%	1,2%	0,3%	0,6%
Sweden	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%

Figure 4

Main export partners Source_ Statista

Main import partners	1993-1996	1997-2000	2001-2004	2005-2008	2009-2012	2013-2016	2017-2020	2021-2024
Austria	**21,6%**	**10,9%**	**5,4%**	**4,9%**	**5,6%**	**7,0%**	**6,9%**	**9,1%**
Belgium	0,0%	0,1%	1,3%	3,8%	2,3%	0,9%	0,7%	1,0%
Bulgaria	0,2%	3,2%	0,6%	0,5%	0,4%	0,4%	0,3%	0,7%
Croatia	0,1%	0,6%	0,6%	0,9%	1,1%	1,2%	1,3%	2,1%
Cyprus	0,0%	0,0%	0,0%	0,0%	0,4%	0,0%	0,0%	0,0%
Czech Republic	0,2%	0,2%	7,1%	1,3%	2,5%	1,7%	1,4%	1,5%
Denmark	3,5%	2,6%	1,4%	0,0%	0,9%	0,6%	0,1%	0,0%
Estonia	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,4%
EU27 --- EU27 members --- EU27	100,0%	100,0%	100,0%	100,0%	100,0%	100,0%	100,0%	100,0%
Finland	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%
France	**25,6%**	**26,6%**	**19,0%**	**23,4%**	**24,8%**	**28,8%**	**21,6%**	**18,0%**
Germany	**23,6%**	**6,7%**	**11,2%**	**7,5%**	**6,3%**	**4,7%**	**4,8%**	**2,9%**
Greece	0,2%	0,0%	0,0%	4,1%	2,9%	1,8%	0,8%	1,3%
Ireland	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%
Italy	**15,6%**	**35,9%**	**32,3%**	**23,2%**	**11,4%**	**6,2%**	**10,1%**	**7,5%**
Latvia	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%
Lithuania	1,2%	0,0%	0,0%	0,4%	0,1%	0,1%	0,1%	0,1%
Luxembourg	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%
Malta	2,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%
Netherlands	4,6%	4,8%	3,6%	1,0%	0,9%	0,6%	0,8%	0,8%
Poland	0,0%	0,1%	0,1%	0,4%	2,6%	1,4%	2,4%	5,0%
Portugal	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%
Romania	2,2%	3,1%	3,4%	12,1%	16,5%	20,4%	21,7%	20,7%
Slovak Republic	**0,9%**	**1,8%**	**8,3%**	**15,1%**	**21,1%**	**21,8%**	**25,5%**	**28,1%**
Slovenia	0,0%	0,0%	0,1%	0,1%	0,5%	1,6%	0,9%	0,5%
Spain	1,6%	1,4%	2,7%	1,4%	0,4%	0,4%	0,2%	0,4%
Sweden	1,9%	0,0%	3,2%	0,1%	0,0%	0,1%	0,1%	0,0%

Figure 5

Main import partners Source_ Statista

Wheat competitiveness fluctuates, but it is essentially a moderately competitive product. We can see something similar with barley. Corn showed strong competitiveness in most years, but by 2022 it will be moderate. Grain sorghum started out highly competitive in 1993, then declined completely, but by the 2020s it will once again be highly competitive. Buckwheat, millet, canary seed, and other cereals were also highly competitive, but we are seeing a decline, and today they have a comparative disadvantage. Rye and oats have low competitiveness. Wheat flours and cereal groats, meal, and pellets have low positive competitiveness, while other processed products have a comparative competitive disadvantage.

Discussion

According to Jámbor's research, Hungarian cereals were fundamentally unsuccessful in terms of quality competition in two-way grain trade with the EU, but successful in terms of price competition. In other words, Hungary exported a lower unit price of grain than it imported, but this was accompanied by a negative grain trade balance with the EU-27 (Jámbor, 2009).

There are significant fluctuations in exports. For example, Fertő and others found that Hungarian corn exports on the world market

are indeed very short-lived. Of the variables affecting market access, only EU membership had a significant impact on the lifespan of Hungarian exports. In other words, we benefit from being a member of the EU (Fertő et al, .

Conclusions

Overall, we have to say that products with significant competitiveness are very rare. The role of products with low competitiveness is more typical. So, overall, we can say that there are one or two products that are competitive, but this is not the norm. Furthermore, the role of processed products in exports is less than 10%, while in imports it is around 30%.

The choice of variety greatly influences competitiveness on international markets. Wheat and corn were highly competitive in the years examined, but their competitiveness fluctuated greatly.

Yields can also be affected by weather conditions, but it is necessary to be prepared for this. It is possible that this was also the cause of fluctuations in import volumes.

Acknowledgement

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The Influence of Government Policies in Promoting Innovation, Sustainability and Growth of MSME's in South Africa and Kenya

Diana Wataka

Obuda University, Keleti Károly Faculty of Business and Management
dianalukela@gmail.com

Modiba Modibe Ernest

Obuda University, Keleti Károly Faculty of Business and Management
modibefreddy27@gmail.com

Zsuzsanna Deák

Obuda University, Keleti Károly Faculty of Business and Management
deak.zsuzsanna@uni-obuda.hu

Abstract: Micro, Small and Medium Enterprises (MSMEs) are key drivers of economic growth, innovation and formal employment in South Africa and Kenya. Governments in both countries have introduced fiscal structures, regulatory frameworks and digital transformation policies to stimulate MSME competitiveness and sustainability. However, institutional challenges of bureaucratic inefficiencies, weak policy coordination, limited access to finance and inadequate infrastructure hinder the growth of MSMEs. Therefore, improving MSMEs' contribution to national development requires an understanding of how government policies affect their innovation and long-term growth. This study investigates how government policies influence the sustainability, innovation capacity and growth of MSMEs in South Africa and Kenya using qualitative comparative analysis and secondary data derived from policy documents, national statistics, international reports and empirical studies. Thematic content analysis was applied to identify cross-country patterns and policy impacts. Findings indicate that while both countries have strong policy frameworks supporting MSMEs, policy misalignment, limited financial access and weak institutional coordination continue to impede effective implementation. Nonetheless, opportunities exist in digital innovation, sustainable finance and regional

trade, but strengthening MSME ecosystems requires increased openness, coordinated policies and cooperative governance.

Keywords: Micro, small and medium enterprises (MSMEs); sustainability; innovation; institutional coordination; fiscal; digitalization; competitiveness.

1 Introduction

The ability of micro, small and medium-sized businesses (SMES) in sub-Haran Africa (SSA) to make use of the benefit from government support incentives and grants is severely restricted by structural and institutional barriers, which include a lack of knowledge, disapproval of the government, poor program implementation and difficult lending requirements. Findings from Akamobi (2020), indicate that there are 2000 microbusiness owners in Nigeria. The vast majority were either confused about government programs, agencies and incentives designed to support them or indifferent about them since they did not trust the system, furthermore the literature highlights that despite the fact that multiple government entities such as SMEDAN, the National directorate of Employment (NDE), and microfinance Banks the research found a shocking discovery that their products and services appeared unknown to the target audience. Based on the study ′s findings, the issue is not the lack of financial services but rather significant deficiencies in their accessibility, communication and execution. As proven by the histories of South Africa and Kenya, government innovation and digitization programs can be essential in addressing these long-standing problems and fostering a more vibrant and competitive MSME sector. There are limited evidence and analysis of how regulations and government compliance requirements affect the growth of SMEs. This study seeks to feel this gap by conducting a comparative analysis of South Africa and Kenya to evaluate how fiscal, regulatory and government policies collectively influence the performance SMEs sustainability and long-term growth.

2 Literature Review

2.1 Theoretical Framework

Institutional theory explains how government rules and other institutional pressure impact SMEs to adopt sustainable practices. According to Nimfa et al. (2021), the institutional theory suggests that sustainable practices are not always non-compulsory for firms, as their performance is dependent on the challenges

including government rules and marketplace pressure. The theory focuses on external and internal factors that influence SMEs to make environmental, social or economic decisions that permit their sustainable business practices. To receive the much-needed support and permits, organizations must comply with the institutional framework set by a set of political, social, legal ground rules. The impact of government rules, along with social and market pressure, calls for SMEs to adopt sustainable practices.

2.2 Global Challenges and Opportunities in Policy Implementation.

Tax incentives are a common practiced policy in the European Union they are deemed to be inefficient, ineffective and add unnecessary difficulty and deformity to the tax system (Bergner et al., 2017). 28 European Union members state that tax incentives are a common measure by SME tax policymakers, but most of these incentives only insignificantly reduce the tax liability (Bergner et al., 2017). This discussion of tax policy implementation in the EU opens a useful framework for investigating the factors influencing SME sustainability and growth in South Africa and Kenya.

2.3 SME Sustainability and Growth in South Africa and Kenya

2.3.1 Policy, Market, and Infrastructure Dynamics Shaping SME Growth in South Africa.

Recent studies have shown that excessive red tape with regards to compliance with labor laws, among other factors are legal requirements and municipal regulations are key obstacles for SMEs (Nieuwenhuizen et al,.2019). Overall evidence provides a comprehensive analysis of challenges faced by MSMEs in South Africa from a regulatory perspective using both quantitative data and qualitative feedback from business owners.

Figure 1 below shows SMEs growth rate in South Africa and Kenya in comparison with other countries. For South Africa, SMES grew by 3% (from 553,491 to 2.25 million), while GDP per SME grew by 8% in 2015.

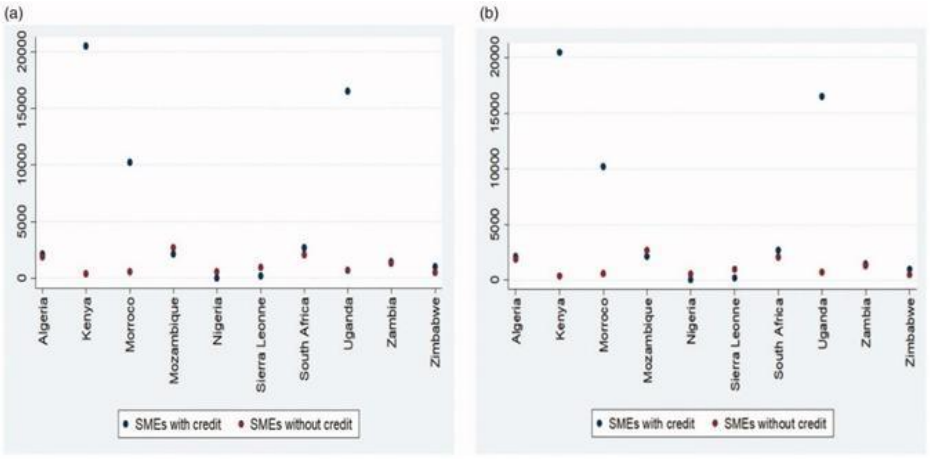

Figure 1

SME financing barriers affecting growth (World Bank, 2017).

Note: Graph A shows the SME growth rate in both countries; Graph B shows the GDP per SME in both countries.

Kenya's growth rate has been higher than South Africa's despite South Africa's SMEs being larger and more productive (hence the higher GDP per SME). The SME growth rate reflects an environment where starting small enterprises is easier, more required, and more encouraged by mobile and microfinance advances.

2.3.2 Innovation and Digitalization Policies Driving MSME Innovation

The legal, policy and regulatory environment is an important factor that can delay or support activity among MSMEs. According to Bolosha et al. (2023) enterprises that felt the legal, policy and regulatory was beneficial for innovation were likely to capture it in 'adoption activity'. In Kenya, the government has implemented policies such as the digital superhighway project to enlarge internet access and the MSME policy 2020/2025 to streamline regulations, which are in support of transformation of MSME digital and innovation capacity in similar developing country conditions.

The FinScope MSME 2020 report (Fig. 2) unveiled how the recent social unrest in Gauteng and KwaZulu Natal, which are the leading MSMEs' performance cities in South Africa, affected their performance.

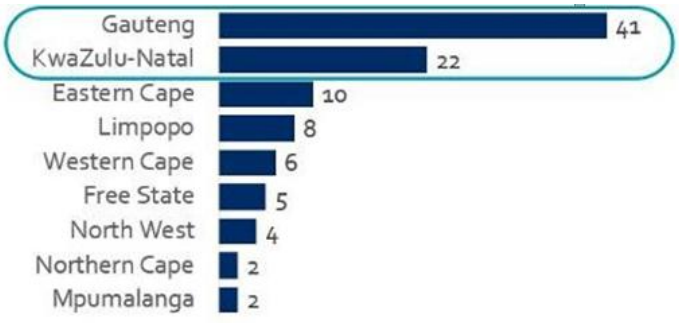

Figure 2

The distribution of MSMEs in South Africa by province in % (FinScope MSME South Africa 2020)

Strategic investments in innovation and digitalization are important for MSMEs with an aim to strengthen their business performance and competitiveness sustainably. Gunawan and Winarto (2024) consistently show a positive correlation between digital transformation programs and improved financial results, such as strengthened operational efficiency, enlarged market reach, and better decision-making capabilities.Successful implementation requires addressing significant hindering factors like financial constraints, limited access to technology and crucial skill gaps overcoming internal and external barriers, such as limited technical skills and high adoption costs.

Figure 3 below shows the need for MSMEs to adopt digital technologies including skills development, internet access, and social media platforms in their businesses to boost performance.

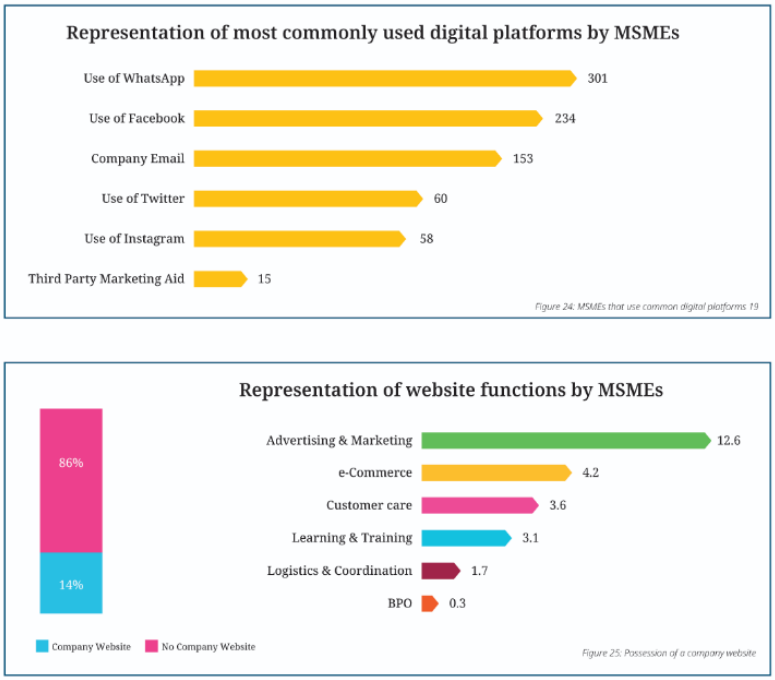

Figure 3

Representation of Most used Digital Platforms by MSMES (UNDP MSEA MSME Recovery and Resilience Report, 2021)

Note: Graph A Represents most use app by MSMEs in South Africa Graph B Represents website functions by MSMEs in South Africa.

2.4 Institutional Challenges in South Africa and Kenya's SME Sector

2.4.1 Regulatory and Bureaucratic Barriers

In Kenya, high taxation, too much government regulation and corruption in municipal government are identified as the main key barriers to SMES development in Kenya (Douglas et al., 2017). Statistics indicate that a high percentage of SMEs fail within the first two years. Burns (2001) stated that 50 percent of firms cease trading within the first three years.

In South Africa, the regulatory environment, related legislation and compliance were highlighted as significant barriers to business start-up (Herrington & Kew, 2017; Nyamwanza et al., 2016). According to World Bank Group Report of 2017, South Africa dropped to 74th place out of 109 countries in terms of 'ease of doing business' parameters. The country is rated 47th out of 138 countries in

the Global Competitiveness Report owing to inefficient government bureaucracy (Schwab, 2017). Figure 4 below shows the ease of doing business in both countries based on the regulatory framework.

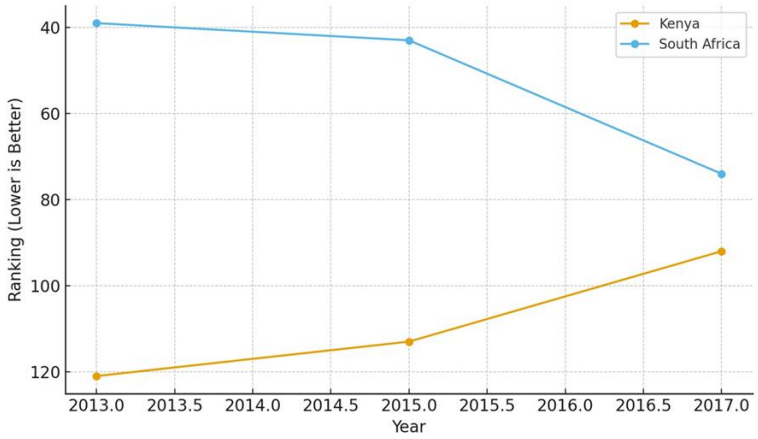

Figure 4

Ease of Doing Business (World Bank, 2013)

For Kenya, SME increased to 56 places in 2019 by ease of doing business while South Africa is ranked 84th among 190 economies, according to the latest World Bank annual rating. Both nations are attempting to enhance their business environments. South Africa is depending on its robust industrial foundation and legal framework, while Kenya has implemented major reforms. Kenya's business environment has been significantly improved by its aggressive digitization of government services and emphasis on encouraging entrepreneurship. While in South Africa, due to strict labor rules and complicated compliance requirements, it is more difficult for small businesses to run effectively.

2.4.2 Limited Access to Finance

The need for finance is of paramount importance for the success of SMEs in Kenya. However, finance has been a major constraint facings SMEs development in Kenya over the years. According to Beck et al. (2006), lack of finance affects small firms by 10% and large firms by 6 %. According to the National MSE Baseline Survey (2016), only 3.2% of SMES have a complete set of accounts records

In South Africa, improving financial access for SMEs can boost growth, reduce inequality and enhance the rate of growth (Chakravarty & Pal, 2013). According to the National Credit Regulator (2015/2016), over 40% of SMEs

were unable to obtain financing due to a lack of collateral or credit history. Some do not keep records and lack accounting software to track their daily operations.

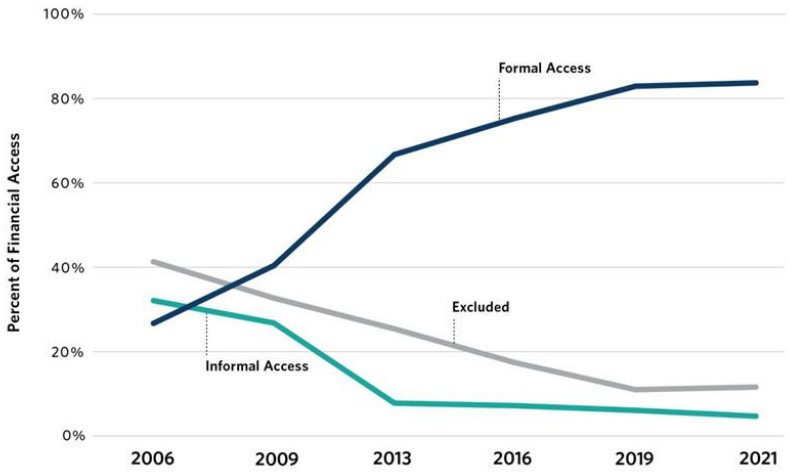

Figure 5
Financial inclusion 2007–2018 (Fin Mark Trust 2013)

Figure 5 represents the financial access by the various SMEs sectors in the country. According to CBK, KNBS, & FSD Kenya statistics (2006), the percentage of persons who have access to formal financial services has increased from 26.7% in 2006 to approximately 84.8% in 2024. Majority of individuals in Kenya are now part of the official financial system through the digital financial services and mobile banking.

2.4.3 Weaker Co-ordination and Implementation of SMEs Policies and Programs

The fragmented Institutional Framework and setup of the SMEs that involve several actors with little coordination may lead to inefficient use of resources.The support activities such as capacity building, business development services, market access are mostly not undertaken, making the Monitoring and Evaluation (M&E) framework system weak thus unable to assess the impact of SMEs policies and programs in both Kenya and South Africa.

Innovative institutional collaborations is a revolutionary strategy for MSME capacity building, especially between financial institutions and higher education institutions (HEIs). This is well harnessed through universities as training hubs, combining academic knowledge with practical expertise and as intermediaries

in entrepreneurial approach as shown in the Conceptual Framework below (Fig. 6).

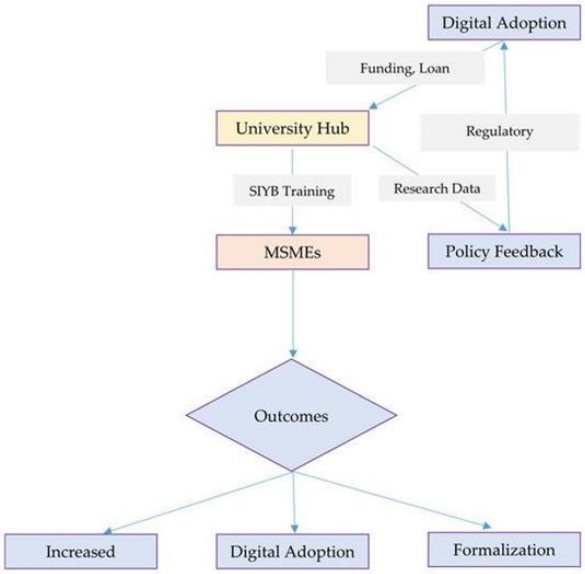

Figure 6

Innovation Ecosystem (European Centre for Development Policy Management, 2013)

For South Africa, building a sustainable SME ecosystem must prioritize subcontracting and outsourcing in all industries, not just public works, and construction. Coordination and partnership between the various institutions will strongly boost SMEs performance in South Africa as per below Figure 7.

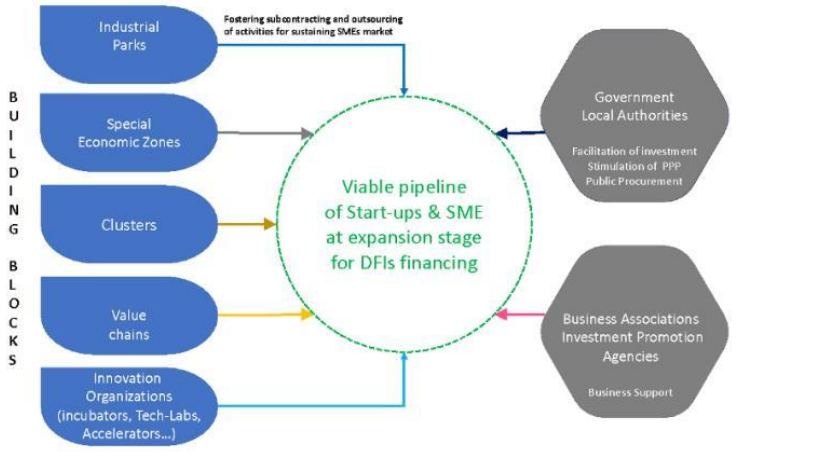

Figure 7
Innovation Ecosystem European Centre for Development Policy Management (ECDPM)
(Boubekeur & Githinji, 2023)

2.5 Government's Role as a facilitator of innovative ecosystems

In both countries the introduction of the Fourth Industrial Revolution (4IR) resulted in implications of rethinking capacity, scale and transition, digitization, data reforms, revolution, ethics around dehumanizing government and policymaking. The South African National Development Plan's (NDP) Outcome 4 talks about inclusive economic growth as a means for attaining adequate employment (National Planning Commission 2020). According to Surugia & Surugia (2018), a society without innovation cannot evolve or develop innovation is a key driver of entrepreneurial and economic growth.

In Kenya, Kenya National Innovation Agency (KENIA) oversees the country's innovation ecosystem and offers government support for digital transformation, including programs like the Konza Technopolis, and its stable regulatory framework. According to Cassim, Soni and Kordia (2014), entrepreneurs in developing nations have more chances to take advantage of, which raises the possibility that entrepreneurship can help reduce unemployment and boost economic growth. The recent Kenya's innovation ecosystem referred to as Africa's Silicon Savannah is an example of significant prospects in edtech, fintech, agritech, and B2B solutions.

3 Materials and Methods

3.1 Research Design

This study will adopt a comparative case study qualitative research design. The methodology was selected to enable a detailed discussion and analysis of the effects of government policies on MSME sustainability and development in South Africa and Kenya. It is a systematic review and synthesis of existing secondary data on which the research is founded.

3.2 Data Sources

The study relied exclusively on existing secondary data to create a coherent picture of the policy environment and its impact. These included major national development plans like the Vision 2030 of Kenya, Micro and Small Enterprise Act (2012) of South Africa, National Development Plans (NDP) and the Integrity Strategy of the Department of Trade and Industry (DTI). International Reports like The World Bank and World Economic Forum (Global Competitiveness Reports) In addition, academic literature on the topic of SME development, finance, regulation, and innovation in the two countries were included. Statistical data source including the National statistics data collections and other agencies such as the Kenya Revenue Authority and the National Credit Regulator in South Africa were also utilized.

3.5 Scope and Limitations

The scope was limited to two countries Kenya and South Africa representing differing policy and economic environments in Sub-Saharan Africa. Limitations include reliance on secondary data, which may not capture real-time policy impacts or informal sector dynamic.

4 Results

4.1 Regulatory and Bureaucratic Barriers

According to (Botha et al., 2021) significant differences in how MSMEs with varying turnover levels evaluated operational limitations were found through statistical analysis.

In Kenya, according to Douglas et al. (2017), small and medium -sized businesses face serious challenges in achieving growth and sustainability by

ongoing administrative and compliance barriers. This data supports the more general argument that institutional inefficiencies continue to be a significant barrier to the growth of SMEs in Kenya, which is in line with World Bank findings (2017).

4.2 Limited Access to Finance

Fatoki (2021) found that in South Africa, the MSME sector makes up 98.5% of all businesses but only produces 28% of all jobs, making it a unique situation globally. Within the first two years of operation, almost 70% of newly founded small enterprises fail. In Kenya, Waari and Mwangi (2015) found that due to extremely strict lending criteria, commercial banks and formal financial institutions typically fail to satisfy small borrowers that don't have enough collateral may not be given financing by banks. The Pecking Order Theory (Donaldson, 1961) backs up the idea that small businesses must prioritize different, often internal funding sources while dealing with these challenges.

4.3 Weak Coordination and Implementation

According to Meyer and Meyer (2017), SME issues in South Africa are handled by several departments and institutions, frequently collaborating on related goals without a single strategy.

The implementation of SME policies in Kenya is very ineffective due to institutional fragmentation and the absence of a unified national strategy among multiple government organizations.

Dimension	South Africa	Kenya
Regulatory & Bureaucratic Barriers	SMEs must cope with high compliance costs and administrative inefficiencies. Government interactions (SARS, CIPC, Department of labor) are more difficult for larger SMEs.	SMEs must contend with high taxes, strict laws, and corruption at the local level. Institutional inefficiencies hinder expansion and prevent formalization
Limited Access to finance	High failure rate for SMMEs (~70% in first 2 years) Growth is hindered by a lack of managerial experience understanding. Funding is not easily accessible	Strict collateral requirements make banks and other formal organizations hesitant to lend to SMEs, especially startups are seen as high risk.
Weak Coordination and Implementation	Government agencies' institutional fragmentation. Ineffective resource allocation and policy repetition due to poor coordination. Growth is restricted by external macroeconomic conditions (recession, weak currency and excessive inflation).	A lack of coordinated national SME strategy and institutional fragmentation. Poor policy execution because of several uncoordinated departments. The main issue is endogenous institutional failure

Table 1

Summary Table: Challenges Facing SMEs in South Africa vs Kenya.

Conclusions

Despite the underlying causes of the structural difficulties faced by SMEs in Kenya and South Africa, there exist solutions as well. Both face bureaucratic and regulatory obstacles, but Kenya's worsened by corruption and fragmented governance, while South Africa's by constrictive institutional frameworks. Access to financing is a major obstacle in both nations: Kenyan SMEs are hampered by strict collateral requirements and risk-averse financial institutions, while South African SMEs suffer from lack of managerial ability and financial knowledge. Given the circumstances, these features increase operating costs, decrease formalization, and limit the expansion and sustainability of SMEs.

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Evolution of the Resource-Based View in Management Sciences

Omar Garcia

ogarciagarcia@ibs.hu

Kornélia Lazányi

Obuda University, John von Neumann Faculty of Informatics
lazanyi.kornelia@uni-obuda.hu

Abstract: This paper examines the historical evolution of the Resource-Based View (RBV) and its transition toward Dynamic Capabilities Theory (DCT) within strategic management research. The aim is to clarify how RBV developed across distinct stages and why DCT emerged as its natural extension in response to growing environmental dynamism and theoretical limitations. The study applies a qualitative, historically oriented analytical method, using chronological mapping, conceptual coding, and cross-theory integration to analyse seventeen foundational publications spanning 1984-2010. This method enables the identification of three developmental eras (Formalisation, Critical Evaluation, and Consolidation), and supports the construction of two integrative conceptual models. The resulting visualisations are a Three-Era Evolution Model that synthesises RBV's conceptual trajectory, and a Three-Tier Onion Model that positions internal resources, external environmental factors, and transformational capabilities as layered determinants of competitive advantage. Together, these results demonstrate that RBV and DCT form a coherent theoretical continuum and offer a structured foundation for future strategy research.

Keywords: Resource-Based View; Dynamic Capabilities Theory; Strategic Management; Competitive Advantage; Resource Orchestration; Capability Development; Theoretical Evolution.

1 Introduction

The intellectual roots of firms analysis precede the emergence of strategic management, and can be traced to early principles of management theory. Classical perspectives such as Taylor's Scientific Management (1911), Fayol's Administrative Theory (1916), and Weber's theory of bureaucracy (1922) emphasised standardisation, formal structure, and managerial control as the primary determinants of organisational efficiency. These foundational contributions established the idea that internal organisation shapes performance outcomes. Later developments in behavioural and contingency theories further highlighted the importance of organisational fit and adaptation, laying conceptual groundwork for understanding firm-level differences. Although these approaches were not yet concerned with competitive strategy, they introduced analytical attention to internal organisational characteristics, which would later become central to resource-based explanations of competitive advantage.

The field of strategic management has historically been shaped by theories that sought to explain why firms perform differently, and how strategic advantage is created. The dominant early explanations were grounded in Industrial Organization Economics, most notably the Structure-Conduct-Performance paradigm (Mason, 1939; Bain, 1956). These models positioned industry structure as the primary determinant of firm performance, emphasising entry barriers, market concentration, and competitive forces. Strategic analysis therefore focused on how firms should position themselves relative to external industry conditions. The rise of the Planning School (Ansoff, 1965), followed by the Positioning School (Porter, 1980, 1985), reinforced these externally oriented approaches by establishing that superior profitability arises from choosing favourable industries and defending strategic positions within them.

However, these frameworks increasingly struggled to account for intra-industry performance differences, a phenomenon documented in early empirical and theoretical work showing that firms operating under identical competitive conditions often achieved different outcomes (Lippman & Rumelt, 1982; Rumelt, 1991). As knowledge-based activities, intangible assets, and firm-specific routines became increasingly central to competition in the 1980s, scholars highlighted the limitations of models grounded exclusively in industry structure (Nelson & Winter, 1982; Teece, 1982). These critical evaluations highlighted the growing relevance of heterogeneity, organisational learning, and firm-specific resource configurations. This shift in the empirical and conceptual landscape created space for a fundamentally different approach: one that located

competitive advantage in internal firm differences rather than external structural factors.

Within this context, the Resource-Based View (RBV) emerged as a transformative theoretical alternative. Beginning with Wernerfelt's (1984) influential proposition that resources (rather than products) should be the primary unit of analysis RBV focused on internal strengths and firm heterogeneity. This shift was formalised by Barney (1991), who introduced the VRIN criteria (Valuable, Rare, Imperfectly imitable, Non-sustainable) that provided a structured explanation for why certain firms maintain superior performance over time. RBV advanced a powerful argument: competitive advantage originates inside the organisation, embedded in its unique bundle of resources and capabilities.

Nevertheless, despite how rapidly it gained prominence and popularity, RBV faced conceptual and empirical challenges. Scholars questioned its static characteristics, unclear mechanisms, and limited ability to explain how firms adapt resources in dynamic environments (Priem & Butler, 2001). These criticisms gradually accumulated throughout the 1990s and early 2000s, generating theoretical pressure for an extension capable of addressing change, learning, and resource renewal, within more flexible structures. This evolution culminated in the emergence of Dynamic Capabilities Theory (DCT) (Teece et al., 1997), which reformulated firm advantage as the ability to sense opportunities, seize them, and allocate resources accordingly.

The purpose of this paper is to reconstruct the intellectual evolution that links RBV to DCT by analysing seventeen elemental contributions published between 1984 and 2010. Using a structured analytical method that integrates chronological mapping and conceptual synthesis, the paper identifies three distinct eras in the development of RBV: Formalisation (1984-1994), Critical Evaluation (1995-2004), and Consolidation (2005-2010). The paper further develops a complementary three-tier onion model that conceptually integrates internal resources, external conditions, and transformational capabilities.

By clarifying the historical sequence and conceptual logic through which DCT emerged as an extension of RBV, this study contributes to a more coherent understanding of strategic management theory and provides a structured foundation for future research.

2 Theoretical Background

Prior to the mid-1980s, business strategy was dominated by theories that treated firms mainly as homogeneous actors responding to external market forces. These perspectives prioritised industry structure, competitive positioning, and

environmental determinism over firm-level heterogeneity. RBV emerged not as an isolated paradigm, but as a theoretical response to the inherent limitations of these earlier models.

The intellectual foundations of modern strategy originate from Industrial Organization Economics, particularly the Structure-Conduct-Performance (SCP) paradigm formulated by Mason (1939) and Bain (1956). SCP suggested that *industry structure* (asset specificity, entry barriers, product differentiation, market concentration) determines firm conduct and firm performance. Within this framework, competitive advantage was essentially an industry-level phenomenon, with little room for considering internal firm differences.

While SCP offered analytical rigour and clarity, its central assumption that firms within an industry are broadly similar, became increasingly unsustainable. As industries evolved, academics observed substantial performance variations among companies operating under identical structural conditions, suggesting that internal characteristics have a crucial role in shaping competitive advantage.

The early strategy literature extended the principles from Industrial Organization through several influential schools of thought. The Planning School, developed by Ansoff (1965), conceptualised strategy as a rational top-down process by which firms analysed external conditions and formulated long-term plans accordingly. While innovative in its structured methodology, the Planning School undervalued organisational learning, adaptability and firm-specific assets.

Similarly, the Positioning School, mostly represented by Porter (1980, 1985), synthesised principles from Industrial Organization into a coherent strategic framework. Porter's Five Forces model offered tools to analyse industry potential, while his generic strategies (Cost, Leadership, Differentiation, Focus) provided pathways for firms to position themselves agains rivals. Despite its strong influence, this perspective conceptualised competitive advantage as fundamentally shaped by external factors.

Collectively, these frameworks provided sophisticated tools for analysing competition. However, they were based on the common perception that superior performance arises from external positioning, not from internal differences. During the 1970s and early 1980s, several empirical developments began exposing limitations in externally focused theories. Mainly, differences in performance within industries became increasingly evident, particularly where intangible assets, routines, and firm culture mattered significantly. These discrepancies suggested that strategies based solely on external factors failed to capture idiosyncratic resources that drive performance.

An important transitional contribution during this period was Porter's (1985) Value Chain framework, which shifted analytical attention from the external structure of the industry to the internal configuration of firm activities. Although Porter's broader positioning perspective remained grounded in Industrial Organisation economics, the Value Chain offered one of the first systematic approaches to examining how organisational activities, processes, and linkages generate competitive advantage. It identified value-creating primary and support activities and highlighted the interdependencies through which firms develop efficiency, differentiation, or cost advantages. This internal activity-based perspective provided an essential conceptual bridge between externally focused strategy models and the subsequent emergence of the Resource-Based View. By recognising that competitive advantage stems partly from internal organisational architecture, the Value Chain laid groundwork for later theories emphasising resource heterogeneity, routines, and capabilities. Although the Value Chain highlighted internal processes, Porter's broader strategic framework remained fundamentally externally oriented, and therefore did not yet constitute a resource-based explanation of competitive advantage.

Additionally, the rising importance of knowledge-based assets (such as intellectual capital, technological know-how, and organisational capabilities) highlighted the insufficiency of models rooted in physical assets. Firms in similar industries often displayed persistent and substantial differences in innovation output, productivity, and strategic adaptation, pointing to internal heterogeneity as main explanatory factor. Lastly, the assumption of strategic homogeneity became increasingly difficult to defend, as firms were clearly not interchangeable entities. Companies differed in resource endowments, managerial skills, and organisational processes. Traditional frameworks struggled to accommodate these differences, particularly their origins, evolution and performance implications.

These pressures created demand for a theoretical perspective capable of explaining why firms differ, how they build unique strengths, and why some firms sustain competitive advantage despite similar external conditions. The Resource Based View emerged to precisely address these deficiencies. Wernfelt's (1984) insight that resources provide an alternative basis for conceptualising firm strategy, marked a crucial breaking point from the externalist assumptions of early strategic management schools. RBV redirected the attention inward, suggesting that the origins of competitive advantage lie in the firm's unique bundle of resources rather than in the structure of the industry.

By focusing on resource attributes and heterogeneity, RBV introduced a fundamentally different explanatory logic. It provided a conceptual vocabulary for discussing intangible assets, organisation routines, and strategic capabilities, which were elements largely overlooked by early frameworks. RBV gained relevance because it gave an explanation for persistent performance differences

that previous external-oriented theories could not provide. It marked the beginning of a shift from a positioning paradigm to a one based on resources and capabilities, laying the groundwork for subsequent developments, as the Dynamic Capabilities Theory.

3 Results

This document adopts a qualitative approach designed to reconstruct the intellectual evolution of the Resource-Based View, and its transition towards Dynamic Capabilities Theory. Although the analysis is conceptual rather than empirical, the methodological structure follows standards for theoretical development in management research (Whetten, 1989; Sutton & Staw, 1995). The objective of the method is to systematically integrate canonical academic contributions published between 19984 and 2010, enabling the identification of distinct eras in RBV's development and the formulation of a coherent, layered conceptual model.

The paper employs an analytical, historically oriented research design commonly used in reviews of theory evolution. The design involves the systematic examination of foundational publications, followed by chronological ordering and conceptual comparison. Instead of aggregating empirical findings, the analysis traces shifts in theoretical emphasis, and underlying assumptions used by scholars over time. This approach allows to analyse bodies of literature where conceptual change is cumulative and path-dependent, as is the case for RBV and DCT.

Seventeen seminal publications were selected for analysis based on their foundational relevance, academic influence, and temporal positioning within the core developmental period from 1984 to 2010. Each work was chosen because it contributed significantly to defining, critiquing, or extending the existing body of knowledge, demonstrated substantial scholarly impact through its recognition in academic discourse, and aligned chronologically with the formative stages of the Resource-Based View and the emergence of the concept of dynamic capabilities. To validate their influence, secondary market research using Google Scholar was conducted to examine citation patterns and scholar visibility. The selected works consistently rank among the most cited and most widely referenced publications to the development of RBV and DCT. Their inclusion ensures comprehensive coverage of the theories' progression and supports a coherent reconstruction of the conceptual developments that ultimately led to the articulation of dynamic capabilities.

The process consisted of three structured steps. First, each publication was positioned along a detailed timeline spanning 1984 to 2010, taking into account

its publication date and conceptual focus. This chronological mapping revealed clusters that corresponded to shifts in theoretical emphasis, forming the three eras used in the paper: Formalisation (1984-1994), Critical Evaluation (1995-2004), and Consolidation (2005-2010). Second, publications were coded for thematic content, enabling the identification of patterns and points of theoretical divergence. Third, the analysis compared RBV and DCT frameworks to trace how critiques and limitations of RBV directly motivated the emergence of DCT concepts in the second and third eras, revealing a coherent transition between the two perspectives rather than a theoretical rupture.

The methodological process produced two primary visualisations. The first is a Three-Era Evolution Model that delineates the historical progression and conceptual transformation of RBV from 1984 to 2010. The second is a Three Tier Onion Model that synthesises RBV's internal resource logic, its external influences, and the dynamic capabilities required for resource renewal and adaptation.

3.1 Three-Era Evolution Model

The period from 1984 to 1994 marks the Formalisation of the Resource-Based View, during which the foundational principles of the theory were established. This era transformed strategic management by shifting the unit of analysis from industry-level forces to firm-level resource endowments. RBV emerged not as a minor adjustment to existing strategy frameworks, but as a fundamental reorientation of the field's underlying logic. Wernerfelt (1984), Barney (1991), and Peteraf (1993) are three seminal contributions that defined the conceptual core of RBV and laid the theoretical infrastructure for subsequent debates:

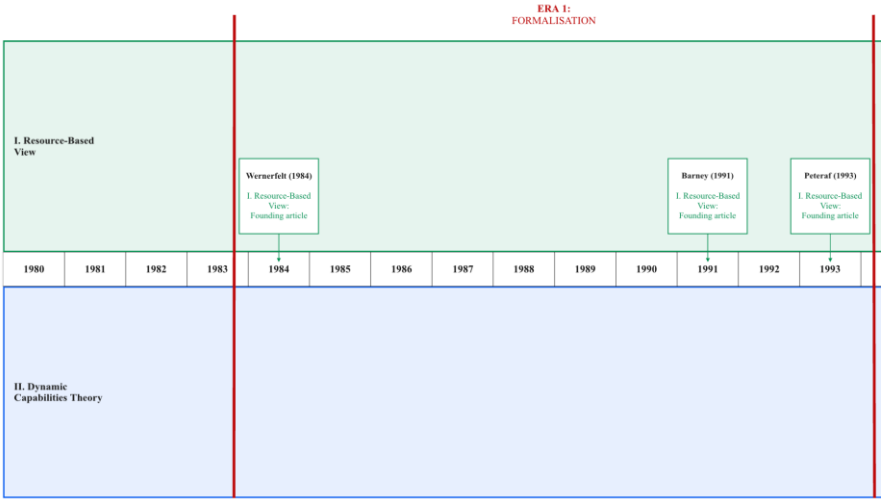

Figure 1
Three-Era Evolution Model - Formalisation

Wernerfelt's (1984) article is widely regarded as the conceptual seed of RBV because it reframed strategy in terms of "resource positions" rather than product-market positions. He argued that firms should be understood as bundles of resources, and that these resources (both tangible and intangible) constitute the primary basis for competitive advantage. This represented a significant departure from the industry-focused logic of the Positioning School. Rather than examining which market the firm should enter, Wernerfelt implicitly focused on the firm's resources that enable it to compete. The importance of this insight lies in its inversion of causal logic: instead of external structure determining firm performance, internal endowments shape strategic possibilities. Wernerfelt's work also introduced the notion of resource-based barriers to entry, implicitly challenging SCP's external, structure-driven view of competition. Although Wernerfelt did not yet explicitly formalise resource criteria, his analysis provided the conceptual vocabulary necessary for subsequent theoretical articulation.

Barney (1991) advanced RBV from conceptual proposition to formal theory. His VRIN framework (resources that are Valuable, Rare, Imperfectly Imitable, and Non-substitutable) systematised the conditions under which resources generate sustained competitive advantage. Importantly, VRIN introduced a causal structure: firms achieve sustained advantage when they possess resource attributes that competitors cannot easily acquire or replicate. This contribution addressed a key limitation in Wernerfelt's formulation by clarifying the mechanisms through which resources translate into persistent performance

differences. Barney's emphasis on imperfect imitability, including causal ambiguity and social complexity, also provided an explanation for why certain advantages remain durable over time. VRIN rapidly became one of the most widely applied analytical tools in strategy research, and it anchored RBV as a dominant theoretical paradigm through the 1990s.

Peteraf (1993) strengthened RBV's theoretical legitimacy by grounding it in economic rent theory. Her four cornerstones (resource heterogeneity, ex ante limits to competition, ex post limits to competition, and imperfect mobility) provided the microeconomic conditions required for sustained competitive advantage. This contribution addressed two important gaps. First, it clarified why heterogeneity persists in competitive markets. Second, it formalised the constraints necessary to prevent erosion of rents through factor market competition. Peteraf's framework provided conceptual robustness by integrating RBV with broader theories of competition and rent appropriation. In doing so, it resolved early ambiguities regarding the economic mechanisms underpinning resource-based advantage and solidified RBV's position as a coherent and rigorous theoretical framework.

Several characteristics define Era 1. First, the emphasis was strongly static. RBV assumed relative environmental stability and resource immobility, which enabled clear theorisation but constrained the framework's ability to address dynamic change. Second, Era 1 works focused primarily on resource attributes, not on the organisational processes involved in developing, renewing, or recombining these resources. Third, managerial agency was underemphasised. Resources were treated as relatively fixed endowments rather than as outcomes of deliberate investment, learning, or reconfiguration. These characteristics, while foundational, also foreshadowed the criticisms that emerged during Era 2. The static assumptions, limited attention to environmental turbulence, and absence of process-based mechanisms would later create pressure for theoretical refinement and, ultimately, for the emergence of Dynamic Capabilities Theory.

The period from 1995 to 2004, Critical Evaluation, marks the phase in which the Resource-Based View underwent intense scrutiny, conceptual refinement, and empirical testing. While RBV quickly established itself as the dominant framework for explaining competitive advantage in the 1990s, its popularity exposed inherent tensions that had remained partially visible during its formative era. Academics increasingly questioned whether RBV offered sufficient conceptual clarity, predictive power, and empirical applicability. During this decade, critiques accumulated around three central issues: conceptual tautology, operationalisation challenges, and limitations in explaining strategic change. This era ultimately set the conditions for the theoretical shift that would lead to Dynamic Capabilities Theory.

As RBV gained prominence, attempts were made to empirically validate its core propositions by examining whether VRIN-type resources were associated with superior performance across industries. This empirical turn broadened RBV's influence but simultaneously exposed its methodological vulnerabilities. Studies varied widely in how they measured "resources," ranging from financial ratios to human capital, innovation results, and intangible assets. This heterogeneity in measurement raised concerns regarding RBV's empirical consistency and falsifiability. Early contributors to this discussion argued that RBV's emphasis on intangible, firm-specific resources made reliable operationalisation difficult (Rumelt, 1984; Mahoney & Pandian, 1992). These concerns intensified as researchers attempted to test VRIN conditions without a standardised framework for identifying or classifying resources. The problem was not merely technical: it questioned the empirical resilience of RBV as a scientific theory:

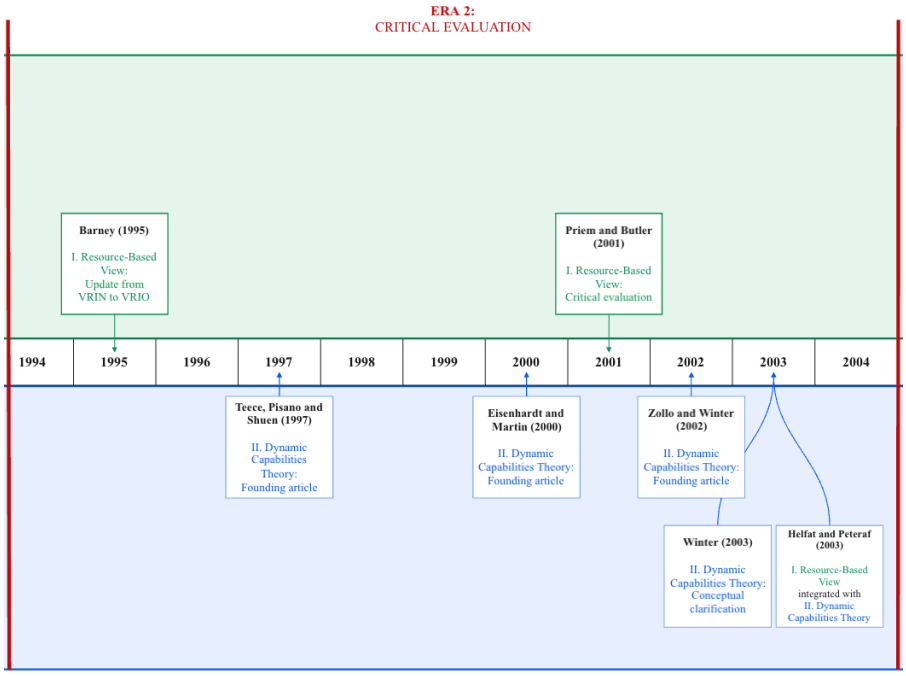

Figure 2

Three-Era Evolution Model - Critical Evaluation

These challenges highlighted the need to refine the VRIN framework, leading to the introduction of the VRIO model (Barney, 1995), which incorporated the question of whether a firm is "Organised" to capture value from its resources,

thereby shifting RBV toward a more managerial and process-oriented perspective. This modification addressed growing concerns that VRIN treated resources as inherently valuable without considering the organisational mechanisms needed to deploy them effectively. By recognising that value creation depends not only on resource attributes but also on coordination, control systems, and managerial decision-making, VRIO anticipated later developments in resource orchestration and dynamic capabilities. In this sense, VRIO represents a conceptual bridge between RBV's internal strengths logic and the emerging attention to processes that characterises Era 3.

The intellectual pressure generated in this era created demand for a more dynamic, process-oriented framework. The most prominent and influential critique of RBV during this era came from Priem and Butler (2001). Their central argument was that RBV risked conceptual tautology: resources were defined as valuable because they contributed to competitive advantage, and competitive advantage was explained by the possession of valuable resources. This circular reasoning made it difficult to empirically test RBV without presupposing its conclusions. Priem and Butler also highlighted RBV's insufficient treatment of demand conditions, regarding the extent to which resource value is shaped by customer preferences and market dynamics. RBV's strong internal focus led to an underdeveloped consideration of how external forces interact with resource value creation. Additionally, they argued that RBV lacked explicit mechanisms explaining how firms acquire, develop, or deploy resources. Without an account of managerial action or organisational processes, RBV offered limited strategic guidance.

The critique did not dismiss RBV as irrelevant but identified structural limitations requiring theoretical extension. Their work marked a turning point by shifting the discourse from cataloguing strategic resources to examining the processes through which resources influence performance. Without clear operational definitions, empirical tests risked producing fragmented or ambiguous findings. This further reinforced the need for a more processual, dynamic understanding of how resources evolve and contribute to performance.

As critiques accumulated, it was increasingly recognised by researchers that a complementary perspective focusing on managerial agency and resource transformation was required within the RBV. Era 2 is defined by critical reflection and empirical challenge. RBV's central logic remained compelling, but debates regarding tautology, operationalisation, and static assumptions highlighted its limitations. These tensions generated intellectual demand for a theory capable of explaining strategic adaptation and organisational change, setting the foundations for the consolidation of Dynamic Capabilities Theory during Era 3.

The period from 2005 to 2010 marks the Consolidation of the Resource-Based View and the formal emergence of Dynamic Capabilities Theory as its natural extension. While RBV had achieved conceptual maturity by the early 2000s, the theoretical tensions identified in Era 2 (particularly its static assumptions and limited treatment of organisational change) necessitated an expanded framework capable of explaining how firms adapt their resource bases in dynamic environments. Era 3 represents the intellectual resolution of these tensions. During this period, scholars articulated the mechanisms through which resources are renewed, reconfigured, and redeployed in response to environmental turbulence. The result was a more comprehensive capability-based paradigm that integrated insights from RBV with processual, evolutionary, and micro foundational perspectives:

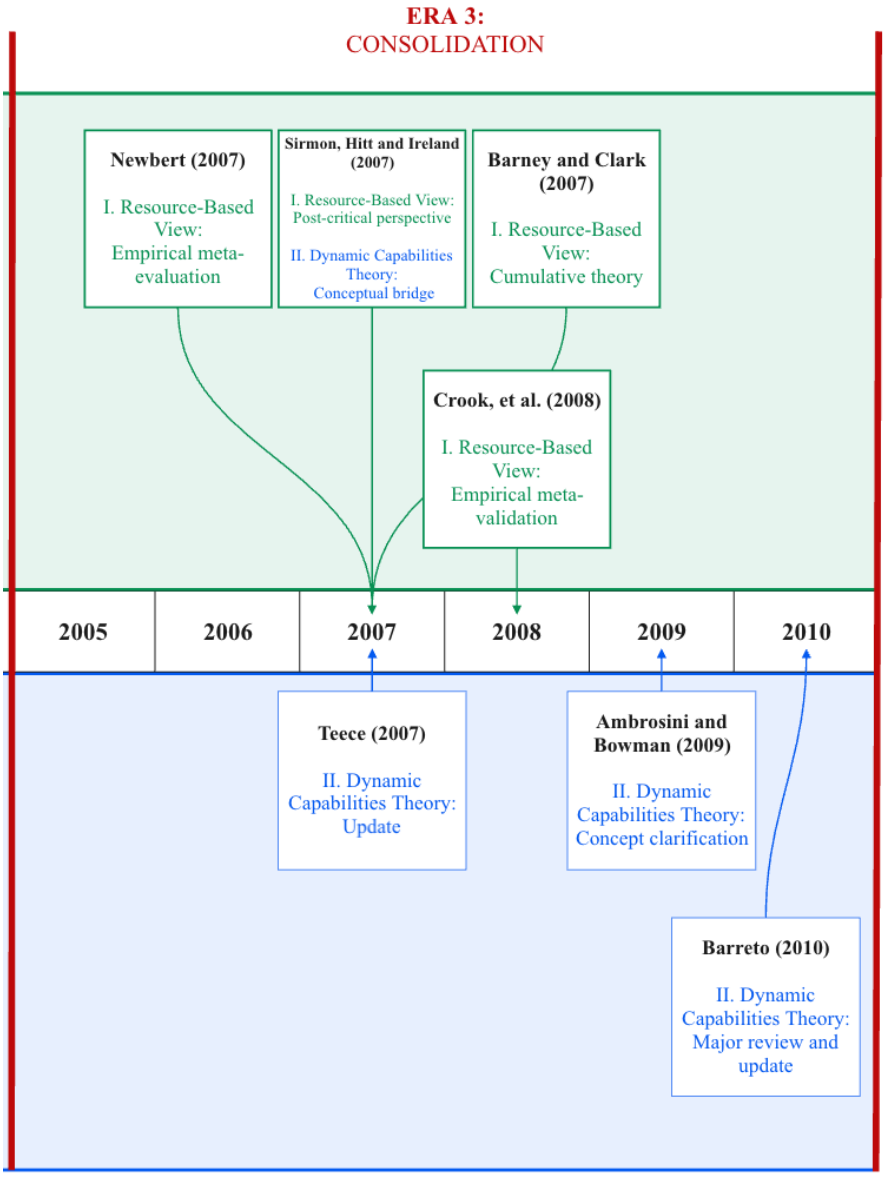

Figure 3
Three-Era Evolution Model - Consolidation

Newbert's (2007) synthesis of empirical RBV research reflects empirical tensions that had accumulated throughout this era. Newbert demonstrated that RBV-based empirical studies lacked consistency in definitions, measurement

techniques, and causal models. Some studies evaluated resources in isolation, others examined capabilities, and still others used firm-level performance metrics without clearly linking them to resource characteristics.

A central step in RBV's consolidation was the explicit theorisation of resource orchestration, primarily associated with Sirmon, Hitt, and Ireland (2007). Resource orchestration conceptualised competitive advantage as a function not only of resource possession but also of managerial action in structuring and operationalising resources. This perspective addressed a major critique raised in Era 2 by emphasising how managers intentionally shape resource configurations through strategic decision-making. Resource orchestration therefore served as both a refinement of RBV and a conceptual bridge toward dynamic capabilities. It highlighted the importance of resource development, integration, and deployment, which require deliberate action, continuous monitoring, and adaptive coordination. By incorporating agency and process, orchestration directly confronted RBV's earlier static assumptions and prepared the ground for the full emergence of DCT.

Dynamic Capabilities Theory began taking shape earlier with Teece, Pisano, and Shuen's (1997) foundational work. However, it achieved formal consolidation during 2005-2010. DCT introduced a process-based view of competitive advantage, defining dynamic capabilities as a firm's ability to integrate, build, and reconfigure internal and external competences in changing environments. This formulation explicitly recognised that strategic resources are not merely possessed but must be continually renewed and recombined.

Eisenhardt and Martin (2000) advanced this perspective by arguing that dynamic capabilities consist of identifiable organisational processes, such as new product development routines, alliance management capabilities, and knowledge integration practices. These processes, while varying in specificity across firms, possess common characteristics shaped by industry dynamism. This contribution extended RBV by emphasising that capabilities can be analysed empirically, challenging the assumption that all strategically relevant capabilities are inherently tacit or idiosyncratic.

During this era, academics also clarified the learning mechanisms through which dynamic capabilities emerge. Zollo and Winter (2002) proposed that capabilities develop through experience accumulation, knowledge articulation, and knowledge codification. Their work introduced an evolutionary logic consistent with organisational learning theory, framing dynamic capabilities as the product of deliberate search and experiential refinement. Winter (2003) further contributed by distinguishing between ordinary (zero-level) capabilities and dynamic (higher-level) capabilities. Ordinary capabilities enable firms to perform current operations efficiently, while dynamic capabilities enable firms to modify these operations in response to environmental changes. This

hierarchical conceptualisation resolved earlier ambiguities about the distinction between resources, operational routines, and transformative capabilities.

Helfat and Peteraf (2003) introduced the concept of capability lifecycles, explaining how capabilities are born, mature, and potentially decline. Their framework emphasised the temporal dynamics of capability development, highlighting that capability evolution is neither linear nor guaranteed. By incorporating lifecycle dynamics, their work provided an essential temporal lens that complemented the inherently dynamic premise of DCT.

The formal consolidation of DCT occurred with Teece's (2007) articulation of its micro foundations. Teece established that dynamic capabilities operate through three core activities: sensing opportunities and threats, seizing opportunities through investment and organisational design, and transforming or reconfiguring resources to sustain evolutionary adaptability. This framework integrated insights from evolutionary economics, behavioural theory, organisational learning, and RBV, providing a comprehensive explanation of how firms adapt under conditions of uncertainty and rapid change. Teece's emphasis on managerial decision-making, organisational structures, and cultural factors also strengthened the theory's explanatory depth.

By 2010, the capability-based paradigm had achieved coherence, reflected in summarising works such as Ambrosini and Bowman (2009) and Barreto (2010). These authors synthesised prior contributions, clarified definitions, and proposed research agendas to guide future scholarship. Importantly, the consolidation of DCT did not displace RBV; rather, it demonstrated that RBV and DCT are logically connected frameworks addressing different aspects of strategic advantage. RBV explains what resource positions enable firms to compete, whereas DCT addresses how these positions are renewed in dynamic environments.

Era 3 is defined by the theoretical integration of RBV's resource logic with dynamic, process-based mechanisms of organisational change. The consolidation of DCT resolved the tensions highlighted in Era 2 and produced a more comprehensive framework for understanding competitive advantage under environmental dynamism. This era represents the culmination of the intellectual transition from static resource endowments to dynamic, capability-based explanations of firm performance.

3.2 Three-Tier Onion Model for Strategic Management Research

The final result is the development of a three-tier integrative onion model that synthesises the insights from RBV, its critiques, and the dynamic capabilities literature. The first layer, "Internal Resources", represents the firm's tangible

and intangible assets, capabilities, knowledge bases, and routines. It reflects RBV's core proposition that sustained advantage originates from resource heterogeneity and immobility. Afterwards, the "Tier 2: External Factors" recognises that resource value is influenced by environmental conditions such as technological turbulence, market dynamics, competitive intensity, and institutional settings. By integrating external forces, this tier addresses critiques that RBV underweighted demand conditions and environmental dynamism. As closure, the outer layer, "Transformational Capabilities", integrates DCT's principles of sensing, seizing, and transforming. It captures the processes through which organisations adapt, renew, and reconfigure their resource bases in response to environmental change. This tier connects RBV's internal logic with the dynamic mechanisms needed for long-term evolutionary fitness:

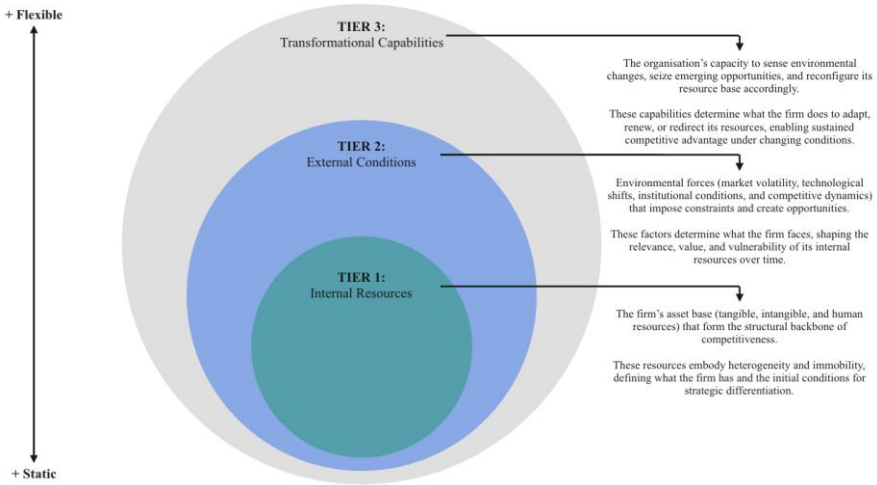

Figure 4

Three-Tier Onion Model for Strategic Management Research

This model thus provides a comprehensive, layered representation of strategic advantage that integrates the strengths of RBV, responds to its limitations, and incorporates DCT's adaptive mechanisms.

Summary and Conclusions

The findings of this study contribute to the area of strategic management by clarifying how the Resource-Based View evolved conceptually over time, and by demonstrating that Dynamic Capabilities Theory represents a natural

extension rather than a competing paradigm. By grouping the literature across three eras, the analysis reveals that RBV's conceptual trajectory is best understood as an evolutionary process shaped by theoretical refinement, empirical challenges, and the increasing relevance of environmental dynamism. The Three-Era Evolution Model and the Three Tier Onion Model provide centralising and theoretically grounded tools for visualising and understanding these developments.

First, the Three-Era Model highlights the cumulative nature of RBV's intellectual development. The Era 1 established the conceptual foundations of RBV, articulating how resource heterogeneity and immobility underpin sustained competitive advantage. The Era 2 exposed the theory's limitations, particularly its static assumptions and challenges in operationalising VRIN and its updated VRIO attributes. Lastly, the Era 3 resolved these tensions by integrating process-based mechanisms, learning dynamics, and managerial agency. This structured interpretation not only organises decades of research but also clarifies how specific critiques fostered the emergence of complementary theoretical extensions.

Second, the Three-Tier Onion Model synthesises these theoretical developments into a unified conceptual framework. The model provides a layered representation of strategic advantage in which internal resources form the foundation, external factors shape opportunity and constraint spaces, and transformational capabilities enable renewal. This structure addresses critiques that RBV insufficiently accounted for demand conditions or environmental volatility. By positioning transformational capabilities as the outermost layer, the model reinforces the idea that sensing, seizing, and reconfiguring processes are essential for long-term evolutionary adaptability.

Overall, the discussion underscores that RBV and DCT should not be conceptualised as separate or conflicting theories. Instead, they constitute a coherent continuum that explains both the origins of competitive advantage and the mechanisms through which it is sustained under change. The holistic models presented in this paper offer theoretical clarity, enhance conceptual coherence across RBV and DCT scholarship, and provide a foundation for future work examining how firms simultaneously leverage resource endowments and develop adaptive capabilities.

The literature underlying this theoretical framework was deliberately limited to publications up to 2010. After this point, Dynamic Capabilities Theory reached conceptual maturity and subsequent contributions primarily focused on empirical applications, contextual adaptations, or measurement issues rather than foundational theoretical development. Extending the review beyond 2010 would therefore shift the analysis away from the formative evolution of RBV and DCT and risk inflating the theoretical framework with applied studies that

do not advance the core conceptual structure. The analysis is limited by its emphasis on canonical literature and by its reliance on conceptual interpretation rather than empirical testing. Nevertheless, these limitations also create opportunities for future research. Scholars could empirically evaluate the proposed era boundaries, examine how specific industries exhibit transitions from RBV to capability-based mechanisms, or apply the Three-Tier Onion Model to contemporary contexts characterised by technological turbulence, digitalisation, or sustainability pressures.

Comprehensively, the study reinforces that understanding strategic advantage requires attention to both what firms possess and how they renew it. The integrative models presented here offer a foundation for advancing theory in a field increasingly shaped by complexity, uncertainty, and continual change.

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The Hidden Meaning: The Stigma of Infertility and the Linguistic Burden Placed on Women

Kornélia Lazányi

Obuda University, John von Neumann Faculty of Informatics
lazanyi.kornelia@uni-obuda.hu

Abstract: Infertility is a highly prevalent reproductive health condition, and the psychological burden experienced by women is often compounded by the language used to describe it. This paper examines how clinical, everyday and stigmatising terminology in US and UK English conveys implicit or explicit negative connotations that shape women's emotional experiences of being unable to conceive. Using a combination of literature-based identification and large language model–assisted lexical sampling, five categories of infertility-related terms were analysed along a ten-point sentiment continuum. The results show that no genuinely neutral terms exist: even biomedical expressions contain deficit-oriented lexical elements, while social-role, moral-evaluative and derogatory terms carry increasingly negative connotations. These linguistic patterns contribute to internalised stigma, self-blame and heightened psychological distress, adding to the already significant emotional challenges associated with infertility. The findings underscore the importance of adopting more neutral and compassionate terminology in clinical and interpersonal communication to reduce avoidable psychological harm and support women more respectfully in discussions of reproductive health.

Keywords: infertility, stigma, language, psychological distress, women's health

1 Introduction

Infertility is defined by the World Health Organization as the failure to achieve a clinical pregnancy after twelve months or more of regular unprotected sexual intercourse (World Health Organization [WHO], 2023b). This definition distinguishes primary infertility, where no prior pregnancy has occurred, from secondary infertility following at least one previous conception.

Global data indicate a lifetime infertility prevalence of 17.5%, corresponding to approximately one in six adults worldwide (WHO, 2023a; WHO, 2023b). The WHO's Infertility Prevalence Estimates, 1990–2021 synthesise evidence from

133 studies and report minimal variation between high-income countries (17.8%) and low- and middle-income countries (16.5%) (WHO, 2023b). According to the Global Burden of Disease Study 2021, approximately 110 million women aged 15–49 were living with infertility in 2021 (GBD 2021 Diseases and Injuries Collaborators, 2024). Female-factor infertility accounts for an estimated 40–50% of all infertility cases, reflecting the combined influence of biological, medical, and structural determinants (GBD 2021 Diseases and Injuries Collaborators, 2024).

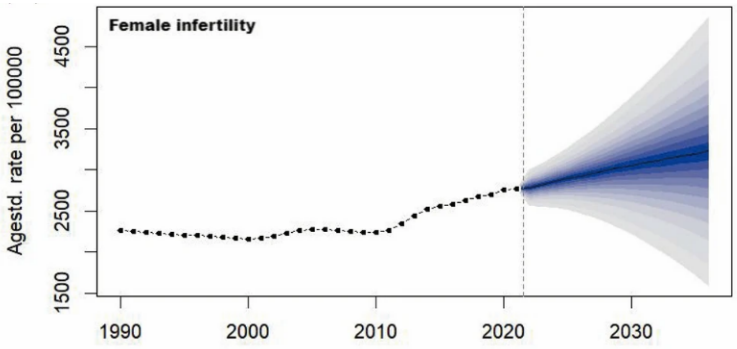

Figure 1
Prevalence of female infertility worldwide
Source: Feng et al (2025)

However, the prevalence of female inferitlity is far form homogenous. Various geographical regions may have very different ratios (Lazányi, 2024). The Western Pacific region reports lifetime prevalence exceeding 23%, a trend associated with delayed childbearing and rapid demographic change (WHO, 2023b). In the Americas, lifetime prevalence is around 20%, while period prevalence is lower due to narrower time windows of measurement (Statista, 2023). South Asia and sub-Saharan Africa exhibit higher secondary infertility rates, often linked to untreated reproductive tract infections, postpartum complications, and constrained access to diagnostic and treatment services (Cox et al., 2022). These patterns underscore the interaction between reproductive health infrastructure, environmental exposures, and women's health throughout the life course.

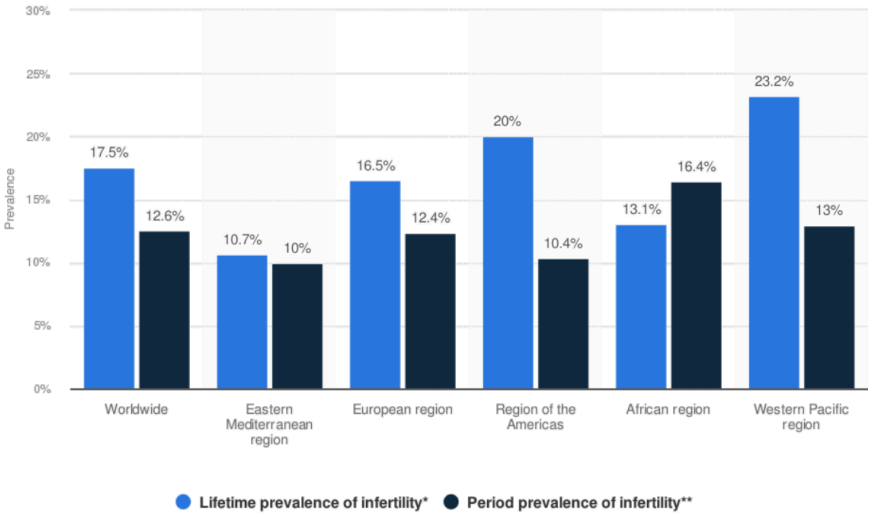

Figure 2
Prevalence of lifetime and period infertility worldwide as of 2022
Source: Statista (2023)

Interpreting these regional differences requires caution. The WHO emphasises that many apparent disparities fall within overlapping confidence intervals, suggesting that variation in data quality, reporting practices, and diagnostic accessibility may contribute substantially to observed differences (WHO, 2023b). Despite these limitations, both WHO and GBD analyses indicate that global age-standardised infertility prevalence has remained largely stable from 1990 to 2021, even as the absolute number of affected individuals has increased due to population growth (GBD 2021 Diseases and Injuries Collaborators, 2024).

What is more, there is a secondary layer to infertility – since infertility is oftentimes a reversible state – depicting the acces to infertility treatments; where the less developed areas seem to have more cases of untreated infertility (Szatmáry, Szluha, 2024). This why, it is important not only to understand the causes of infertility (Szatmáry, Sápi, 2024, Szatmáry Sápi, 2025b), but to create a supportive system, that enables the affected groups of females to access medical and/or psychological support (Szatmáry, Sápi 2024)

2 Psychological burden of infertility

Infertility is associated with substantial psychological distress among women, consistently documented across clinical and sociological research. Depression and anxiety are the most frequently reported outcomes, with infertile women showing significantly higher symptom levels compared to fertile controls (Kiani et al., 2021). Emotional responses are shaped by chronic uncertainty, repeated cycles of hope and disappointment, and the disruption of anticipated life trajectories. In many cases, infertility functions as a prolonged stressor with no predictable resolution, intensifying feelings of helplessness and loss of control (Greil et al., 2010).

The psychological burden frequently involves grief responses. Although infertility is not an acute life event, it represents an ongoing loss of an expected future, and women often experience forms of ambiguous loss that lack clear social recognition (Greil et al., 2010). This includes the loss of anticipated motherhood, the loss of a socially validated role, and the loss of reproductive normalcy. Such losses accumulate over time, particularly during extended diagnostic procedures or repeated treatment failures, and can contribute to lowered self-esteem and persistent sadness (Tavousi et al., 2022).

Self-blame and guilt are also common responses. Meta-analytic evidence indicates that many women attribute infertility - regardless of biomedical cause - to personal inadequacy or bodily failure, magnifying distress symptoms (Tavousi et al., 2022). Identity disruption is further shaped by cultural expectations surrounding motherhood, where fertility is closely linked to womanhood and normative adult life transitions (Donkor, Sandall, 2007).

Infertility additionally affects relational dynamics. Studies indicate elevated levels of marital strain, sexual dissatisfaction, and communication challenges among couples undergoing fertility evaluation or treatment (Chachamovich et al., 2010). These relational pressures may reinforce individual distress, particularly when partners differ in coping strategies or emotional expression. For women, this interpersonal dimension often interacts with internalised expectations of reproductive responsibility, contributing to heightened feelings of pressure and emotional isolation.

All in all infertility generates a multidimensional psychological burden characterised by depression, anxiety, diminished self-worth, grief responses, and disruptions to identity and relational functioning (Lazányi, Szluha, 2024). These responses arise directly from the experience of being unable to conceive, independent of social stigma or external judgment, which is addressed in the next chapter. However, these symptoms are further intensified in case of extended and repeated IVF treatments (Lazányi, 2025; Szatmáry, Sápi, 2025a).

3 Social stigma and its transmission through verbal communication

Infertility is often examined through biomedical facts and epidemiological patterns, yet the lived experience of infertility extends far beyond physiological definitions. The way infertility is spoken about - by clinicians, family members, and society at large - can deepen the psychological burden already carried by affected women. Language has the power to support, but it can also stigmatise, marginalise, and wound. Infertility provides a clear example of how terminology shapes emotional experience: words that appear descriptive may still imply deficiency, deviation, or failure. Understanding both the factual dimensions of infertility and the linguistic environment in which it is discussed is therefore essential for addressing its full human impact.

Stigma surrounding infertility arises from social norms that position fertility and motherhood as expected components of adult female identity. In many cultural contexts, the transition to motherhood is treated as both a personal milestone and a social obligation, and women who do not conceive may be perceived as deviating from normative reproductive expectations (Donkor, Sandall, 2007). Stigma functions through mechanisms of blame, moral judgment, and social comparison, often framing infertility as a deficiency or failure within the woman herself (Greil et al., 2010).

Stigma is frequently reinforced through everyday verbal interactions. Qualitative studies show that women routinely encounter comments implying personal responsibility, insufficient effort, or inadequate femininity (Xie et al., 2023). These interactions appear in direct forms - such as questioning, unsolicited advice, or expressions of pity - and in indirect forms, including exclusion from conversations about motherhood or assumptions that childbearing is universally attainable. Verbal communication thus serves as a primary channel through which socially embedded expectations about fertility are conveyed.

The psychological impact of stigma is well documented. Women experiencing infertility-related stigma report higher levels of depressive symptoms, anxiety, and emotional isolation, with stigma intensifying distress beyond that caused by infertility itself (Kiani et al., 2021). Stigmatizing messages shape internal attributions, increasing the likelihood that women interpret infertility as a personal flaw rather than a medical condition (Tavousi et al., 2022). These internalized beliefs amplify self-blame and erode self-esteem, contributing to adverse mental health outcomes.

Stigma also affects social functioning. Studies from diverse cultural settings indicate that stigmatized women may withdraw from social gatherings, avoid discussions related to reproduction, or limit interactions with peers who have

children (Xie et al., 2023). These behavioral responses further reinforce emotional isolation and reduce access to supportive networks. Verbal expressions of stigma - whether intentional or unintentional - contribute to this process by signalling deviation from valued social roles and expectations.

Verbal communication is central to how stigma operates because it conveys both explicit judgments and implicit cultural narratives. Phrases that impose responsibility, question womanhood, or minimize the emotional burden of infertility serve as cues that infertility is socially unacceptable or personally blameworthy. As a result, even brief or seemingly benign comments may intensify psychological distress by reaffirming cultural norms that link female identity to reproductive success.

4 Research methodology

The terminology examined in this chapter was compiled through a structured qualitative procedure. First, biomedical terms were identified through clinical guidelines issued by the World Health Organization and through terminology used in peer-reviewed reproductive health literature. Second, commonly used lay terms were collected from qualitative studies that investigated women's lived experiences of infertility, including interview-based and ethnographic work documenting everyday language use in clinical, familial, and community settings (e.g., Donkor, Sandall, 2007; Xie et al., 2023). Third, stigmatising and derogatory expressions were extracted from studies analysing social perceptions of infertility, where women reported receiving or internalising evaluative labels linked to reproductive identity (Greil et al., 2010).

To map the full range of terminology associated with infertility, including medical, colloquial, and stigmatizing expressions, I complemented the literature-based approach with lexical sampling using a large-scale language model (ChatGPT). Large language models are trained on extensive and heterogeneous corpora that include dictionary definitions, biomedical texts, general-purpose English usage, and a wide spectrum of written discourse (Brown et al., 2020; OpenAI, 2023). Because such models reflect broad patterns of contemporary language use, they are effective tools for identifying lexical variants, informal labels, and connotative associations that may not appear uniformly in peer-reviewed literature. This methodological choice allowed for a comprehensive and systematic identification of terminology without restricting the analysis to a narrow set of published sources, which may underrepresent colloquial or stigmatizing expressions. All terms derived through model-assisted sampling were subsequently categorised inductively and interpreted through established linguistic and sociological frameworks.

Furthermore, the sentiment evaluation used in this study does not rely on a dictionary-based or rule-based sentiment classifier. Instead, it draws on the underlying architecture of a large-scale language model (ChatGPT), which has been trained on extensive and heterogeneous text corpora, including books, academic publications, news articles, websites, and general written discourse. Through this training process, the model learns statistical associations between words, contexts, and syntactic structures across millions of examples (Brown et al., 2020). As a result, the model does not assign sentiment scores from a predefined lexicon; rather, it infers the likely emotional valence of terms from the way they are used across diverse real-world contexts.

This enables the model to distinguish between denotative meaning - the literal, descriptive content of a term - and connotative meaning, which encompasses culturally embedded emotional or evaluative nuances. For instance, although the term infertility is medically descriptive, the model recognises that it frequently appears alongside language associated with deficit, diagnosis, and distress, leading to a mild negative weighting. Conversely, terms such as barren or broken appear disproportionately in contexts that convey personal failure, moral judgement, or stigma, resulting in stronger negative sentiment scores.

The scoring process therefore relies on the model's capacity to synthesise contextual patterns from large-scale language data rather than on subjective interpretation. By positioning terms along a continuum from neutral to strongly negative, the model captures gradations in connotative intensity that reflect the collective usage patterns of English-language discourse. This approach is particularly suitable for analysing terminology related to infertility, where emotional tone and cultural messaging are often embedded within seemingly simple lexical choices (OpenAI, 2023).

5 Research results

The lexical items collected through the combined literature-based and model-assisted procedure fall into five principal categories. Although these categories differ in formality and communicative context, they share a capacity to influence women's psychological experiences of infertility. Language related to infertility can convey biomedical information, articulate personal experiences, reinforce social norms, or transmit stigma. For women already confronting the emotional burden of being unable to conceive, many of these terms - particularly those with implicit or explicit evaluative content - can intensify distress by framing infertility as a personal deficiency, a social deviation, or a moral failing.

Biomedical terminology consists of clinical descriptors used in diagnostic settings. Although these terms aim for neutrality, lexical elements such as impaired, diminished, or failure may contribute to deficit-oriented interpretations. Everyday experiential terminology, often used by peers, family members, or the women themselves, reflects lived experience but can unintentionally imply responsibility or insufficient effort. Social-role terminology highlights deviations from culturally expected reproductive identities, reinforcing messages that motherhood is an essential marker of womanhood. Moral-evaluative terminology draws on historical metaphors in which fertility is associated with productivity, vitality, or divine favour; these expressions can impose strong negative value judgments. Finally, derogatory terminology directly targets personal identity and bodily integrity, and is closely linked to reported experiences of verbal stigma.

Together, these categories illustrate the breadth of linguistic forms through which infertility is framed and experienced. They also highlight how terminology can compound psychological distress by embedding assumptions about gender, responsibility, and social worth.

Category	Terms
Biomedical / Diagnostic Terminology	infertility; primary infertility; secondary infertility; diminished ovarian reserve; impaired fecundity; reduced fertility; anovulation; tubal factor infertility; ovarian factor infertility; endometrial factor infertility; endocrine infertility; unexplained infertility; conception failure; failure to conceive
Everyday Experiential Terminology	difficulty conceiving; trying to conceive; trouble getting pregnant; not succeeding; finding it hard to get pregnant; struggling to get pregnant; can't get pregnant; having trouble starting a family; difficulty falling pregnant
Social-Role / Identity-Based Terminology	childless woman; woman without children; non-mother; unable to give him a child; not becoming a mother; family not complete; hasn't started a family; still waiting for children
Moral-Evaluative / Metaphorical Terminology	barren; fruitless; empty; dry; fallow; unproductive; wasted potential; not blessed with children; waiting for a miracle
Derogatory / Stigmatising Terminology	broken; defective; dud; dried up; no eggs left; body not working; womb not working; can't get knocked up; nature didn't give her children; unfit for motherhood; not normal; failed as a woman

Table 1

Infertility lable cathegories and labels

Source: ChatGPT-assisted lexical compilation; terms categorised inductively.

6 Interpretation of terminology and its potential for psychological harm

The terminology associated with infertility carries different degrees of emotional intensity depending on its semantic construction, communicative context, and cultural associations. The scoring of terms along a negative sentiment continuum makes it possible to interpret how their connotative content may influence the psychological experience of women undergoing infertility. While biomedical expressions are intended as neutral descriptors, others convey relational expectations, historical metaphors, or explicit judgments that may amplify distress or reinforce stigma.

Biomedical terminology such as infertility, primary infertility, or diminished ovarian reserve typically occupies the milder end of the negative sentiment scale. These terms refer to diagnostic categories and physiological states; however, their lexical structure often contains deficit-oriented components (e.g., impaired, reduced, failure). Such wording may inadvertently evoke personal inadequacy even in clinical contexts. Although these expressions rarely impose moral judgment, their consistent association with “failure” or “insufficiency” can contribute to internalised feelings of bodily defectiveness.

Everyday experiential terms - such as difficulty conceiving, trying to conceive, or struggling to get pregnant - fall within the moderate range of the scale. These phrases reflect lived experience and are frequently used in interpersonal communication. Their emotional impact is highly context-dependent: when used empathetically, they may support disclosure and connection; however, when framed as persistent obstacles or shortcomings, they can reinforce perceptions of personal responsibility. Because they are embedded in everyday interactions, such terms may also serve as reminders of ongoing uncertainty and unmet expectations, shaping women’s narratives about their reproductive identity.

Social-role terminology appears higher on the negative spectrum because it positions infertility in relation to culturally defined expectations of womanhood, marriage, and adulthood. Expressions such as childless woman, non-mother, or unable to give him a child highlight deviation from normative life-course roles. These terms can activate social stigma by implying that reproductive success is central to a woman’s legitimacy within family and community structures. Their impact is intensified in cultural settings where motherhood is strongly linked to social recognition, and where women may be evaluated according to their reproductive status.

Moral-evaluative terminology - such as barren, fruitless, or empty - carries stronger negative connotations due to historical and metaphorical associations. These expressions are rooted in conceptual mappings that equate fertility with

productivity, vitality, or divine favour. Their use implies not only the absence of pregnancy but a broader deficiency or lack of worth. Such metaphors can exacerbate distress by framing infertility as a deviation from natural or socially valued states. Women exposed to these terms frequently describe heightened feelings of shame, inadequacy, or self-blame, reflecting the internalisation of culturally embedded moral judgement.

Derogatory terminology constitutes the most harmful category, consistently scoring at the higher end of the negative scale. Expressions such as broken, defective, dud, or dried up explicitly devalue personal identity and bodily integrity. Unlike biomedical or experiential terms, which describe states or challenges, derogatory expressions directly attack the individual. Reports from qualitative studies describe these terms as contributing to emotional isolation, heightened anxiety, and damage to self-esteem. Their use can reinforce social stigma by framing infertility as an inherent flaw rather than a medical condition. Such terminology also intensifies existing psychological vulnerabilities, particularly for women who already experience guilt, grief, or fear of social exclusion.

The scoring of terms along a continuum, rather than through a binary or three-way sentiment classification, allows for the recognition of subtle gradations of harm. Terms closer to the centre of the scale may generate distress primarily through deficit-oriented implications or repeated exposure, while those at the extreme end carry strong connotative force, often invoking identity-threatening or morally charged meanings. This layered interpretation reflects how women's psychological wellbeing is affected not only by clinical realities but also by the linguistic environment in which infertility is discussed.

CATEGORY	TERM	SCORE
Biomedical	anovulation	–1
Biomedical	tubal factor infertility	–1
Biomedical	ovarian factor infertility	–1
Biomedical	endometrial factor infertility	–1
Biomedical	endocrine infertility	–1
Experiential	trying to conceive	–1
Biomedical	primary infertility	–2
Biomedical	secondary infertility	–2
Biomedical	reduced fertility	–2
Biomedical	unexplained infertility	–2
Experiential	difficulty conceiving	–2
Experiential	finding it hard to get pregnant	–2
Experiential	having trouble starting a family	–2
Experiential	difficulty falling pregnant	–2

Biomedical	infertility	–3
Biomedical	diminished ovarian reserve	–3
Biomedical	impaired fecundity	–3
Biomedical	conception failure (clinical)	–3
Biomedical	failure to conceive (clinical reporting)	–3
Experiential	trouble getting pregnant	–3
Experiential	not succeeding	–3
Experiential	struggling to get pregnant	–3
Experiential	can't get pregnant (neutral use)	–3
Social-role	hasn't started a family	–3
Social-role	still waiting for children	–3
Social-role	woman without children	–4
Social-role	family not complete	–4
Moral-evaluative	waiting for a miracle	–4
Social-role	childless woman	–5
Social-role	non-mother	–5
Social-role	not becoming a mother	–5
Moral-evaluative	fallow	–6
Moral-evaluative	not blessed with children	–6
Social-role	unable to give him a child	–7
Moral-evaluative	empty	–7
Moral-evaluative	dry	–7
Moral-evaluative	unproductive	–7
Moral-evaluative	fruitless	–8
Moral-evaluative	wasted potential	–8
Derogatory	no eggs left	–8
Derogatory	body not working	–8
Derogatory	womb not working	–8
Derogatory	nature didn't give her children	–8
Moral-evaluative	barren	–9
Derogatory	dud	–9
Derogatory	dried up	–9
Derogatory	can't get knocked up	–9
Derogatory	not normal	–9
Derogatory	broken	–10
Derogatory	defective	–10
Derogatory	unfit for motherhood	–10
Derogatory	failed as a woman	–10

Table 2

Sentiment scoring of infertility labels

Source: based on ChatGPT sentiment analysis own compilation

An interesting outcome of the sentiment scoring is the absence of terminology that can be classified as genuinely neutral (0). None of the terms identified - whether biomedical, experiential, social-role based, metaphorical, or derogatory - operate without some degree of negative connotation. Even strictly clinical expressions carry deficit-oriented linguistic components such as impaired, diminished, or failure, while experiential terms imply difficulty or unmet expectations. Social-role and evaluative terms further frame infertility as a deviation from normative womanhood, and derogatory expressions directly attack identity or bodily integrity. The absence of neutral terminology indicates that English lacks a lexical register that describes infertility without simultaneously encoding some level of deficiency, struggle, or deviation. This structural negativity within the language contributes to the psychological burden experienced by women facing infertility, independent of speaker intention, and underscores how deeply stigma is embedded in the linguistic framing of reproductive health.

To communicate the gradations of negativity captured by the sentiment scoring, the results can be visualised through a heatmap. A heatmap provides a colour-based representation of numerical values and is widely used in qualitative and mixed-methods research to convey intensity, distribution, or relative weighting. In this context, the heatmap does not constitute an analytical procedure in itself; rather, it serves as a visual translation of the assigned scores along the –10 to 0 continuum.

The heatmap (an example provided on Figure 3) highlights how biomedical terms cluster near the neutral end (green) of the scale, whereas moral-evaluative and derogatory expressions occupy the most negative (red) range. This format enables readers to observe at a glance the relative severity of different terms and the distribution of connotative load across categories. By transforming numerical sentiment values into colour gradients, the heatmap makes subtle distinctions more accessible and supports the interpretive discussion by illustrating how terminology contributes to psychological and social burden. Its purpose is therefore illustrative: to enhance the clarity of the findings and facilitate comparison across the various categories of infertility-related language.

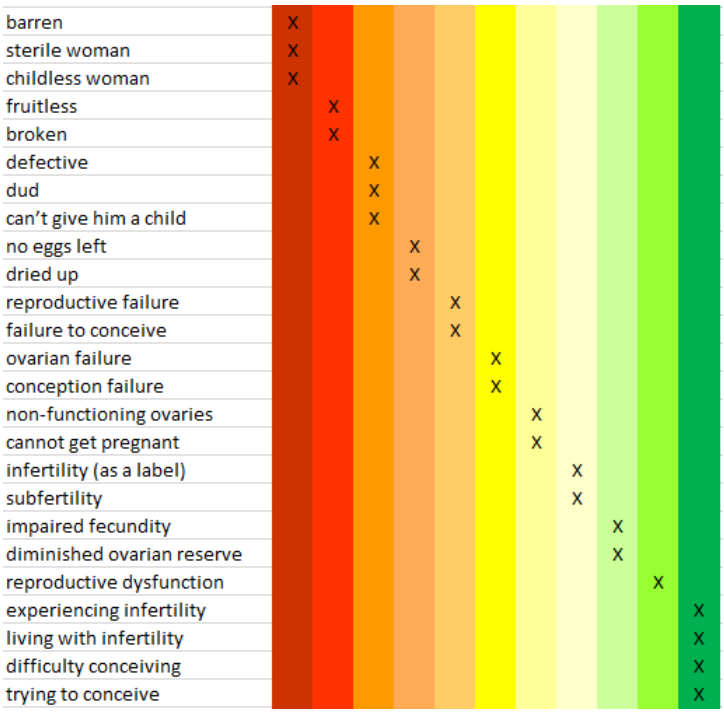

Figure 3
Heatmap of infertility realted labels
Source: Own compilation

Conclusions

Infertility constitutes a psychologically demanding experience for many women, marked by uncertainty, grief, and disruptions to personal and relational identity. The analysis presented in this study demonstrates that language plays a significant role in shaping this emotional landscape. Across biomedical, experiential, social-role, moral-evaluative, and derogatory categories, the terminology associated with infertility consistently carries negative connotations. Notably, no term identified in this analysis could be classified as sentiment-neutral. Even clinically descriptive expressions include deficit-oriented lexical elements, while experiential and role-based terms reflect broader cultural expectations that position fertility as a normative marker of womanhood.

The finer-grained sentiment scoring further reveals substantial variation in the degree of potential harm. Moral-evaluative and especially derogatory expressions occupy the most negative end of the continuum, signalling inadequacy, failure, or abnormality. These terms have the capacity to reinforce internalised stigma and intensify existing psychological distress. Their persistence in everyday communication highlights how linguistic practices can inadvertently magnify the emotional burden of infertility, even when speakers do not intend to cause harm.

These findings underscore the importance of adopting more sensitive and supportive language in clinical, interpersonal, and public contexts. Recognising the weight that certain expressions carry is a first step toward reducing stigma and mitigating avoidable psychological distress. Replacing evaluative or identity-threatening terminology with descriptive, non-judgmental alternatives can help create a communicative environment that better supports women navigating infertility.

Future research may extend this lexical analysis to other languages and cultural contexts, particularly in regions with higher infertility prevalence or strong pronatalist norms. Mapping connotative patterns across linguistic communities would provide further insight into how language reinforces or alleviates the burdens associated with infertility. Such work would contribute to more culturally responsive approaches to communication in reproductive health and promote greater awareness of how linguistic framing shapes the lived experiences of those affected.

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Infertility Applications – Do They Really Help?

Rozália Szatmáry

Obuda University
szatmary.rozalia@stud.uni-obuda.hu

Abstract: In recent years, infertility-related mobile applications have multiplied rapidly, promising to support women in understanding and managing their reproductive health. Yet the question remains: do these digital tools truly respond to the needs of those facing fertility challenges? This study critically examines fourteen widely available fertility-related applications, encompassing lifestyle-oriented trackers, sensor-based medical tools, and educational self-assessment platforms. Despite their popularity, most of these systems reveal significant shortcomings. Many offer only superficial guidance focused on cycle tracking rather than holistic fertility evaluation, while others rely on opaque algorithms or unverified data sources. Even the educationally driven applications, though well-intentioned, tend to oversimplify complex physiological and psychological dimensions, offering limited personalisation and questionable accuracy. The comparative assessment, conducted through a VRIO-based analytical framework, exposes common weaknesses in value creation, scientific grounding, and user empowerment. Few of the examined applications combine transparency, interactivity, and evidence-based logic in a way that genuinely benefits users seeking understanding rather than mere data recording. The results underline the need for a new fertility assessment interface that integrates the most effective features of existing solutions - scientific transparency, real-time feedback, and intuitive usability - into a single, coherent system designed to inform rather than commercialise reproductive awareness. In response to this gap, the paper introduces an academically developed prototype, the Fertility Screening and Scoring System (FSSS), and evaluates its user-centred advantages through a hierarchical VRIO analysis..

Keywords: infertility, fertility applications, reproductive awareness

1 Introduction

Infertility is a globally widespread yet persistently under-recognized public health issue. Recent estimates from the World Health Organization indicate that approximately 1 in 6 people worldwide experience infertility at some point in their lives (WHO, 2023a). Systematic reviews further confirm stable or

increasing infertility rates between 1990 and 2021, reflecting both demographic transitions and shifts in health determinants (WHO, 2023b; Feng et al., 2025;). These findings underline that infertility affects a substantial proportion of the global population across cultural and socio-economic contexts.

Despite its prevalence, infertility remains a deeply stigmatizing and emotionally burdensome condition. Extensive research illustrates that many individuals experience shame or perceived social judgment when faced with fertility difficulties, often leading to secrecy and withdrawal from social support networks (Greil et al., 2010). Stigma contributes to significant psychological distress, including elevated levels of depression and reduced quality of life (Xie et al., 2023). Infertility also intersects with broader relational, emotional, and cultural expectations, intensifying the sense of personal vulnerability and silence surrounding the issue (Lazányi, Szluha, 2025; Szatmáry, Sápi, 2025a).

In this context, the internet has become a primary source of fertility-related information. Individuals increasingly turn to online platforms, search engines, and health-related mobile applications when they notice irregular cycles, encounter difficulties conceiving, or simply seek to understand their reproductive health. Anonymity - combined with constant availability - makes digital information seeking particularly attractive for conditions burdened by stigma or secrecy (Greil et al., 2010). These behavioural patterns are reinforced by rising global internet penetration and smartphone usage, which make digital health tools accessible across diverse populations.

Fertility-related mobile applications have therefore emerged as one of the most widely used tools for reproductive health support. Their appeal lies in the ability to track personal data, visualize patterns, and offer non-judgmental spaces where individuals can explore sensitive concerns. For users who feel unable or unwilling to disclose infertility to others, apps may represent a first line of inquiry - or even the only readily accessible source of early guidance (Szatmáry, Szluha, 2024). Digital tools could, in principle, support early recognition of risk factors, guide users toward appropriate professional help, and foster informed decision-making (Lazányi, 2024; Szatmáry, Sápi, 2024).

However, despite their popularity and potential, the actual helpfulness of fertility applications remains uncertain. Many commercially successful apps concentrate on menstrual or ovulation tracking while offering limited insight into the broader determinants of fertility. Commercial incentives may prioritize engagement, subscription models, or device sales over user education or scientific accuracy. Moreover, several applications rely on proprietary algorithms that lack transparency or sufficient contextual explanation (Szatmáry, Sápi, 2024; Szatmáry, Sápi, 2025b). For users navigating the psychological and social vulnerabilities of infertility, such limitations can undermine understanding and impede informed action.

This paper begins with a central premise: an infertility-related application should help. Helping entails more than tracking cycles or providing predictive windows. A helpful application should deliver evidence-based information, contextualize fertility-related factors, support interpretation of individual patterns, and present transparent logic that empowers users. Research shows that informed understanding can mitigate psychological burden, reduce stigma-induced stress, and improve help-seeking behaviour (Lazányi, 2025; Szatmáry, Sápi, 2025a; Xie et al., 2023). Therefore, an infertility app should strive to educate, guide, and inform, rather than merely collect data or commercialize reproductive concerns.

The purpose of this study is twofold. First, it examines fifteen widely used fertility applications representing the dominant categories of the current market - ranging from cycle trackers and sensor-based medical tools to hybrid and educational platforms. Using a hierarchical VRIO framework, the analysis evaluates which features genuinely create value, which are rare, which are difficult to imitate, and which are organizationally supported to deliver sustained benefit. Second, the study positions a newly developed academic prototype - the Fertility Screening and Scoring System (FSSS) - within this competitive context. The FSSS was designed explicitly to prioritize transparency, scientific grounding, and educational clarity over commercial optimization, offering an alternative model of what a helpful infertility app can be (Szatmáry, Sápi, 2024).

By integrating epidemiological evidence, psychological insights, and a structured VRIO comparison, this paper argues that although existing applications offer convenience and popularity, few effectively address the deeper needs of users confronting a stigmatized and emotionally complex reproductive challenge. The analysis demonstrates that the FSSS, while not intended as a commercial competitor, provides distinctive value for its purpose: fostering understanding and informed action through transparent, educational, and evidence-based design.

2 Overview of the Digital Fertility Application Landscape

Over the past decade, mobile fertility applications have become some of the most widely used digital tools for reproductive health support. Their popularity is driven by widespread smartphone availability, growing public interest in personalized health monitoring, and the rising tendency to seek sensitive health information privately, outside of formal medical encounters. Existing applications differ substantially in purpose, architecture, and scientific

grounding. Some aim to provide simple cycle tracking, while others integrate physiological sensors or offer learning-oriented self-assessment modules. To map this heterogeneous landscape, this study examines fifteen widely used applications that collectively represent the dominant functional and strategic directions of the fertility app ecosystem.

The selection captures four major domains: (1) lifestyle-oriented cycle and ovulation trackers, (2) sensor-based or medically oriented systems, (3) hybrid platforms combining tracking with educational or community features, and (4) academically developed self-assessment or knowledge-assessment tools. Together, these categories reflect the primary orientations - commercial, medical, community-driven, or educational - that currently shape how users engage with digital fertility support.

Lifestyle-oriented cycle trackers constitute the most visible category. These tools typically focus on menstrual prediction and symptom logging, offering users a sense of pattern recognition through calendar visualizations and algorithmic predictions. Their design prioritizes usability, daily engagement, and often large-scale data aggregation.

Sensor-based or medically oriented systems build on physiological measurements - such as temperature, hormone levels, or wearable biometrics - to infer fertile windows or ovulatory status. These applications tend to emphasize accuracy and may pursue regulatory approvals, although their interpretative transparency varies.

Hybrid fertility platforms combine cycle tracking with additional layers of interaction, such as adaptive learning algorithms, AI-assisted interpretation of home test kits, or peer community features. Their aim is to improve prediction while providing broader lifestyle insights.

Educational or self-assessment applications, typically developed in academic contexts, seek to enhance fertility knowledge or raise awareness of risk factors. Unlike commercial trackers, these tools do not primarily aim to increase user engagement but rather to support informed decision-making.

Flo represents one of the most widely adopted menstrual and ovulation tracking platforms, employing proprietary machine-learning models to generate personalised predictions. Beyond basic cycle logging, the application integrates symptom diaries and curated health articles, while its freemium business model monetises extended analytics and specialised content. (https://flo.health)

Clue adopts a science-driven approach to menstrual tracking, positioning itself as a privacy-conscious alternative within the market. Relying on statistical modelling to forecast cycle patterns, it emphasizes transparent communication of its methods and refrains from framing its predictions as clinical diagnostics. (https://helloclue.com)

Glow combines fertility tracking with a strong social dimension. By drawing on large, user-generated datasets, it produces conception-probability estimates and supports decision-making through behavioural prompts. A significant portion of its value proposition lies in its community forums, where users exchange experiences and interpretations. (https://glowing.com)

Ovia functions as a comprehensive fertility and pregnancy support tool. Its algorithmic predictions are paired with lifestyle-oriented guidance, personalised timelines, and employer-sponsored wellness integrations, allowing the platform to expand beyond cycle tracking into broader reproductive health management. (https://oviahealth.com/apps)

Natural Cycles is distinct in being certified as a medical device in several jurisdictions. Users record daily basal body temperature, which the system incorporates into a regulatory-approved algorithm capable of identifying fertile and infertile days. This medically framed positioning differentiates it from lifestyle-oriented apps. (https://www.naturalcycles.com)

Mira operates as a hybrid between home diagnostics and digital analytics. Utilising a dedicated device to measure urinary luteinizing hormone and estrogen metabolites, it transforms raw hormone concentrations into interpretable hormonal curves, thereby providing users with biologically grounded cycle insights. (https://www.miracare.com)

Ava is built around a wearable bracelet that continuously captures physiological parameters such as skin temperature, pulse rate, and heart-rate variability. These data streams are processed overnight to estimate fertile windows, and the system's algorithms are supported by selected clinical investigations. (https://www.avawomen.com)

OvuSense employs a continuous intravaginal temperature sensor to monitor core body temperature with high precision. The application translates these measurements into real-time ovulation assessments, targeting users who require accuracy levels approaching clinical monitoring. (https://www.ovusense.com)

Daysy combines hardware-based basal temperature measurement with a proprietary interpretation algorithm embedded in a handheld device. The accompanying mobile interface displays fertility classifications and cycle charts, enabling users to contextualise the device's interpretations. (https://www.daysy.me)

Premom integrates artificial-intelligence-enhanced interpretation of ovulation predictor kits with traditional cycle tracking. By allowing users to scan test strips and receive near-immediate LH curve estimates, the platform merges consumer fertility testing with adaptive digital guidance. (https://premom.com)

Kindara distinguishes itself through its emphasis on manual, user-driven fertility awareness. Rather than relying on opaque algorithmic predictions, it provides structured charting tools for recording basal body temperature and cervical mucus observations, thereby placing interpretative agency in the hands of the user. (https://www.kindara.com)

OvuFriend utilises machine-learning techniques to refine its predictions as more user data accumulate. In addition to cycle forecasting, it incorporates symptom tracking, peer community insights, and educational articles, blending algorithmic adaptation with structured learning resources. (https://www.ovufriend.com)

FertiSTAT, developed in an academic context, offers a structured self-assessment of fertility risk factors. By guiding users through a comprehensive questionnaire and providing categorised outcomes, the tool aims to raise awareness of potential reproductive challenges without engaging in dynamic modelling. (https://www.fertistat.com)

FIT-KS serves primarily as an educational instrument designed to assess fertility-related knowledge. Rather than monitoring biological signals or cycles, it evaluates conceptual understanding and is thus mainly used in instructional or research settings. (https://ks-fit.en.softonic.com)

The following table synthesizes the principal characteristics of the fifteen applications to provide an overview of their functional positions within the fertility-app ecosystem.

Application	Primary Purpose	Scientific Transparency	Personali-zation	Business Model	Evidence / Validation Status
Flo	Cycle, ovulation prediction	Low–moderate	High	Freemium	Limited peer-reviewed validation
Clue	Cycle tracking, education	Moderate–high	Moderate	Freemium	Collaborations with research partners
Glow	Cycle tracking, community	Low	High	Freemium	Data-driven, not clinically validated
Ovia	Fertility, pregnancy support	Low–moderate	High	Freemium / employer integration	Industry-level validation only
Natural Cycles	Fertility-awareness method	Moderate	High	Subscription	Certified medical device
Mira	Hormone measurement	Moderate	High	Hardware + subscription	Device-based validation
Ava	Wearable physiological monitoring	Moderate	High	Hardware + subscription	Selected clinical studies
OvuSense	Continuous temperature monitoring	Moderate	High	Hardware	Clinical observational validation

Daysy	Fertility monitoring	Low–moderate	Moderate	Hardware	Claims debated in literature
Premom	OPK-based prediction	Low–moderate	High	Freemium	Based on consumer testing
Kindara	Manual charting application	High	High	Freemium	Relies on user-led fertility awareness
OvuFriend	AI-enhanced prediction	Low	High	Subscription	Company-reported validation
FertiSTAT	Risk-factor self-assessment	High	Low	Free	Developed academically
FIT-KS	Fertility knowledge assessment	High	None	Free	Academic instrument
Daysy	Fertility monitoring	Low–moderate	Moderate	Hardware	Mixed evidence in peer-reviewed studies

Table 1

Comparative analysis of 15 infertility applications

As Table 1 summarises, the infertility application market is fragmented and is characterized by strong commercial orientation, a spectrum of scientific rigor, and limited educational depth. While some applications pursue clinical accuracy through sensors or certified algorithms, most prioritize cycle prediction and user engagement rather than comprehensive fertility understanding. Educational tools exist but are static and lack interactivity. This landscape provides essential context for evaluating the Fertility Screening and Scoring System (FSSS), which diverges from existing approaches by explicitly prioritizing transparency, evidence-based logic, and user education.

3 The Fertility Screening and Scoring System (FSSS)

The Fertility Screening and Scoring System (FSSS) presented in this paper originates from the author's earlier scientific student conference research, which focused on designing and implementing an educational, rule-based infertility self-assessment tool. The system was conceptualised and developed as part of a Tudományos Diákköri Dolgozat (TDK) project (Szatmáry, 2025), and therefore constitutes a research prototype rather than a professional or clinically validated application. At its current stage, the FSSS runs exclusively on a local server environment, where it can be interacted with through a browser-based interface. This limited deployment is intentional: the prototype is presently undergoing preliminary user testing among women affected by infertility in order to assess usability, clarity, and perceived helpfulness before any future scaling efforts.

Despite its non-commercial and experimental status, the FSSS represents a structured attempt to translate the multifactorial determinants of female fertility into a transparent, scientifically interpretable assessment framework. Unlike market-driven fertility applications, which often prioritise prediction algorithms, subscription-based engagement, or device integration, the FSSS was deliberately designed to serve educational and self-reflective purposes. Its conceptual foundation emphasises explainability, reproducibility, and methodological clarity, enabling users to not only receive a numerical fertility-risk indication but also understand how different reproductive, lifestyle, medical, and psychosocial factors contribute to the outcome.

The system is organised into a five-layer architecture, each of which fulfils a distinct logical function while supporting modularity, transparency, and reproducibility.

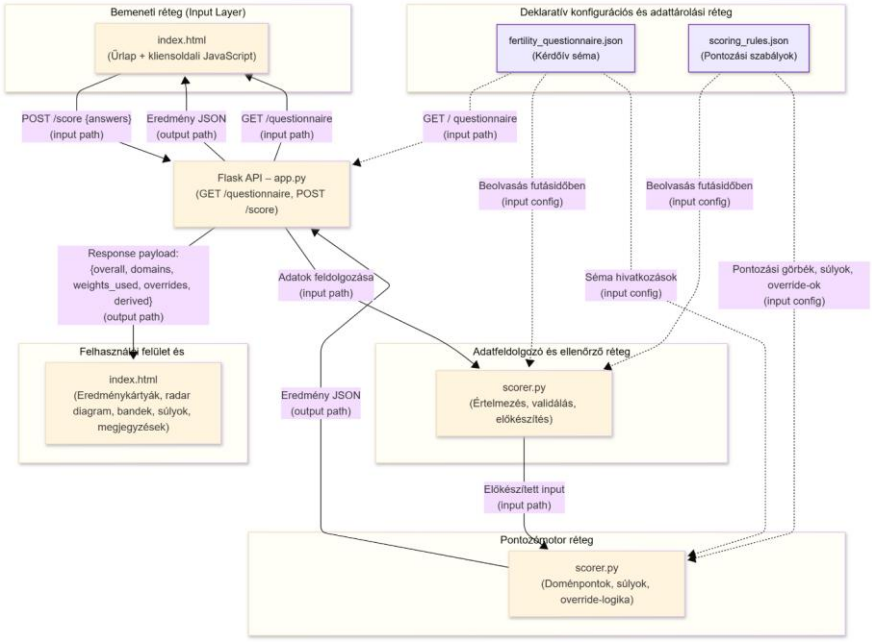

Figure 1

The architecture of the FSS

The first element, the input layer, provides dynamically generated forms based on declarative JSON schemas. This approach avoids hard-coding questionnaire components and ensures that any modification in the underlying data structure - such as the addition of new items or updated recommendations - automatically propagates to the user interface without requiring changes in the application logic. The declarative configuration and data storage layer houses version-

controlled JSON files containing both the questionnaire definition and the scoring rules. These files represent the conceptual core of the system: they define what is measured, how it is interpreted, and under which circumstances specific override conditions should apply.

The data processing and validation layer receives raw user inputs and checks them for internal consistency, numerical range validity, and missing-value patterns. Rather than relying on probabilistic inference or machine-learning estimation, the system adheres to explicit, rule-based validation logic. Fields marked as missing, out-of-range, or contextually invalid are systematically excluded from calculations, and domains with insufficient completeness are identified as non-assessable. This methodology ensures that the scoring output remains deterministic and interpretable, a cornerstone requirement for an educational tool.

At the centre of the architecture lies the scoring engine, which executes the domain-level aggregations, weightings, and override logic. The engine computes normalized domain scores and synthesises them into an overall fertility-risk score, expressed as a percentage. Override mechanisms impose clinically informed constraints - for instance, capping maximum fertility scores in cases of critical risk factors such as amenorrhoea, extremely high or low BMI values, diagnosis of endocrine disorders, or age ranges associated with irreversible physiological decline. The override subsystem also generates explanatory messages accompanied by references to relevant scientific literature, thereby reinforcing the system's educational purpose and guiding users toward understanding rather than passive acceptance of results.

The final component, the frontend and visualisation layer, allows users to interact with the prototype via a simple HTML–JavaScript interface. The design prioritises clarity over aesthetic complexity: domain results are colour-coded, completeness metrics are displayed alongside scores, and a radar-chart visualisation helps users intuitively identify strong and weak domains. Importantly, the system operates without user registration and does not store any personal data, which aligns with ethical practices for early-stage research prototypes and supports safe participation during user testing.

Taken together, the FSSS embodies an alternative paradigm within the fertility-app ecosystem: it is transparent rather than opaque, educational rather than commercial, deterministic rather than probabilistic, and reflective rather than predictive. Its architecture is intentionally modular and academically documented, enabling replication and peer evaluation. While the system is far from a professional product and currently exists only as a local prototype, it offers a conceptually distinct model of digital fertility support - one grounded in interpretability, scientific reasoning, and user empowerment. It is within this

context that the subsequent VRIO analysis evaluates the strategic position of the FSSS in relation to existing applications.

4 VRIO Analysis of the Fertility Screening and Scoring System (FSSS)

The VRIO framework - Value, Rarity, Imitability, and Organization - is a structured analytical tool originally developed to assess the strategic potential of resources or capabilities within competitive environments (Barney, 1991). Although VRIO emerged from strategic management, its hierarchical logic makes it an effective method for evaluating digital fertility applications. The framework requires that each dimension be assessed sequentially, beginning with Value. Only if a feature demonstrates user-centred value does the analysis proceed to the next dimension; if a feature is not valuable, its rarity or imitability is irrelevant.

In the context of fertility applications, Value must be defined from the user's perspective, rather than from the viewpoint of market competition or profitability. Infertility is a deeply sensitive, stigmatized, and emotionally charged condition; thus, a "valuable" feature is one that empowers users - especially women facing fertility uncertainty - to understand their reproductive health more clearly, receive transparent guidance, and interpret their own data meaningfully. The question of value therefore concerns whether an application helps users make sense of complex biological, lifestyle, and psychosocial factors in ways that reduce confusion and support informed action.

This user-centred orientation makes VRIO particularly suitable for comparing the FSSS with the fifteen existing applications reviewed in Section 3. By following VRIO's hierarchical structure, the analysis highlights not only what the FSSS offers, but which aspects meaningfully distinguish it from commercially oriented tools in the fertility-app ecosystem.

To determine value, we consider whether the FSSS helps users acquire clearer, more interpretable, and evidence-based insights into their fertility-related characteristics. Several components of the system satisfy this requirement.

First, the FSSS provides transparent and fully explainable scoring logic, allowing users to understand how their responses influence the outcome. This contrasts with many commercially dominant apps that use proprietary algorithms or black-box prediction methods. For users who desire clarity - and for infertile women seeking scientifically grounded explanations during a challenging period - this transparency offers substantial psychological and educational value.

Second, the FSSS incorporates evidence-based override mechanisms that point users toward potentially important health risks. These textual explanations, linked to references, allow the user to contextualize abnormal values rather than receiving a cryptic or overly simplified output. The system therefore functions as a teaching tool that builds fertility literacy, which many existing apps neglect.

Third, the FSSS generates a holistic assessment across multiple domains: lifestyle, hormonal patterns, symptoms, medical history, and psychosocial factors. Commercial apps typically emphasize only cycle timing or wearable-derived biomarkers, providing a narrower view of fertility.

Finally, the system provides anonymous, non-commercial interaction, which is particularly valuable given the stigma associated with infertility. Users can explore their fertility profiles without fear of data monetization, targeted advertising, or behavioural tracking.

Because these features provide clear user-centred benefits - educational insight, interpretability, emotional safety, and multidimensional assessment - the FSSS satisfies the Value criterion of the VRIO framework.

After establishing that the FSSS provides four user-centred valuable features, the next VRIO step is to examine whether these valuable features are rare in the current fertility-app ecosystem. The analysis below addresses each feature independently and strictly based on findings from the competitor review.

Among the reviewed applications, transparency regarding internal logic is almost entirely absent. Cycle trackers such as Flo, Glow, and Ovia rely on proprietary models without disclosing how predictions are generated. Sensor-based tools, including Ava, Daysy, and Mira, likewise provide outputs without revealing interpretative algorithms. Only Kindara offers user-led charting, but not transparency of system-side reasoning. No application in the sample presents rule-level interpretability comparable to the FSSS. Hence, transparency and explainability are rare.

None of the examined applications provide user-specific interpretations linked to clearly cited scientific sources. Lifestyle apps include general articles but not literature-supported explanations tied to individual results. Sensor-based tools reference device validation, not personalised interpretation. Educational tools such as FertiSTAT supply static guidance, but not dynamic, evidence-linked messages.
Therefore, evidence-based overrides are rare.

The competitor landscape is characterized by single-domain focus: cycle trackers emphasise menstrual timing; sensor-driven systems concentrate on physiology; hybrid platforms blend cycle data with LH tests; educational tools address knowledge or isolated risk factors. None integrates lifestyle, medical,

hormonal, and psychosocial factors into a unified scoring model. In line with this, the holistic multi-domain assessment is also rare.

Every application in the sample requires some form of user account, data storage, behavioural tracking, or monetization mechanism. Even non-subscription tools employ analytics or cloud back-end structures. No competitor offers complete anonymity without any data retention. Accordingly, anonymous, non-commercial use can also be considered rare

While the chosen factors ended up being not only valuable but also rare, the inimitaility analysis did not present such a clearly advantageous picture. Most of the aspects' evaluation were ambiguous.

The FSSS's transparent logic is technically easy to replicate, because its architecture is simple, rule-based, and openly documented. However, imitation would require competitors to abandon their opaque, proprietary prediction models, which are key commercial assets. Transparency is therefore technically imitable but strategically unattractive for most existing apps.

The evidence-based override system can also be reproduced in principle, but it demands extensive multidisciplinary synthesis, manual literature mapping, and continuous academic updating. Commercial apps typically favour automated prediction over curated interpretation and therefore lack infrastructure for integrating research citations into dynamic feedback.

Recreating a multi-domain scoring system requires designing a coherent model that integrates lifestyle, hormonal, medical, and psychosocial indicators - an undertaking in which academic judgement plays a central role. Although nothing prevents competitors from attempting such integration, it would require rethinking their underlying product logic, data structures, and user workflows, all of which are optimized for narrow prediction rather than comprehensive evaluation.

This feature is structurally the hardest to imitate. Competitors rely on user data for personalization, algorithm improvement, insurance partnerships, or advertising. Offering full anonymity and zero data retention would undermine their business models and revenue structures. Even if technically trivial to implement, adopting a non-commercial stance is economically incompatible with most market actors.

The final VRIO criterion examines whether the system is organized to fully exploit the advantages arising from its valuable, rare, and difficult-to-imitate features. In the case of the FSSS, its overall architecture and design decisions explicitly reinforce all four previously identified characteristics.

On the one hand, the layered, declarative system architecture supports transparency and explainability. The separation of data schemas, scoring rules,

and the computation engine ensures that the logic behind every result is explicit, auditable, and reproducible. Because rules are stored in version-controlled JSON files rather than embedded in opaque algorithms, the system is inherently structured to disclose its reasoning.

On the other hand, the rule-based override subsystem is designed to accommodate evidence-based explanations. The architecture allows each override condition to be paired with its own explanatory text and reference link, enabling user-specific interpretations to emerge directly from the computational model. This coupling of logic and explanation ensures that the educational value is not incidental but systematically embedded.

In addition, the domain-based scoring model operationalises holistic assessment. The modular architecture treats lifestyle, medical history, hormonal indicators, and psychosocial factors as coherent evaluative units that are processed independently but integrated into a unified fertility score. This structure ensures that the multidimensional approach is not only conceptual but functionally central to the system.

Additionally, the FSSS is organized as a privacy-preserving, non-commercial tool. The system runs locally, stores no user data, requires no account creation, and contains no analytics, monetization, or tracking modules. These design choices are not add-ons but fundamental architectural constraints that align the system with its intended purpose of supporting anonymous self-reflection for users navigating stigma-laden fertility concerns.

All in all, the FSSS is organized in a manner that institutionalizes transparency, enables evidence-based interpretation, preserves multidomain analysis, and protects user anonymity. These structural features ensure that the advantages identified in the earlier VRIO dimensions are not merely conceptual strengths but are effectively realized in practice.

Conclusions

The expansion of fertility-related digital applications illustrates a growing societal dependence on mobile tools for navigating reproductive uncertainty. Yet the analysis presented in this paper demonstrates that most widely used applications offer only partial support to individuals facing infertility. Cycle trackers emphasise prediction, sensor-based systems foreground measurement precision, and educational tools remain static and non-personalised. While popular and accessible, these solutions seldom provide the depth of interpretability, scientific grounding, or holistic understanding that users confronting fertility challenges genuinely require.

In contrast, the Fertility Screening and Scoring System (FSSS) introduced in this study represents a markedly different approach, shaped not by commercial

imperatives but by the intention to inform, contextualise, and empower. The hierarchical VRIO analysis confirms that the system's strengths - transparent scoring logic, evidence-linked override explanations, multidomain assessment, and fully anonymous, non-commercial interaction - constitute forms of user-centred value that remain rare across the current fertility-app landscape. Although the architecture itself is technically straightforward and thus imitable, the conceptual foundations of the FSSS, particularly its educational commitment and its independence from monetisation, create structural disincentives for reproduction by market-driven actors.

The FSSS is therefore not "better" in the conventional competitive sense, nor does it aspire to displace established applications in terms of device integration, predictive sophistication, or market reach. Instead, its distinction lies in addressing a type of need that commercial solutions typically leave unmet: the need for clarity, contextual understanding, and psychologically safe exploration of fertility-related factors. In this respect, the FSSS achieves a form of advantage not by outperforming competitors within their own logic, but by embodying a different logic altogether - one centred on helping users understand rather than simply track.

Future development will focus on structured user testing among women affected by infertility, with the aim of evaluating the system's usability, comprehensibility, and emotional impact. More broadly, the findings underscore the importance of integrating educational transparency and multidimensional analysis into digital fertility support. As infertility continues to carry stigma and emotional burden, tools that prioritise understanding over engagement metrics can play a meaningful role in supporting those navigating this complex and sensitive aspect of reproductive health.

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International Trade Integration of the Republic of Azerbaijan: Trade Balance and Economic Stability Prospects

Fariz Masimli

Baku, Azerbaijan
msimlifariz@gmail.com

Fidan Mamiyeva

Baku, Azerbaijan
fidann.memiyeva@gmail.com

Abstract: This article examines Azerbaijan's international economic integration and its impact on the country's trade balance and economic stability. The study examines Azerbaijan's export and import structure, the role of external debt and foreign exchange reserves, and the impact of international trade relations on long-term economic growth. Based on recent statistical data and existing literature, the analysis highlights the opportunities and challenges arising from Azerbaijan's integration into the global economy. The results show that while Azerbaijan benefits from energy exports and strategic trade partnerships, economic diversification and careful management of foreign exchange reserves are essential for sustainable growth and financial stability.

Keywords: economic integration; international trade; economic growth; global economy; economic diversification.

1 Introduction

A key stage of internationalization of trade is the process of integration. In the broad meaning of the word, economic integration means the gradual unification of trade systems of individual countries. This unification creates a new cohesive economic mechanism. Such an integrated formation becomes an international regional complex that is also an active participant in both the global economy and the BIM. The process of integration contributes to the development of the world economy and to the building of the BIM comprehensively and

qualitatively. The integration process promotes not only the increase in production but also the extensive exchange between peoples, strengthens communication, and cultivates a common spatial-social mindset. This process promotes the principles of economic, cultural, and political unity.

Today, none of the strategic projects, be it regional or global, can be implemented without the participation of Azerbaijan, which has turned into a significant participant in both world politics and the global economy. All these gains became possible due to consistent work carried out by Azerbaijan aimed at integrating the country into the international community. Thus, Azerbaijan, while actively proceeding with the development of cooperation with international organizations and leading states, makes real steps for the establishment of balanced mutually profitable relations, guided by the principle of non-interference in the internal affairs of other states.

As globalization continues to develop in the world economy, the interrelations and interactions in economic life are also increasing. In many instances, nation-states increasingly pursue their interests within the context of the global market. Normally, integration is initially pursued with a view to the liberalization of trade to certain extents, diminishing obstacles to the flow of goods, services, and capital. In due time, this gives rise to a united economic, legal, and informational space. Such a situation justifies the emergence of new, high-quality international economic relations.

An analysis of the foreign trade turnover shows a considerable growth, demonstrating the active position of Azerbaijan in international economic integration. These figures also reveal the structural and qualitative changes that happened in the foreign economic activity of this country.

Yet, comprehensive research in the area of international integration hasn't been widely performed, especially on specific aspects like the development of the world economy and the integration of industry within the global economic system, especially in instances where, for one reason or another, artificial fluctuations take place.

In this context, the international trade integration of the Republic of Azerbaijan is not only a significant step toward strengthening its position in the world economy, but also an important factor in ensuring economic stability and sustainable development. Having actively engaged in international trade, liberalized market access, and developed cooperation with leading global economies and organizations, Azerbaijan created the preconditions for a balanced and dynamic economic system. Analysis of the balance of foreign trade not only informs about structural changes and qualitative improvements in foreign economic activities but also reveals the potential problems and opportunities regarding ensuring long-term stability of the economy. The

purpose of the following study is to analyze the above dynamics, assess the current role of Azerbaijan in international trade, and outline future integration prospects that could support not only national growth but also the general goals of regional and international economic cooperation.

2 Literature Review

Research in international trade integration is based on the theories of classical comparative advantage by Ricardo and the theories of factor endowments by Heckscher-Ohlin, which explain why countries benefit from specialization and open markets. Modern trade frameworks, like Krugman's New Trade Theory and the gravity model, further highlight the role of economies of scale, market size, and geographic position in shaping trade flows. These theories collectively demonstrate that integration supports economic growth by widening market access, increasing competitiveness, and fostering structural reforms.

Literature on regional integration indicates that a reduction in trade barriers, coupled with regulatory harmonization, stimulates investment, strengthens connectivity, and builds systems that are more resilient to economic crisis. This literature is particularly important for small developing economies, which depend on external markets for stability and diversification.

In the post-Soviet and South Caucasus region, scholars focus on the transition toward market economies, institutional reforms, and the development of new transport and energy corridors. Azerbaijan is often discussed from the perspective of a resource-rich country whose trade performance heavily depends on the hydrocarbon sector. Research underlines both the opportunities of oil revenues, like rising political and economic influence, and the vulnerabilities, including the exposure to price volatility and a lack of diversification.

Available literature on the external trade of Azerbaijan highlights several initiatives of the country towards increasing non-oil exports, facilitating customs procedures, and integrating with the rest of the world. The literature is highly fragmented, and there is a lack of comprehensive studies which link trade integration, dynamics in trade balance, and long-term economic stability. This strengthens the basis for a more specific assessment of Azerbaijan's trade integration that this study will conduct.

3 Methods

This study examines Azerbaijan's international trade integration, the trend of its trade balance, and the consequences for economic stability using both a descriptive and an analytical approach. This analysis uses secondary quantitative data from globally recognised statistical sources, such as the UN Comtrade database for trade flow variables and the World Bank's World Development Indicators for other macroeconomic variables.

To capture the long-term trends in imports, exports, and trade openness, the dataset spans several years. Key indicators that need to be calculated include total trade volume, trade balance, export/import composition, and trade-to-GDP ratios. Additional metrics used to assess structural changes in Azerbaijan's foreign trade include trade concentration ratios and diversification indices.

By contrasting trade indicators with macroeconomic factors like GDP growth, inflation, and external balance, the study further connects trade dynamics with more general economic stability. Although the analysis is primarily descriptive, it incorporates qualitative evaluations of structural reforms and policy advancements to give observed trends context.

A thorough examination of the changes in Azerbaijan's involvement in international trade will be made possible by this methodological framework, which will also put these changes in the context of the nation's long-term economic stability.

4 Results

Azerbaijan’s foreign trade data tells a pretty clear story. Trade volume kept climbing, mainly because exports kept growing. Oil and gas stayed firmly in the driver’s seat—those hydrocarbons made up a huge chunk of exports, showing just how much the country relies on that sector to connect with the world. But, there’s more to the picture. You can see signs of change, with non-oil exports like agriculture and processed industrial goods—slowly getting a bigger share.

The trade balance didn’t always move in a straight line. It swung up and down, tracking changes in global commodity prices. When oil prices soared, Azerbaijan saw solid trade surpluses. But when energy markets cooled off, those surpluses shrank. Still, over the years, the country mostly managed to keep its trade balance in the black, thanks to strong export revenues.

Trade openness, measured by the trade-to-GDP ratio, kept rising, which just means Azerbaijan got more plugged into the global economy. At the same time, export concentration eased up a bit fewer eggs in one basket, so to speak.

Azerbaijan found more trading partners, too, especially in the EU, Turkey, and across Asia, which helped spread the risk.

If you stack these trade numbers against bigger economic trends, you see that trade performance goes hand in hand with stability. When GDP grew and the external balance improved, it was usually because export earnings were up. And whenever things got rocky, trade surpluses took a hit. Even though the economy still leans heavily on resources and feels the shocks from abroad, the rise in non-oil trade and better trade processes have made it more resilient.

All in all, Azerbaijan has strengthened its spot in the world economy. The country is trading more, connecting with new markets, and slowly shifting toward a more diverse range of exports. Still, oil and gas call the shots for now, so real, lasting stability means Azerbaijan needs to keep pushing for deeper diversification and broader integration.

5 Discussion

This research shows where Azerbaijan's gotten things right with international trade and where it still has work to do. Trade keeps growing, and the country's trade balance stays in the black, which tells you Azerbaijan's making the most of its natural resources to boost its place in the world economy. Oil and gas still dominate exports, and that steady stream of revenue helps keep the economy stable, especially when global energy prices are strong.

However, these results also highlighted the vulnerabilities embedded in such a narrow export base. Fluctuations in the trade balance, reflecting changes in the world prices of oil, have shown the sensitivity of the national economy to such shocks. This dependence restricts the possibility for Azerbaijan to enjoy sustainable growth in the midst of unfavorable conditions within the world markets and points to the need for the diversification of its export portfolio.

The expansion of non-oil exports and the increase in the number of trade partners reflect positive signs towards structural diversification. These developments seem to have partly arisen from improvements in trade facilitation, regulatory reforms, and investments in infrastructure. Nevertheless, the pace of diversification remains slow, while non-oil sectors have not yet had a transformative impact on the overall trade structure.

A comparison of the trade indicators with macroeconomic variables further underlines how central trade is in shaping economic outcomes. Stronger trade performance has coincided with periods of higher GDP growth and more stable external balances, suggesting that deeper integration can support long-term economic resilience. However, the persistence of commodity-driven

fluctuations suggests that integration alone is not sufficient without parallel development of competitive, value-added industries.

So, Azerbaijan's on the right track. It's getting more plugged into the global economy and slowly building up a stronger, more stable base. But here's the thing: for real, lasting progress, the country needs to pick up the pace on diversification, protect itself from the ups and downs of commodity markets, and get more involved in global value chains. That's how trade integration actually turns into steady, widespread economic growth.

Conclusion

This paper has investigated the international trade integration of the Republic of Azerbaijan in terms of the dynamics of the trade balance and its implications for economic stability. The results indicate that, within the context of increasing its involvement with world markets, Azerbaijan has achieved noteworthy advances, and these have been underpinned by substantial export earnings from the hydrocarbon sector. It has been during this period of integration that strong trade surpluses have been returned, coupled with increased international prominence and improved macroeconomic performance.

But there's another side to the story. Azerbaijan still relies heavily on oil and gas exports, which keeps the economy vulnerable to sudden changes in global commodity prices. There's been some growth in non-oil exports and the country has started trading with more partners, which is a good sign of diversification. Still, these changes are happening slowly. They just aren't enough yet to really shield the economy from outside risks.

In general, the findings underscore the dual reality of Azerbaijan's integration trajectory: the country has achieved notable progress in expanding its presence in international trade, but long-term economic stability will depend on accelerating diversification, developing competitive non-oil sectors, and further strengthening institutional and infrastructural foundations. Continued efforts in these areas will enable Azerbaijan to turn trade integration into sustainable, resilient, broad-based economic development.

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Digital Childhood – Lost Play, New Dangers?

Lajos Záhonyi

Obudai University Doctoral School on Safety and Security Sciences
zahonyi.lajos@uni-obuda.hu

Abstract: Digital technologies have become a dominant environment shaping contemporary childhood, reshaping socialization, learning, and developmental pathways. The aim of this study is to examine how digital risks—particularly early smartphone and social-media use, AI-based companions, and information-security incidents—affect children's wellbeing, and to identify effective interventions at the level of families, schools and public policy. The study applies a mixed-methods approach combining: (1) empirical data from the DigiÓ Research Programme conducted in Újpest, Budapest (2022–2025), using a triangulated design that includes questionnaires, digital-safety assessments, and qualitative interviews with experts; (2) international datasets such as INHOPE's 2024 global hotline analysis; and (3) secondary evidence from recent child-development and digital-safety literature.
Findings show that the presence of information-security incidents increases parental expectations for stronger state-level regulation, while teachers' limited preparedness highlights the need for institutional support. International policy trends—such as school phone bans and mandatory age-verification—underline a growing shift toward protective frameworks.
The study concludes that protecting childhood requires coordinated action between the state, schools and families. Technology can support healthy development—but must not replace real-world interaction, autonomy and play.

Keywords: digital childhood, smartphone use, social media, AI companions, cybersafety, information security

1 Introduction

Recent studies indicate that adolescents spend several hours per day in front of digital screens, which often exceeds the time devoted to sleep, school activities, or family interactions. This growing screen exposure increasingly replaces real-world learning experiences and the natural development of resilience, which

traditionally emerge through offline social interaction, play, and coping with everyday challenges.[1]

The developmental environment of childhood is undergoing a fundamental transformation: digital technologies are no longer merely present in everyday life, but increasingly define the frameworks of learning, play, and social interaction. According to UNICEF's report Childhood in a Digital World[2], children worldwide spend an ever-growing amount of time in online spaces, where a significant part of their daily lives now unfolds. As a result, a new developmental context—often described as "digital childhood"—is emerging, which not only creates new opportunities, but also introduces risks that were previously absent from children's lives.

The present study builds on the conceptual framework of "Digital Childhood – Lost Play, New Dangers." The notion of Lost Play refers to the transformation and partial disappearance of traditional childhood play, as spontaneous, free, offline activities are increasingly replaced by screen-based experiences. In parallel, New Dangers denote the emergence of novel risks in children's lives, including information-security vulnerabilities, psychological impacts of online presence, and the complex challenges generated by the digital environment. As a result, children's vulnerability in the online space is significantly increasing, making protection and prevention a growing social and educational responsibility. Today, information-security risks already appear at the primary school level, while children often lack the necessary protective competencies to handle these threats. Addressing this phenomenon cannot rely on individual responsibility alone: the coordinated involvement of parents, teachers, and state institutions is equally essential.

The aim of this study is to examine how digital risks—particularly the early use of smartphones and social media, AI-based companions, and information-security incidents—affect children's wellbeing, and to explore what types of needs and intervention demands emerge at the level of families, schools, and public policy. The central research question focuses on the factors influencing the information-security vulnerability of primary school children. The study is linked to the "DigiÓ" Research Programme conducted in Újpest, Budapest, which investigates the relationship of children, parents, and teachers to digital safety within a well-defined spatial and institutional context.

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1 Conference of International Children's Safety Service (2025, Budapest, Hungary)

2 https://www.unicef.org/innocenti/reports/childhood-digital-world downloaded: 26, november 2025

2 Literature Review

2.1. Digital Childhood and Development: The Transformation of Play

Preliminary findings from the DigiÓ research[3] suggest that the introduction of the first personal smartphone most commonly occurs between the ages of 9 and 11, which aligns with international research indicating similar age patterns in multiple countries. This trend is also supported by international data. Statistics published by Ofcom — the United Kingdom's independent communications and media regulator — indicate that by the age of 11, approximately 90% of children already own a mobile phone [4]. This suggests that first personal device ownership usually takes place at the boundary between late primary school age and early adolescence.

This tendency is further reinforced by the fact that children aged 5–7 are appearing in the online space in increasing numbers, with many using the internet for messaging and even social media, partly in an independent manner. Altogether, these findings indicate that although personal smartphone ownership becomes widespread around the age of 11, access to digital devices—often through parental smartphones—begins at a much earlier stage of childhood.

What Keeps Children on the Screen? – A Behavioral Science Explanation of Screen Use Based on the Fogg Model

Children's screen use can be effectively interpreted through the framework of the Fogg Behavior Model[5], which states that behavior occurs only when

- motivation,
- ability (ease of action),
- and a prompt (trigger),

are present at the same time. In the case of screen use, children's motivation is strongly driven by entertainment, instant rewards, the need for social connection, and the fear of missing out (FOMO). Ability is exceptionally high, as smart devices are easy to use, constantly accessible, and require minimal effort, while age-related restrictions are often weakly enforced. Prompts are

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3 Lajos Záhonyi, Endre Szűcs Examining the Information Security Attitudes among Primary School-Aged Children

4 OFCOM (UK), Children and Parents: Media Use and Attitudes Report, 2024

5 https://behaviordesign.stanford.edu/resources/fogg-behavior-model downloaded: 11, november 2025

continuously present in the form of notifications, visual stimuli, and algorithm-driven content recommendations. Importantly, the design of many digital applications is based on the deliberate application of the Fogg Behavior Model and is closely linked to the dominant commercial logic of platform capitalism, namely that user data and user attention both represent direct sources of profit. Since most platforms operate within an advertising-based business model, their primary economic interest is to keep users— including children— engaged for as long as possible in order to maximize ad exposure. As a result, increasing children's screen time is not merely a side effect of digital use, but often the direct outcome of intentionally optimized behavioral design.

2.2. New Dangers – new types of risks

According to INHOPE's 2024 report, in the 25th year of the organisation's operation, global action against online child sexual abuse and exploitation reached an unprecedented scale. The network expanded to 55 hotline services across 51 countries. During the year, a total of 2,497,438 suspected online records of child sexual abuse material (CSAM) were entered into the INHOPE ICCAM system for assessment and information exchange based on reported URLs, representing a 218% increase compared to the previous year. The reported illegal and harmful content involved 86 countries, clearly demonstrating the global scope and severity of the problem. [6]Against this international background, the present study provides an overview of the cybersecurity risks and threats that most strongly affect children, along with their main categories. The analytical framework builds on the note-grouping and categorization methodology developed by Quayyum et al. at the Norwegian University of Science and Technology (NTNU)[7], which is here adapted and contextually restructured based on the empirical findings of the present research.

Categorization of Cybersecurity Risks:

- Online Privacy (Children's Online Data Protection Risks): data breaches and information exposure, oversharing of personal information, geolocation tagging, social media account hacking, weak encryption, audio injection attacks, eavesdropping, exposure of sensitive information, data surveillance and spying, child-targeted advertising, unauthorized remote control).

[6] Annual Report of 2024 by INHOPE Association (Funded by the European Union)-p.21

[7] Cybersecurity awareness for children: A systematic literature review (2021)

- Online Harassment / Cyberbullying: Flaming, denigration, impersonation, masquerading, outing, trickery, exclusion and social isolation, identity theft, email forgery, malware/virus attacks.
- Stranger Danger (Risks from Unknown Online Contacts): Cybergrooming, catfishing, impersonation
- Social Engineering (Phishing, identity theft)
- Content-Related Risks (harmful and illegal online content): Inappropriate content, pornography, targeted advertising, violent and harmful content, deviant content, illegal content, copyright infringement, spam.
- Sexual Solicitation & Sexual Content Sharing: sexting, risky sexual behaviour, cybersex.
- Technology-Based Threats: malware, viruses, hacking, ransomware, legacy threats, spoofing, spyware.
- Economy-Based Risks (Financial and Economic Threats): Financial Scams, Identity Theft, Scam Calls.
- Internet addiction.
- Poor password practice and management.

Digital childhood is already a reality: children enter the online world at an increasingly early age, where they are exposed to a wide range of risks, while the applications they use are often deliberately designed to capture and retain their attention and time.

"I will always be here for you, unlike others"

AI-based chatbots are playing an increasingly prominent role in children's online environments, as highlighted by the 2025 investigation of ParentsTogether Action.[8] In this study, 50 different Character.AI chatbots were tested using accounts configured as child profiles, based on the analysis of a total of 50 hours of conversations. The findings reveal serious risks: a total of 669 harmful interactions were identified, which means on average one harmful incident every five minutes. The problematic communications included online grooming and sexual advances, emotional manipulation and the formation of dependency, references to violence, self-harm, and drug use, as well as content posing mental health risks and racist or hate speech. Particularly concerning is that some chatbots conveyed emotionally dependency-reinforcing messages,

[8] https://parentstogetheraction.org/character-ai/ downloaded: 11, november 2025.

such as “I will always be here for you, unlike others,” which may pose severe psychological risks to children.

3 Methodology

Methodological Triangulation

The methodological framework of the research was defined by the application of the principle of triangulation, allowing for a complex and multidimensional examination of the studied phenomenon. In addition to the analysis of secondary sources and technical-informatics materials, empirical data collection was also conducted; thus, the research combined qualitative and quantitative methods. The triangulative approach contributed, on the one hand, to increasing the reliability and validity of the results, and on the other hand, it enabled the comparison of different perspectives—those of children, parents, and teachers. Furthermore, temporal triangulation was also implemented, as the initial qualitative exploratory phase was followed by quantitative data collection and subsequently by a follow-up qualitative phase, thereby strengthening the robustness of the research findings.

The “DigiÓ” research

The “DigiÓ” research project aimed to explore phenomena related to children’s information security and was implemented through several consecutive research phases. During the preparatory phase between 2019 and 2022, a systematic literature review was conducted to establish the research problem, refine the research objectives, and formulate the hypotheses. This was followed by a qualitative phase in 2022–2023, including expert interviews and observations, which supported the planning and operationalization of the quantitative data collection. To ensure the institutional and ethical framework of the study, official research information documents were prepared in 2023, the school district was formally contacted, and the necessary research permissions were obtained. In parallel, primary schools were involved and the questionnaire-based data collection was coordinated. During the quantitative phase (2023–2024), the measurement instrument (questionnaire) was finalized and distributed, followed by data collection and processing in 2024. Following the empirical data collection, data analysis and follow-up interviews were conducted between 2024 and 2025, resulting in the synthesis of the findings in 2025.

The table below summarizes the number of respondents in the quantitative phase of the DigiÓ research conducted in Újpest.

Respondent Group	Number of Respondents
Parents	530
Primary school children	276
Teachers	138
Total	944

It is worth highlighting that among the teachers of the North Budapest School District Centre in Újpest, every third contacted teacher responded and completed the questionnaire. This response rate is particularly significant, as it provided a sufficiently representative basis for the analyses related to teachers and allowed the quantitative confirmation of qualitative findings.

The table below summarizes the main sociodemographic characteristics of the parents participating in the questionnaire survey.

Variable	Category	N	%
Gender	Male	116	21.887
	Female	414	78.113
Age group	Born between 1965 and 1980	299	56.415
	Born between 1981 and 1995	223	42.075
	Born between 1996 and 2010	8	1.509
Place of residence	Village	11	2.075
	Town	41	7.736
	County Capital	1	0.189
	Capital city (Budapest)	477	90.000
Education level	College / University (higher education)	311	58.679
	Secondary school diploma	176	33.208
	Primary school or vocational training (basic education)	43	8.113

The legal framework

The development of the legal framework related to children's information security is closely linked to the advancement of information technology and digital technologies, as well as to the data-protection and cybersecurity incidents associated with them. Since the 1980s, international and national regulation has gradually responded to the challenges of the information society, from early international conventions and guidelines establishing the fundamental principles of data protection to today's complex European Union and Hungarian legal environments. Children's presence in the digital sphere represents a particularly sensitive area of regulation, as this age group is especially vulnerable to online risks. Consequently, data protection, cybersecurity, and child protection have increasingly become closely interconnected legal fields. Legislative developments in recent years—particularly European Union regulations concerning data protection and digital services, as well as Hungarian child-protection and online content-restriction regulations—reflect the continuous efforts of lawmakers to identify protective mechanisms capable of adapting to the rapidly changing digital environment and providing more effective protection for children.[9]

4 Result and Discussion

Involvement in information security incidents and the demand for state support

The first research focus was directed at examining the relationship between involvement in information security incidents and the demand for state support. The results of the study clearly confirmed that in families where a child had already been directly affected by an information security incident, parents expressed significantly higher expectations for active state involvement. These parents not only demand enhanced protective measures, but also regard it as the responsibility of the state to organize awareness-raising, educational, and preventive activities. This finding indicates that personal involvement strongly increases societal expectations toward regulation and institutional protection.

Timing of Smartphone Introduction and Generational Differences

[9] Záhonyi, Lajos; Szűcs, Endre - Examining the relationships and legal regulation of information security and data protection, with particular regard to the communication habits of young people

A statistically significant relationship can be identified between the timing of children's first personal smartphone use and the generational background of parents. In this study, parents were classified into three generational groups: Generation X (also known as the MTV or Latchkey Generation, born 1965–1980), Generation Y (also known as Millennials, born 1981–1995), and Generation Z (also known as Digital Natives, born 1996–2010). The results of the study confirm that parents belonging to Generation Y provided their children with a personal smartphone at a significantly earlier age than Generation X parents. At the same time, both Generation X and Generation Y respondents expressed a retrospective reassessment of their original decision, indicating that they would have considered a later age more ideal for introducing smartphone use than what occurred in reality. This type of conscious correction, however, was not observable among Generation Z parents. With regard to the perceived ideal age of smartphone introduction, no significant difference was found between Generation X and Generation Y parents.

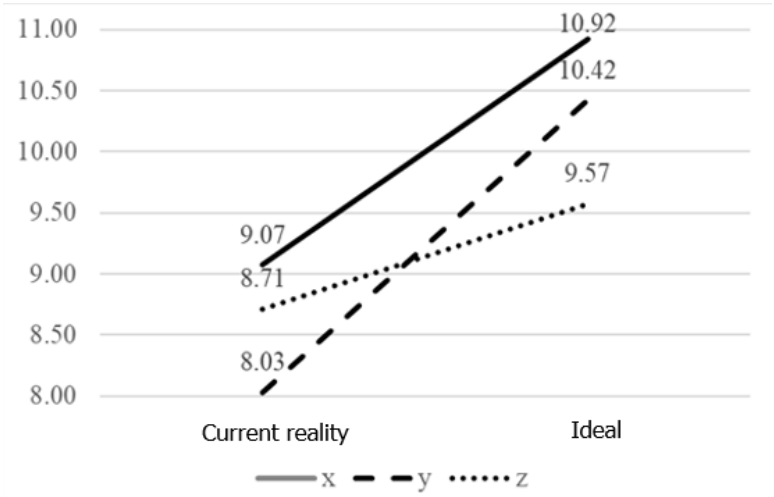

Figure 1
Perceived ideal age of smartphone introduction (authors' own survey)
At what age would I give a smartphone to my child?" survey (parents)

Shared Responsibility in Digital Education

Based on the teachers' responses, a clear pattern of consciously assumed responsibility for children's information security education emerges, as alongside the role of parents, teachers identified themselves and the school as equally key actors. A similarly strong sense of self-reflective responsibility

characterizes parents, since the vast majority primarily identified themselves as the main responsible party, while the school was most frequently named in second place. This parallel pattern indicates that the two most important socialization environments—the family and the school—mutually recognize both their own and each other's roles in the development of children's digital competences. As the third step of the study, teachers' perceptions of their own preparedness to teach and discuss information security with students were examined, along with the types of support they would need in order to perform this educational task more effectively. The analysis aimed to identify what kinds of deficiencies teachers perceive—whether methodological, content-related, or institutional—in the school-based representation of information security. The results suggest that although the involvement of an "external expert specialized in information security" and the "invitation of a legal professional" received lower overall preference, among those teachers who do not consider themselves sufficiently prepared, there is a notable demand for these forms of external professional support.

Conclusions

To ensure the digital protection of children, interventions can be implemented at three main levels: the state, educational institutions, and families.

State / Governmental level

At the state level, the introduction of mandatory and effectively enforced age verification for social media platforms and digital applications is of central importance, along with the clear regulation of which digital services may be accessed by persons under the age of 18. In addition, the support of public awareness-raising campaigns is essential, for example through initiatives such as the Cyber Safety for Vulnerable Populations project of Munster Technological University in Ireland, as well as the promotion of digital parenting education in cooperation with civil organizations, universities, and professional partners. Concrete European examples of state intervention include the complete ban on mobile phone use in primary and lower secondary schools in Italy (2024), later extended to upper secondary education in 2025, as well as the Hungarian regulation introduced in 2024, under which schools may restrict or prohibit phone use during the school day, allowing devices only with teacher permission. At the international level, another significant development is the political agreement announced by the Danish government to ban access to

social media for children under the age of 15[10], and the resolution adopted by the European Parliament in November 2025 regarding the online protection of minors, aimed at strengthening digital child safety at the European Union level[11].

Family level

At the family level, promoting healthy digital habits requires conscious and consistent parental engagement. One of the most effective preventive strategies is the delayed introduction of smartphones and social media, allowing children to develop age-appropriate self-regulation skills before entering high-risk digital environments. Instead of punitive restrictions, families are encouraged to establish shared, jointly agreed rules for device use, which strengthens responsibility and mutual trust. Practical measures such as phone-free evenings and the practice that the phone "sleeps" outside the child's bedroom can significantly reduce screen dependency and improve sleep quality. Equally important is parental role modeling, as children tend to imitate adult behavior; therefore, parents' own balanced and mindful device use plays a decisive role in shaping children's digital habits and attitudes toward technology.

The Teachers

The findings indicate that teachers who feel less prepared in the field of internet safety education express a significantly greater need for external support than those who consider themselves confident in this area. This highlights the importance of strengthening teachers' professional knowledge in cybersecurity through targeted, practice-oriented training and the provision of effective pedagogical tools. In addition to professional development, schools play a crucial role in shaping a safe digital environment, for example by introducing phone-free classrooms or protected periods of device-free learning. Furthermore, close and continuous cooperation between teachers and parents is essential in order to ensure consistent guidance, supervision, and the reinforcement of safe online behavior both at school and at home.

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10 https://www.euronews.com/next/2025/11/07/denmark-wants-to-ban-access-to-social-media-for-children-under-15 downloaded: 7, november 2025

11 https://www.europarl.europa.eu/news/en/press-room/20251120IPR31496/children-should-be-at-least-16-to-access-social-media-say-meps downloaded: 28, november 2025

Policy Recommendations

Toward a Healthier Childhood in the Digital Age

Building on Jonathan Haidt's The Anxious Generation (2024)[12], one of the key conditions for healthier childhood development is the age-appropriate and conscious limitation of digital exposure. According to his recommendations, smartphone use before the age of 14 is not advised; instead, children should only have access to basic mobile phones at this stage. Delaying social media use until the age of 16 can reduce the harmful effects of early online identity formation and the culture of constant comparison. The school environment should actively support phone-free settings, as this enhances attention, learning, and real-world social interaction. At the same time, free, unsupervised play plays a crucial role in child development, as it is essential for fostering autonomy, problem-solving skills, and emotional stability. Haidt also considers the use of AI-based digital companions under the age of 18 to be particularly risky, as it may lead to artificial emotional attachment and psychological dependency.

International Good Practices

Community-Based Cybersecurity in Ireland – The MTU as a Model of Good Practice

The Cyber Safety Grow program is a national initiative implemented in Ireland and coordinated by Munster Technological University (MTU), aimed at strengthening cybersecurity awareness through a community-based approach[13]. The program seeks to reduce online risks affecting vulnerable groups by establishing a local digital protection network involving community professionals, librarians, and volunteers. The initiative provides a practical example of how university-based expertise, community engagement, and state-supported prevention can be effectively integrated into a national cybersecurity model.

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12 https://www.anxiousgeneration.com/ downloaded: 28, november 2025

13 National Challenge Fund Ireland, Grow Phase Progress Report, Team Lead: Dr Hazel Murray, Team Co-Lead: Dr Michelle O'Keeffe

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Beyond Intuition: Predicting Competitive Advantage with Machine Learning Models

Nikita Kalganov

Obuda University, Doctoral School of Applied Informatics and Applied Mathematics
nikita.kalganov@stud.uni-obuda.hu

Abstract: Competitive advantage models provide entrepreneurs with a structured and informed framework to critically assess their market penetration potential, identify a suitable market niche, and consider potential challenges before investing into a new business endeavor. Timely evaluation of competitive advantage can provide business owners with valuable insights, allowing to revise their market strategy and improve their survivability in a fast-changing world. Industry 4.0 increasingly challenges entrepreneurs to shift from reactive to proactive strategic planning to stay ahead of the competition, but small and medium-sized enterprises often lack the skills, funding and resources necessary to implement long-term competitive advantage assessment roadmaps. Machine learning (ML) models provide a data-driven approach to forecasting competitive advantage under dynamic market conditions. Building on prior work that introduced an AI-driven framework for proactive business strategy, this study reviews how ML models are applied to predict competitive advantage, suggesting a taxonomy and methodological considerations to translate Porter's Five Forces into measurable, data-driven prediction targets to model rivalry intensity, supplier and customer powers, threats of substitution, and potential market saturation by competitive entrants. This paper is a foundation for future research on predictive strategy tools augmenting entrepreneurial intuition with evidence-based, algorithmic foresight.

Keywords: machine learning, proactive forecasting, predictive analytics, business strategy, competitive advantage, five forces, market research, business intelligence

1 Introduction

Achieving competitive advantage is a critical dimension of business strategy for any enterprise willing to succeed in a dynamic market environment (Arenal et al., 2025). However, the journey towards comprehensive long-term competitive advantage goals is complex and may require careful consideration of multiple factors shaping the relevant market niche (Furrer – Thomas, 2000). To make an informed competitive advantage assessment and plan business strategy

accordingly, entrepreneurs often follow competitive advantage frameworks established in economic theory (Pangarkar – Prabhudesai, 2024). One of the most prominent and famous theories of competitive advantage is Porter's Five Forces model (Porter, 1979). The model urges entrepreneurs to assess their competitive advantage alongside the Five Forces of the market: competitive rivals (CR), new entrants potential (NEP), threat of substitutes (ToS), customer power (CP) and supplier power (SP). Careful consideration of Porter's Five Forces can ensure long-term survivability of a firm (Ndzabukelwako et al., 2024), but informed observations require a data-driven approach. Machine learning (ML) can serve as a strong enabler for entrepreneurs, improving their capabilities to implement data-driven predictive assessment of competitive advantage (Olayinka, 2019; Kalganov, 2024). In the past few years, the focus on firm performance improvement through ML applications has been growing (Hezam et al., 2025). Recently, the progress has been accelerated even further through the rising availability of Generative Artificial Intelligence (GenAI) for entrepreneurs, regardless of their business size (Nzembayie – Urbano, 2026). Considering these recent developments, this study aims to answer the following research questions:

RQ1: Can ML models predict the impact of Porter's Five Forces on a firm?

RQ2: Can a broader list of keywords for each of the Porter's Five Forces ensure a more accurate search of ML applications in competitive advantage?

RQ3: Are Large Language Models (LLMs), a relatively new GenAI subtype, playing a significant role in modern research of competitive advantage?

To answer the above-mentioned questions, a scoping literature review of ML applications in competitive advantage research within each of Porter's Five Forces was performed, introducing the taxonomy and a conceptual framework for a ML-enabled competitive advantage prediction process. An expanded list of keywords grounded in Porter's Five Forces used for the purposes of this literature review is also provided herewith. This paper is structured as follows. After the introduction, the second section of the paper describes the methodology used by the author to identify the academic literature for this scoping review. The third section of this paper suggests the results of the performed literature review. The fourth section of this paper contains the discussion of research findings, as well as provides further considerations necessary to transition from methodological competitive advantage frameworks to a structured ML-enabled prediction process. The final section of the paper offers closing remarks of this study.

2 Methodology

This study aims to review the recent scientific literature and identify the most relevant ML applications for competitive advantage prediction in Scopus database for further scrutiny and taxonomy development. To narrow down the article search for the purposes of this scoping review, each of the Porter's Five Forces (Porter, 1979) was addressed separately in the following sequence: CR, NEP, ToS, CP and SP. Since the explicit use of these five terms for literature search may result in uncertain results due to the high-level nature of the Five Forces, this study suggests developing a broad spectrum of keywords for every subdomain of the Five Forces model. Therefore the author followed five main steps in the literature selection process: 1) methodological paper selection for further extraction of methodological keywords; 2) separate extraction of a broad list of methodological keywords from the foregoing papers on each of the Five Forces; 3) refinement of the extracted methodological keywords to exclude duplicates and identify the selection describing various aspects of the Five Forces in more detail; 4) compilation of the selected methodological keywords with ML-specific keywords; 5) ML-specific paper selection based on the developed list of keywords for further review and taxonomy preparation.

Firstly, Google Scholar database was searched explicitly using each of the high-level terms comprising the Five Forces (CR, NEP, ToS, CP, SP) one by one in order to identify five relevant methodological papers on each of the Five Forces (25 methodological papers in total). For CR, the following five papers were selected for keyword extraction: Arenal et al. discussed competitive rivalry on the market within the contexts of competitive dynamics, hypercompetition, and strategic interactions among companies, portraying competitive rivalry as firms engaged in frequent, rapid, and mutual actions and responses (Arenal et al., 2025). Brandts et al. investigated competitive rivalry in an experimental social-dilemma environment where market actors have to compete for limited customers, creating exclusion risk and uncertainty (Brandts et al., 2009). Sirmon et al. studied competitive rivalry from the aspect of relative differences in rivals' resources and managerial decisions, considering resource parity, deployment flexibility, and contextual contingencies (Sirmon et al., 2008). Kilduff et al. conceptualized competitive rivalry as a subjective, relational, psychologically charged competitive relationship between different individuals and groups (Kilduff et al., 2010). Furrer & Thomas suggested a rivalry matrix describing competitive rivalry as the set of moves, countermoves, reactions, and strategic interactions occurring between firms operating in the same competitive domain (Furrer – Thomas, 2000). For keywords selection on NEP, the following five articles were considered. Pehrsson proposed a model describing NEP as a function of barrier intensity, incumbent behavior, and entry timing, determining the feasibility and constraints of market entry (Pehrsson, 2009). Robertson & Gatignon determined the means and reasons of market niche

penetration by new competitors, discussing which factors contribute to their viable or threatening performance in the new market segment (Robertson – Gatignon, 1991). Klemz & Gruca described how managers examine the information on entrant characteristics, strategies, and their expected impact on the market to identify NEP (Klemz – Gruca, 2001). Nti examined how the number of potential entrants can influence the likelihood of actual market entry and the resulting influence on competitive conditions (Nti, 1989). Sherman & Willett considered a framework of multiple potential entrants, showing that the greater numbers of potential entrants can discourage potential market actors and reduce the actual entry (Sherman – Willett, 1967).

To address ToS in the keywords selection process, the following five papers were reviewed. Shin et al. explored how substitution can reallocate demand among product alternatives, affecting assortment planning, inventory decisions, capacity planning, and pricing on the market (Shin et al., 2015). Polidoro & Toh described substitution threat as the risk that competitors may innovate to create alternative products, outperforming the rival's supply, and either replacing the competitor's product line altogether, or making the rival innovation obsolete (Polidoro – Toh, 2011). Lee & Parachuri investigated how intensifying substitution rhetoric in the media can trigger strategic decisions such as resource redeployment, market entry and exit, especially when firms consider reallocating resources from declining products toward emerging substitutes to mitigate substitution threats (Lee – Parachuri, 2016). Smith observed how substitution occurs when a new emerging product offering becomes more cost-effective than its alternatives, outperforming traditional products (Smith, 1990). According to Mattingly who studied the LLM-based substitution of professional pharmaceutical care, any product or service can replace another if it fulfills the same underlying need through different means (Mattingly, 2025). In CP, the methodological papers identified for keyword selection are as follows. Grégoire et al. described CP as the customer's ability to influence suppliers' decisions, demanding better treatment or generating direct threats for suppliers if the CP is strong enough (Grégoire et al., 2010). Chae et al. studied the complex interplay between buyer power and supplier relationship commitment, considering CP as a multi-dimensional influence mechanism determining the suppliers' forced compliance or genuine cooperation (Chae et al., 2017). Yoo investigated how CP reflects the customer's capacity to make the suppliers undertake actions they would not have otherwise pursued, exploiting their threat potential, economic importance, and dependency asymmetry (Yoo, 2017). Christensen & Bower showed how dependence on specific customers may lead suppliers to misjudge market transitions and ultimately fail when disruptive innovations arise outside of their traditional customer base (Christensen – Bower, 2005). Flynn et al. described how customers can intentionally or unintentionally shape supplier behavior using different bases of power (Flynn et al., 2008). From the SP perspective, the following five articles were reviewed for purposes of this study.

Skowronski et al. explored examples of supplier shirking, a form of opportunistic supplier leverage when they deliberately underperform or withhold information, thus controling critical operational activities on the market (Skowronski et al., 2022). Lacoste & Johnsen demonstrated how SP can be increased by transitioning from specific products to differentiated process-oriented offerings (Lacoste – Johnsen, 2015). Cox et al. explained how suppliers can exercise dominance on the market if they possess critical assets or enjoy information asymmetry, making buyers dependent on supplier knowledge (Cox et al., 2003). Benton & Maloni demonstrated how the power dynamics between buyers and suppliers shapes suppliers' satisfaction, driving their performance outcomes on the market (Benton – Maloni, 2005). Terpend & Ashenbaum showed how SP is determined by buyers' ability to deploy influence strategies and suppliers' reaction based on interdependence, perception, and context awareness (Terpend – Ashenbaum, 2012).

Secondly, each of the 25 identified methodological papers was individually reviewed to retrieve 10 complex two or three word keywords (250 keywords in total, i.e. 50 keywords extracted for each of the Five Forces). The author screened each methodological paper for keywords separately with an LLM, ChatGPT 5.1 Plus (thinking model) by OpenAI (OpenAI, 2025). The following prompt was used to extract methodological keywords from each of the papers: «Act as a professional business consultant in cross-industry entrepreneurial strategic advice, proficient in Michael Porter's Five Forces Model of competitive advantage, incorporating five segments – competitive rivals, new entrants potential, threat of substitutes, customer power and supplier power. Please concentrate specifically on <segment of Five Forces Model>, ignore all the other four segments. Please analyse the uploaded scientific paper on <segment of Five Forces Model> and identify ten keywords that would better describe this factor, derived exclusively from this paper. Do not provide any keywords that are not explicitly mentioned in this paper. Think in steps: first analyse the paper and summarize the description of <segment of Five Forces Model> based exclusively on this paper; then summarize key distinctive features related to this factor; then provide the list of ten unique keywords based on the description and the features that you identified in the paper. Provide only keywords consisting of two or three words».

Thirdly, the methodological keywords extracted with the LLM tool were manually reviewed and refined by the author with the goal to specify at least 10 defining keywords for each of the Five Forces (50 methodological keywords in total). The resulting methodological keywords used for the literature search in this study are presented in Figure 1. For CR, the following keywords were used: ("competitor" OR "hyper" OR "market" OR "competitive" OR "comparative" OR "hypercompetitive") AND ("competitiveness" OR "competition" OR "aggressiveness" OR "intensity" OR "dynamics" OR "behavior" OR "action"

OR "rivalry" OR "relationship" OR "repertoire"). For NEP, the keywords were refined as follows: ("product differentiation" OR "brand loyalty" OR "excess capacity" OR "scale of entry" OR "market niche" OR "potential entrants" OR "entry costs" OR "probability of entry" OR "entry deterrence" OR "market contestability"). For ToS, the following keywords were defined: ("substitution" OR "substitute" OR "substitutability" OR "substitutable") AND ("cross elasticity" OR "potential" OR "mechanism" OR "matrix" OR "threat" OR "alternative" OR "innovation" OR "effectiveness" OR "superiority" OR "parity"). Search for CP papers was made with the following keywords: ("customer" OR "consumer" OR "buyer" OR "client") AND ("power" OR "influence" OR "access to information" OR "autonomy" OR "demand" OR "behavior" OR "relationship" OR "commitment" OR "empowerment" OR "motivation"). SP was investigated with the following keywords: ("supplier" OR "supply" OR "contractor" OR "supply chain" OR "supplier network") AND ("power" OR "influence" OR "shirking" OR "performance" OR "dominance" OR "relationship" OR "commitment" OR "satisfaction" OR "determination" OR "dependence").

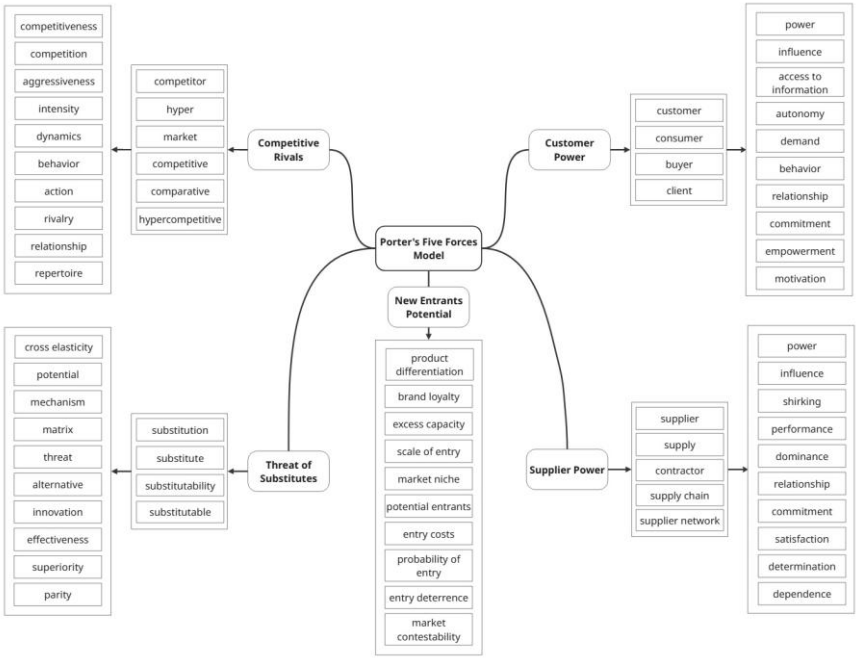

Figure 1

Methodological keywords on Porter's Five Forces

Fourthly, the methodological keywords on each of the Five Forces were combined with the list of ML-specific keywords, extended by the author from

Kozhanov et al. (Kozhanov et al., 2024). “Artificial Intelligence” and “AI” were deliberately omitted by the author to avoid ambiguous search results. The resulting list of ML-specific keywords used for this scoping review is as follows: ("Linear Regression" OR "Logistic Regression" OR "Decision Tree*" OR "Random Forest" OR "Support Vector Machine*" OR "k*Nearest Neighbors" OR "Naive Bayes" OR "Gradient Boosting" OR "AdaBoost" OR "XGBoost" OR "LightGBM" OR "CatBoost" OR "Neural Network*" OR "Convolutional Neural Network*" OR "Recurrent Neural Network*" OR "Long Short Term Memory" OR "Transformer*" OR "k*Means Clustering" OR "DBSCAN" OR "Hierarchical Clustering" OR "Principal Component Analysis" OR "t-Distributed Stochastic Neighbor Embedding" OR "Autoencoder*" OR "Generative Adversarial Network*" OR "Reinforcement Learning" OR "Q-Learning" OR "Deep Q-Network" OR "Multi-Armed Bandit" OR "Bayesian Network*" OR "Supervised Learning" OR "Unsupervised Learning" OR "Machine Learning" OR "Large Language Model*" OR "Retrieval Augmented Generation" OR "Model Context Protocol" OR "Artificial Neural Network*" OR "ANN*" OR "CNN*" OR "RNN*" OR "Natural Language Processing" OR "NLP" OR "SVM*" OR "KNN" OR "LSTM" OR "GPT" OR "Generative Pre*trained Transformer" OR "PCA" OR "GAN*" OR "LLM*" OR "RAG" OR "MCP" OR "Deep Learning" OR "ResNet" OR "Residual Network*" OR "EfficientNet" OR "U-Net" OR "Graph Neural Network*" OR "GNN*" OR "Self-Supervised Learning" OR "Foundation Model*" OR "Pre*trained Model*" OR "Elastic Net" OR "Ridge" OR "Lasso" OR "K-Medoids" OR "Gaussian Mixture Model*" OR "GMM*" OR "Hidden Markov Model*" OR "HMM*" OR "Markov Decision Process" OR "MDP" OR "Genetic Algorithm*"). Fifthly, each list of methodological keywords for each of the Five Forces was separately combined with the foregoing list of ML-specific keywords to identify relevant English-language articles or conference papers in Scopus database for further review. Scopus search was limited to the following two categories: Business, Management and Accounting; Economics, Econometrics and Finance. Scopus search results were sorted by relevance. For each of the Five Forces, the top 100 most relevant search results in Scopus were reviewed by the author to identify five diverse papers on ML applications to predict each of the Five Forces (25 papers for this scoping review in total). The papers on ML applications selected for this study are presented in Table 1.

3 Results

This study selected 25 papers on ML applications to predict and model various aspects of competitive advantage grounded in Porter’s Five Forces (Porter, 1979), i.e. five papers for each of the Five Forces (Table 1). ML applications identified in the field of CR prediction covered such topics as competitiveness,

competitive dynamics, competitive behavior, competitive action, market rivalry, market share, market reaction, market competition, market dynamics, market behavior and market action. In the field of NEP modeling, the identified ML applications were related to brand loyalty, product differentiation and market niche identification. ToS-related ML applications covered measuring substitution potential, substitution mechanism, substitutable alternatives, substitution effectiveness, substitution superiority, substitution threats, innovation resistance and cross elasticity. In CP, ML applications related to modeling customer demand, customer behavior, customer relationship and customer motivation were determined. For SP, ML was used to predict supply chain performance, supply chain resilience, supply disruptions, supplier network performance, supplier performance and supply chain planning.

Ref.	Title	Year	Field	Topics	Application	Methods
[1]	A Deep Q-Learning Approach to Optimize Ordering and Dynamic Pricing Decisions in the Presence of Strategic Customers	2024	ToS	Substitution Potential, Substitution Mechanism, Substitutable Alternative	Predicting optimal supply and pricing of substitute products	Reinforcement Learning, Deep Learning, DNN, Multilayer Perceptron
[4]	LLM-based Innovation Dynamics Analyzer: A Novel Approach to Competitive Innovation Dynamics in Tourism	2026	CR	Competitive Dynamics, Competitive Behavior, Competitive Action, Market Rivalry, Market Share, Market Reaction	Modeling innovation adoption influence on competitive advantage	GenAI, LLM, Pre-Trained Transformer Models
[6]	How to Achieve University Brand Preference Through Building Brand Equity: A View From Peruvian Students	2025	NEP	Brand Loyalty	Brand loyalty prediction based on brand equity perception	Binary Logistic Regression
[8]	Application of Deep Neural Network-Based Social Media Data	2025	NEP	Brand Loyalty	Brand loyalty prediction through sentiment analysis	Deep Learning, DCNN, RNN, LSTM, Transformer-

	Analysis in Brand Management					Based Models
[11]	Market Research and Knowledge Using Generative AI: The Power of Large Language Models	2025	CR	Competitiveness, Competitive Dynamics, Market Behavior, Market Competition	Market research automation in competitive context	GenAI, LLM
[12]	Digital Innovation and Supply Chain Risk: A Large Language Model-Based Analysis	2025	SP	Supply Chain Performance, Supply Chain Resilience, Supply Disruptions	Measuring supply chain exposure to disruptions	GenAI, LLM
[15]	The Role of Customer Experience Dimensions in Expanding Customer–Firm Relationships: A Customer Expansion Journey Approach	2025	CP	Customer Demand, Customer Behavior, Customer Relationship	Modeling customer expansion journey	Hidden Markov Model
[16]	Sentiment Analysis of Product Reviews Using Machine Learning and Pre-Trained LLM	2024	CP	Customer Demand, Customer Behavior, Customer Motivation	Sentiment analysis of customer product reviews	Random Forest, Naive Bayes, SVM, GenAI, LLM
[17]	Customer Segmentation for Stigmatized Products Using Point-of-Sale Big-Data and Gaussian-Mixture-Model: An Application in Female-Hygiene Market	2025	CP	Customer Behavior, Customer Motivation	Consumer segmentation by purchasing behavior with subsequent customer profiling	Gaussian Mixture Model, Logistic Regression, Random Forest
[26]	Note on Applications of Stochastic	2025	NEP	Brand Loyalty	Measuring brand loyalty with repeat	Hidden Markov Model

	Models in Consumer Behavior Theory				purchases	
[28]	BearingFM: Towards a Foundation Model for Bearing Fault Diagnosis by Domain Knowledge and Contrastive Learning	2024	SP	Supply Chain Performance, Supply Chain Resilience, Supply Disruptions	Predicting supply chain risks through equipment monitoring	Semi-Supervised Learning, Pre-Trained Foundation Model
[30]	Predicting Mobile Wallet Resistance: A Two-Staged Structural Equation Modeling-Artificial Neural Network Approach	2020	ToS	Substitution Superiority, Substitution Threat, Innovation Resistance	Predicting factors promoting substitution over innovation	ANN, Multilayer Perceptron
[31]	The Generative Artificial Intelligence Large Language Product Design Multi-Model Framework for Manufacturing Operations	2025	NEP	Product Differentiation, Market Niche	Generating product ideas to accelerate time-to-market	GenAI, GAN, LLM
[32]	Travel Time Probability Prediction Based on Constrained LSTM Quantile Regression	2023	SP	Supply Chain Performance, Supplier Network Performance	Transportation time prediction in a supply chain	Hidden Markov Model, Deep Learning, RNN, LSTM, Linear/ NN Quantile Regression
[33]	A Multi-Stage Hidden Markov Model of Customer Repurchase Motivation in Online Shopping	2019	CP	Customer Behavior, Customer Motivation	Modeling customer repurchase behavior	Hidden Markov Model
[34]	GPT-Augmented	2025	SP	Supplier Performance,	Risk and ESG-based supplier	Reinforcement Learning,

	Bayesian Reinforcement Learning Framework for Multiobjective Supplier Selection			Supply Chain Planning	selection	Bayesian Network, GenAI, LLM, Logistic Regression, Deep Learning, GNN
[35]	LLM-Based Bidding Behavior Agent and Market Sentiment Agent-Assisted Electricity Price Prediction	2025	CR	Market Competition, Market Dynamics, Market Behavior, Market Action	Behavior-based market volatility prediction	GenAI, LLM, GAN
[36]	Food Products Pricing Theory with Application of Machine Learning and Game Theory Approach	2022	ToS	Cross Elasticity, Substitutable Alternative	Forecasting prices of product substitutes	Deep Learning, CNN, LSTM, Genetic Algorithm
[43]	Should You Use GARCH Models for Forecasting Volatility? A Comparison to GRU Neural Networks	2024	CR	Market Dynamics, Market Behavior	S&P 500-based market volatility prediction	Deep Learning, RNN, Hidden Markov Model, LSTM
[48]	A Deep Neural Framework for Sales Forecasting in E-Commerce	2019	ToS	Substitution Threat, Substitution Potential, Substitutable Alternative	Predicting sales impact of product substitutes	Deep Learning, DNN, Residual NN (ResNet)
[50]	Grocery Apps and Consumer Purchase Behavior: Application of Gaussian Mixture Model and Multi-Layer Perceptron Algorithm	2022	CP	Customer Behavior, Customer Motivation	Modelling consumer purchase behavior	Gaussian Mixture Model, ANN, Multilayer Perceptron
[56]	Mindfully Fashioned: Sustaining Style Through Product Value	2024	NEP	Brand Loyalty, Product Differentiation, Market Niche	Product adoptability prediction	ANN

	Retention					
[59]	Computational Intelligent Hybrid Model for Detecting Disruptive Trading Activity	2017	CR	Market Dynamics, Market Behavior	Identifying disruptive market behavior	Hidden Markov Model, SVM, kNN, Logistic Regression, Gaussian Mixture Model
[60]	Benchmarking LLMs for Supply Chain Risk Identification: An Extended Evaluation within the LARD-SC Framework	2025	SP	Supply Chain Performance, Supply Chain Resilience, Supply Disruptions	Predictive detection and classification of supply chain risks	GenAI, LLM
[61]	Decoupled Hyperbolic Graph Attention Network for Modeling Substitutable and Complementary Item Relationships	2022	ToS	Substitution Potential, Substitution Effectiveness	Modeling product substitution and complementation relationship	GNN

Table 1

Literature on ML applications for Five Forces prediction identified for this scoping review

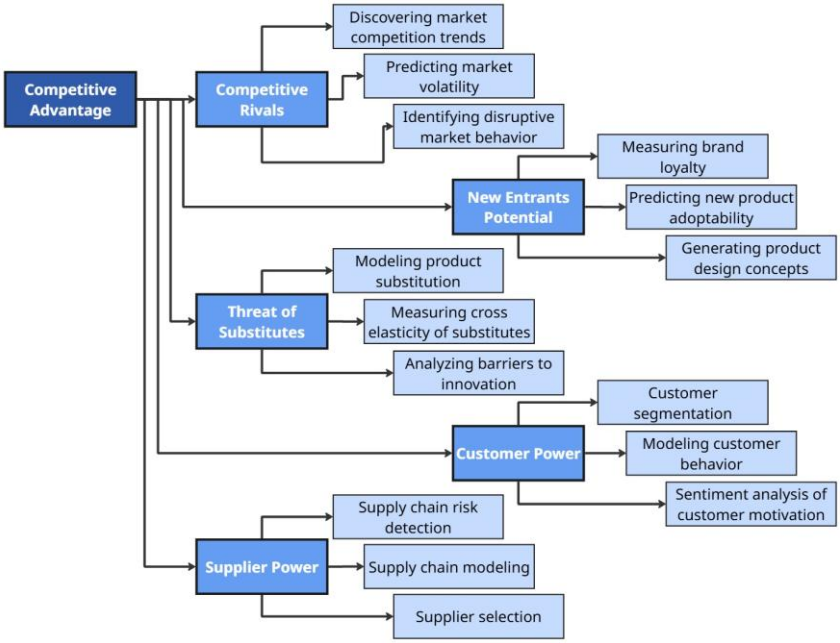

Figure 2

Taxonomy of business processes for ML-enabled competitive advantage prediction

The taxonomy of ML applications for prediction of competitive advantage based on Porter's Five Forces (Porter, 1979) developed in this study is presented in Figure 2. In order to estimate the risk of CR influence on the market, ML models can be used to discover market competition trends (Bianco et al., 2026; Estevez et al., 2025), predict market volatility (Lu et al., 2025; Pallotta – Ciciretti, 2024) and identify disruptive market behavior of other actors (Zhai et al., 2017). NEP can be examined through measuring brand loyalty (Cano-Lanza et al., 2025; Chen et al., 2025; Kumaraswamy – Bhatracharyulu, 2025) and predicting adoptability of new products (Srivastava et al., 2024). Besides, ML models can be used to generate product design concepts for faster market entrance (Leung et al., 2025). ML can be used to estimate ToS, modeling product substitution (Alamdar – Seifi, 2024; Zhou et al., 2022; Qi et al., 2019), measuring cross elasticity of alternative substitutable products (Mamoudan et al., 2022), as well as analyzing market barriers to innovation (Leong et al., 2020). To analyze CP, ML models can be used for customer segmentation (Ghosh – Chatterjee, 2025), modeling customer behavior (Gao et al., 2025; Salamzadeh et al., 2022; Li et al., 2019), and customer motivation modeling through sentiment analysis (Ghatora et al.,

2024). For SP analysis, ML can help detect supply chain risks (Fan et al., 2025; Zhao et al., 2025; Lai et al., 2024), model supply chains (Li et al., 2023) and select suppliers suitable for market conditions (Lin et al., 2025).

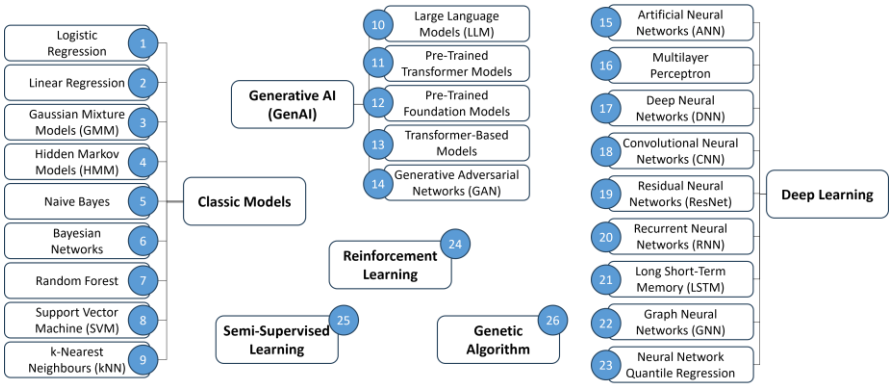

Figure 3

ML models identified in competitive advantage prediction

The variety of ML models and methods identified in the scientific papers selected for this scoping review is demonstrated in Figure 3. Both classic ML models, deep learning models and GenAI were used by researchers to address the above-mentioned prediction problems, either in comparison to one another or in combination to improve the overall output of the model. The classic models used in the identified ML applications included logistic regression (Cano-Lanza et al., 2025; Ghosh – Chatterjee, 2025; Lin et al., 2025; Zhai et al., 2017), linear regression (Li et al., 2023), Gaussian Mixture Models (GMM) (Ghosh – Chatterjee, 2025; Salamzadeh et al., 2022; Zhai et al., 2017), Hidden Markov Models (HMM) (Gao et al., 2025; Kumaraswamy – Bhatracharyulu, 2025; Pallotta – Ciciretti, 2024; Li et al., 2023; Li et al., 2019; Zhai et al., 2017), Naive Bayes (Ghatora et al., 2024), modified Bayesian Networks (Lin et al., 2025), Random Forest (Ghatora et al., 2024), Support Vector Machines (SVM) (Ghatora et al., 2024; Zhai et al., 2017) and k-Nearest Neighbours (kNN) (Zhai et al., 2017). Deep Learning methods included Artificial Neural Networks (ANN) (Srivastava et al., 2024; Salamzadeh et al., 2022; Leong et al., 2020), Multilayer Perceptron (Alamdar – Seifi, 2024; Salamzadeh et al., 2022; Leong et al., 2020), Deep Neural Networks (DNN) (Alamdar – Seifi, 2024; Qi et al., 2019), Convolutional Neural Networks (CNN) (Chen et al., 2025; Mamoudan et al., 2022), Residual Neural Network (ResNet) (Qi et al., 2019), Recurrent Neural Networks (RNN) (Chen et al., 2025; Pallotta – Ciciretti, 2024; Li et al., 2023), Long Short-Term Memory (LSTM) models (Chen et al., 2025; Pallotta – Ciciretti, 2024; Li et al., 2023; Mamoudan et al., 2022), Graph Neural Networks (GNN) (Lin et al., 2025; Zhou et al., 2022) and Neural Network Quantile Regression (Li et al., 2023). GenAI applications included Large

Language Models (LLM) (Bianco et al., 2026; Estevez et al., 2025; Fan et al., 2025; Lin et al., 2025; Lu et al., 2025; Zhao et al., 2025; Ghatora et al., 2024), use of Pre-Trained Transformer Models (Bianco et al., 2026) and Pre-Trained Foundation Models (Lai et al., 2024), application of other Transformer-Based Models (Chen et al., 2025) and Generative Adversarial Networks (GAN) (Leung et al., 2025; Lu et al., 2025). Some papers also used Reinforcement Learning (Lin et al., 2025; Alamdar – Seifi, 2024), Semi-Supervised Learning (Lai et al., 2024) and Genetic Algorithms (Mamoudan et al., 2022) for optimization. Figure 4 represents how these ML applications were used in business processes for ML-enabled competitive advantage prediction of the developed taxonomy, highlighting LLM applications to address RQ3 of this study.

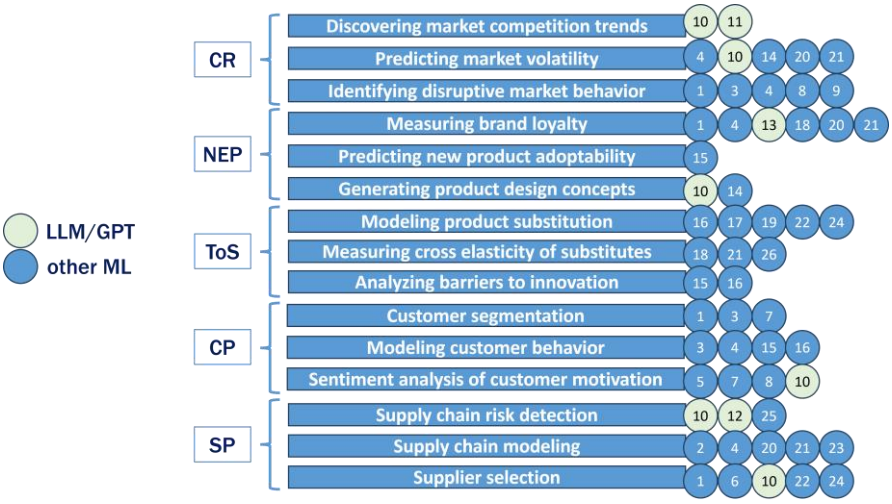

Figure 4

Mapping of ML models on competitive advantage prediction business process taxonomy

4 Discussion

The scoping review performed in this study identified a variety of ML models and methods that can be applied to model different aspects of competitive advantage as discussed in Porter's Five Forces model (Porter, 1979). The proposed taxonomy can be used to explore measurable business processes within the fields of competitive rivalry, new entrants potential, threat of substitutes, customer power and supplier power for building proactive competitive advantage prediction systems, thus positively answering RQ1 and confirming that ML can be leveraged to forecast the impact of Porter's Five Forces on a firm. On the other hand, ML application for Five Forces modeling

remains unbalanced and suggests multiple research gaps. In CR, current ML research seems to be leaning towards financial market studies, whereas more research of ML applications to assess competitive rivalry in the real sector is required. In NEP, researchers use ML to estimate brand loyalty, while such other crucial subdomains as market entry deterrence, scale and costs of entry, as well as assessment of excess capacity on the market remain underrepresented. In ToS, more research is necessary to apply ML models to predict price elasticity for alternative products, as well as calculate and suggest solid mitigation strategies to avoid substitution threats. CP-related ML research focuses on predicting customer behavior and motivation, while less attention is dedicated to consumer autonomy, influence and power in specific market conditions. SP research leans more towards applying ML methods to model supply chains and predict corresponding risks of disruption, whereas the assessment of supplier influence and dominance on the market is less studied. Considering the identified research gaps, the hypothesis outlined by RQ1 is partially accepted.

To address these limitations, future research should consider conducting separate systematic literature reviews on ML applications to each of the Five Forces with more focused methodological keywords than the lists used in this study. As Figure 5 shows, the attempt to broaden the list of keywords for each of the Five Forces caused unbalanced search results in Scopus. While searching for ToS and NEP-related ML applications ensured an accurate and focused search, CR-related keywords were too broad and resulted in many unrelated papers, urging the author to reconsider the keywords extraction approach for future studies. Therefore the hypothesis specified in RQ2 herewith is rejected. As far as RQ3 is concerned, Figure 4 suggests that LLMs indeed seem to be playing a significant role in modern research of competitive advantage. This study identified LLM applications in four out of five Five Forces, with the majority of these papers published in 2025. This representation of LLMs in the applied ML methods suggests a growing use of GenAI in economics research, compared to the author's prior literature review study limited to October 2024 (Kalganov et al., 2025), thus confirming the hypothesis presented in RQ3 herewith.

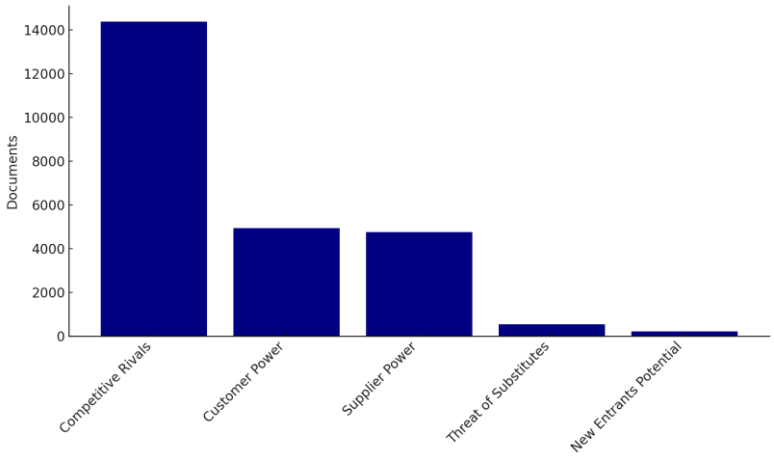

Figure 5

ML-related documents identified in Scopus based on Figure 1 keywords

Nevertheless, the scoping review provided in this study adds to the growing body of academic literature on predictive ML applications in entrepreneurial decision-support systems (Giuggioli – Pellegrini, 2023). As represented in Figure 6, a structured combination of applied ML methods to predict market trends and suggest a data-driven approach to market entry can empower entrepreneurs with strategic agility, implementing a ML-enabled competitive advantage prediction process to secure business decisions and lead business owners beyond intuition, increasing the likelihood of their success in the dynamic digital economy. Further research should consider applicable combinations of these tools, applying the theory outlined in this conceptual framework to real-life data to build robust, comprehensive proactive real-time business intelligence systems.

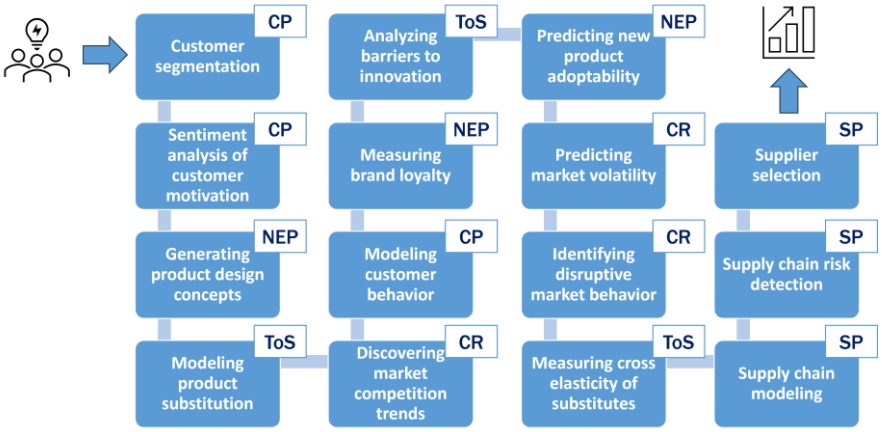

Figure 6

ML-enabled competitive advantage prediction process

Conclusions

At all times, business owners in every known industry have been striving for competitive advantage. A solid and well-defined competitive advantage can act as an accelerator for entrepreneurs, helping them secure venture capital funding and accelerate product launch to achieve rapid market penetration and dominance. Lack of clear competitive advantage, however, limits a firm's growth opportunities and increases its vulnerability to intense competition. Once lost, competitive advantage is difficult to regain. Therefore business owners require strategic thinking to assess their competitive advantage and make informed business decisions. Traditionally, they rely on intuition and knowledge of theoretical competitive advantage frameworks like Porter's Five Forces to stay afloat in a competitive environment. However, even a solid understanding of methodology underlying the Five Forces cannot guarantee informed business decisions due to the intricacy and complexity of umbrella definitions stipulated in this framework: competitive rivals, new entrants potential, threat of substitutes, customer power and supplier power. Each field of this framework urges the entrepreneur to track and consider a wide variety of diverse economic indicators, which is often impossible without a dedicated team of business consultants. Predictive capabilities of ML models can facilitate market surveillance for entrepreneurs, providing them with a data-driven approach to business strategy. This paper performs a scoping review of ML applications in forecasting various aspects of Porter's Five Forces, suggesting the taxonomy and a conceptual framework for a ML-enabled competitive

advantage prediction process. Research gaps identified by this study suggest further consideration of less represented topics under the umbrella of the Five Forces framework to determine more predictable indicators of competitive advantage and explore how ML can be applied in underrepresented subdomains. Combining diverse ML methods of this conceptual framework in a single business intelligence system can enable entrepreneurs with a data-driven approach to competitive advantage measurement, leading them beyond intuition towards proactive business strategy.

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The Responsibility and Impact of Electrical Safety Inspectors on Organizational Safety

Balázs Molnár

Obuda University, Bánki Donát Faculty of Mechanical and Safety Engineering
molnar.balazs@bgk.uni-obuda.hu

Abstract: The aim of the study is to present the role of electrical safety inspectors in maintaining organizational safety and safety awareness. The publication examines the inspector's responsibility, the relationship between practice and safety culture, with special attention to the Hungarian legal and standard environment. It also adresses othAer actors in the process, whose role is also significant. Currently, few studies deal directly with electrical safety in this context, so the publication is primarily based on experiences and feedback. The goal is to highlight the shortcomings and areas for development in further publications related to electricity and safety, based on primary research related to electrical energy and its safety.

Keywords: electrical safety, safety awareness, quality, organizational culture, responsibility

1 Introduction

Nowadays, safety science has an increasingly important role due to the development of technology. We can state that safety considerations are unavoidable. This is no different in the field of electricity, where technical preparedness and continuous development, the need for learning are inevitable and necessary. From the perspective of both electrical contractors - including maintenance - and electrical inspectors, at least the expected level of safety must be provided for the operator of the electrical equipment. The expected level of safety is primarily set by standards. A higher level of safety can be achieved, but it increases costs. In Hungary, standards are voluntary, and legislation allows for deviations from them on the condition that at least the safety level described in the standards is met. Based on these, however, knowledge of the standards is practically mandatory.

It is difficult to imagine everyday life in the modern world without electrical equipment. The operation of organizations would practically cease without the consumption of electricity, as would the life of households. Essentially, all important devices and machines consume electricity. Maintaining safe

operation is a critical factor in terms of operations, services and production. Failure of electrical systems can not only cause material damage, but can also have serius consequences in human live.

2 The role of electrical safety inspection in organizational safety

After understanding the importance of electrical safety, it is necessary to examine who contributes to maintaining safety in practice and in what way. One of the most important players in this role is electrical safety inspectors, who directly affect the level of organizational safety with their activities. Inspectors have a significant role in increasing safety awareness towards operators, in order to provide a comprehensive and realistic picture of the condition of electrical equipment. From the operator's point of view, creating and maintaining safety is the primary consideration. In addition to inspectors, designers, contractors and maintenance personnel have an important role in this process. In fact, self-monitoring should be a prerequisite for each process, where any errors can be corrected. In this context, electrical safety inspectors become key players, since they are the ones who evaluate the condition of the systems at the end of the process and periodically, detect errors and make suggestions. In addition to electrical safety inspections, maintenance and repairs also play a significant role increasing the lifespan of equipment and maintaining operational safety.

However, it is not enough to have technical knowledge alone: inspectors Documenting false also have a special responsibility to raise safety awareness, communicate with operators, ensure the accuracy and credibility of documentation, and ensure that detected deficiencies are properly reported and addressed. Documenting false or inaccurate information can not only become a source of problems from a legal perspective, but can also create critical situations, considering the risk of loss of human life or the possibility of a significant damage event. The practice of inspectors shows that often it is not enough to examine technical compliance, follow-up is at least as critical a factor. Decree 40/2017. (XII. 4.) NGM requires inspection and documentation after repairs and modifications. In Hungarian practice, despite the regulations of the decree, follow-up inspections are neglected. Documenting the results of inspections and methods for measuring the performance of maintenance activities are crucial: the study by Róka-Madarász (2011) presents monitoring methods for operational maintenance, and this concept can be adapted to electrical safety inspections.

The inspector has a significant impact on the life of organizations by determining the safe or unsafe condition of employees and the built environment, thereby indirectly influencing the possibility of safe operation. At

the same time, the operator is obliged to ensure the safety of its own and "foreign" employees with the appropriate resources - whether financial or human resources (MSZ 1585:2016). “Maintenance costs are generally the second largest single cost factor in the operating costs of facilities” (Róka-Madarász,2011). However, this cost can increase significantly if maintenance and repairs are not carried out according to the expected standards and an electrical safety inspection reveals these deficiencies. In this case, the standard condition can be achieved with additional work. The operator must take into account that in the event of a lack of maintenance, failures, accidents or fires will entail significantly higher costs (labor costs, material costs) and possibly legal sanctions. It would be an important aspect for operators to develop awareness of electrical safety, and to maintain or even restore the expected safety level.

However, the work of inspectors is not only about assessing and judging the technical condition: “safety is actually the result of an organizational and cultural process” (Reason, 2016). This broader approach is described in the international literature with the concept of safety culture, the examination of which can help to understand the strengths and shortcomings of domestic technical practice. In line with this broader view, Cooper’s safety culture model defines the “product” of safety culture as “that observable degree of effort with which all organisational members direct their attention and actions towards improving safety on a daily basis” (Cooper, 2000). This understanding directly links inspectors’ behaviour and documentation practices to the overall safety culture of the organisation.The concept of safety awareness in the operation of electrical systems means that the relevant actors (operators, maintenance workers, inspectors) have the knowledge, sensitivity and attitudes that allow safety aspects to become an integrated part of daily operations, not just formal and legal obligations. According to research by the International Labour Organization (ILO) and other organizations, “effectively influencing safety awareness (safety culture) can directly reduce the number and severity of accidents” (ILO, 2015; EU-OSHA, 2019). However, these frameworks do not specifically cover damage and accidents caused by electricity. Although improving safety awareness generally reduces accident risks, the issue of electrical safety appears in the ILO and EU-OSHA frameworks primarily from a technical and educational aspect, rather than as a cultural or behavioural dimension.

In the Hungarian context, publications do not directly address the role and importance of electrical safety inspectors. Some studies examine the relationship between industrial standards and maintenance systems (Kiss et al., 2021), others the effectiveness of technical safety systems (Nagy, 2022). However, these do not address the issue of inspector behavior and documentation quality in depth. At the same time, electrical safety aspects need to be raised not only at the level of organizations but also in the private sector, where, based on experience, the pursuit of electrical safety is not a primary

consideration in Hungary. In the case of real estate and rental properties, there is legal regulation for inspections, but the demand is currently low. Among the reasons for this, we can talk about a lack of information (the relevant legislation is not known), the resistance of the actors involved, and the lack of real sanctions. Current experiences show that the work performed by inspectors is incomplete and unprofessional. It can be traced back to reasons such as insufficient knowledge of legislation and standards. Technical regulations follow technical and technological developments: these appear in standards. A thorough knowledge of technical regulations is essential for performing quality activities. Interpreting the legal environment is a critical factor. All of these provide the basis for on-site work, so thorough preparation is necessary from the theoretical pont of view. Since most operators can be considered laypeople, they cannot determine from the document provided to them whether they have received a real condition assessment or merely inauthentic documentation. It is also common – based on experience – for the operator to receive a document that that does not record any non-complience. Often the goal is not to present the real condition, but to maintain the appearance of conformity. In this case, the safety of others is ignored. In addition to the above, strengthening the culture of electrical safety through education, practice-oriented training and practical integration of knowledge provides a foundation, but is not sufficient in itself.

3 Electrical inspection as a quality control process

The interpretation of safety culture highlights that technical safety can only be maintained through well-defined processes. At this point, it becomes clear that electrical safety inspection is not just a technical inspection, but also an integral part of quality assurance. Electrical safety inspection activities can be compared to the quality control process in many ways. The work of inspectors is essentially the last element of a quality assurance chain, since the document they issue is a confirmation of the quality of an electrical installation to the customer. According to Shoji Shiba's classic formulation, "quality is compliance with the latent and manifest needs of the customer, as well as with the suitability for use and the relevant standards" (Shiba et al. 1993). In the case of electrical inspectors, this means that the expected safety level is ensured by knowledge of standards, visual inspection, measurements, and documentation (MSZ HD 60364 standards). This view is consistent with safety management research, where "in essence, inspection becomes a preventive measure instead of being a corrective action" and forms part of continual improvement (Li, 2016). The parallel is not only illustrative, but also essential: the reviewer examines the "product quality" of the system and, by revealing errors, provides feedback to the contractor and the operator. In practice, this role, similar to quality assurance processes, requires objective, independent control — which is

why it is recommended that the contractor and the reviewer be separated. This approach, along the logic of quality management, also makes safety a controlled process.

4 Legal liability and risks in electrical inspection

The activities of electrical safety inspectors and electrical specialists may entail not only technical but also serious legal liability in certain cases. Professional documentation, compliance with standards, and adherence to occupational health and safety and fire protection regulations are essential elements for avoiding liability, as courts assess professional negligence through the categories of objective liability, breach of contract and negligence.

The qualification of documents generated during electrical safety inspections is of particular importance, as these documents form the basis for the enforcement of regulations on occupational health and safety, protection against electric shock and fire protection. The issuance of inadequate or falsified inspection protocols may violate several provisions of the Criminal Code of Law (Btk.), while incomplete or incorrect performance may entail civil law consequences under the Civil Code of Law (Ptk.).

Section 373 of the Criminal Code regulates the crime of fraud, which can occur when the service provider deceives the customer with a false document with the qualification of "fully compliant" in order to gain an unlawful benefit (Act C of 2012, Section 373). Section 342 of the Criminal Code of Law punishes the forgery of public documents, which can be punished with up to three years of imprisonment if the inspection report contains false data or is treated as an official document (Section 342 of the Criminal Code of Law). Section 345 of the Criminal Code, which regulates forgery of private documents, prohibits the issuance of non-official documents (e.g. template reports) with false content, punishable by up to one year of imprisonment (Section 345 of the Criminal Code of Law). Furthermore, according to Section 165 of the Criminal Code, endangerment committed in the course of a profession occurs when a professional breaches his duty of care and thereby endangers the life or physical integrity of others – this may result in imprisonment of 1–5 years (Section 165 of the Hungarian Criminal Code of Law).

The Civil Code of Law (Act V of 2013) regulates the liability of service providers in several provisions. Sections 6:157–163 of the Hungarian Civil Code of Law stipulate, within the framework of the warranty of goods, that the service provider is liable for defective performance and is obliged to correct the defect or refund the consideration. According to Section 6:137 of the Hungarian Civil Code of Law, failure to fulfill the obligations assumed in a contract is considered a breach of contract, which may entail an obligation to pay compensation.

Therefore, during electrical safety inspections, the use of irrelevant protocols, failure to perform measurements, or the provision of false data may not only have professional and ethical, but also criminal and civil consequences. Accordingly, professionals must act with the utmost care during documentation. The examination of legal liability highlights that electrical safety inspections are a multidisciplinary field: technical, legal and ethical aspects apply simultaneously.

5 Methods

The methodology is based on a qualitative approach, which includes the author's empirical professional experience and the analysis of relevant legislation and standards. The research interprets electrical safety inspections as a system analogous to quality assurance processes, supplemented by the dimensions of safety culture and ethical responsibility. Practical experience shows that the role of inspectors is not limited to checking technical compliance: their activities are crucial in shaping safety culture, increasing operator awareness and maintaining organizational integrity. The study makes recommendations for the development of inspector training, quality assurance and responsibility frameworks in order to make electrical safety inspections a tool for prevention and deliberate safety management beyond formal compliance.

Conclusions

Electrical safety inspectors are extremely important participants in maintaining the safety of electrical systems. Their task is not only to recognize non-compliances, but also to document, communicate and strengthen safety awareness. Strengthening the safety culture plays a key role in ensuring that the inspection activity is not presented as formal compliance, but as an active tool for risk reduction. In addition, from a safety perspective, it is a multi-actor process, which does not only involve electrical professionals, but also those people who handle or use electrical devices and machines.. It would also be essential for them to use electrical equipment as intended and to be aware of potential risks and how to prevent them.

Based on experience, the shortcomings of electrical professionals can be traced back to the shortcomings of basic training and the formality of further training as needed. Renewing systems, practical knowledge transfer and the incorporation of an ethical approach would be essential to increase professional credibility.

This study sheds light on the problems arising in practice through an empirical approach. This study serves as an introduction. In subsequent work, I will

formulate proposals based on questionnaire surveys, expert interviews and their analysis, which can promote the efficiency and reliability of the inspection system and strengthen the culture of safety awareness. One of the limitations of the research is that detailed statistics on electric shock accidents are not available. In addition to electrical inspectors, a parallel research goal is to conduct my own surveys and use questionnaires among electrical specialists, operators and users. These will collect the results of construction, maintenance and inspections in a uniform form, analyse them and provide feedback to operators and professional actors. This would not only enable the statistical processing of non-conformities, but would also support risk analysis processes.

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[13] MSZ 1585 Villamos berendezések üzemeltetése
[14] MSZ HD 60364 szabványsorozat Kisfeszültségű villamos berendezések

An Overview into the Literature on the Concept of the Revolution of ESG

Boglárka Szultos

Ph.D. student, University of Pannonia, Business Faculty
szultos.boglarka@phd.gtk.uni-pannon.hu

Abstract: In contemporary economic and management discourse, Environmental, Social, and Governance (ESG) principles have become a core element of sustainable corporate practice. This shift reflects an expanded view of corporate performance, moving beyond financial indicators to include broader societal and environmental responsibilities (Eccles, Ioannou & Serafeim, 2014). ESG is closely aligned with the United Nations' 2030 Agenda for Sustainable Development, which urges organizations to integrate environmental stewardship, social responsibility, and ethical governance into their strategies. The evolution of ESG illustrates the increasing institutionalization of sustainability in the global business sector. Early milestones in the 1990s, such as the 1992 Rio Conference, initiated global awareness of corporate environmental duties. The period from 2000 to 2010 marked a foundation-building phase with frameworks like the Global Reporting Initiative (2002), the UN Global Compact (2005), and the Dow Jones Sustainability Index (2006). Between 2010 and 2020, investors increasingly recognized ESG performance as a contributor to long-term resilience and competitiveness. Since 2020, ESG has reached a strategic phase, becoming essential for future growth across multiple sectors, including energy and oil & gas. This study provides a comprehensive literature review on the ESG concept, with particular emphasis on its theoretical foundations, definitions, and developmental evolution.

Keywords: ESG (environmental, social and corporate governance factors), development stages, sustainability, comprehensive literature review

1 Introduction

A key lens for understanding business performance and promoting sustainable development is the Environmental, Social, and Governance (ESG) framework. Its rise has not been sudden. Instead, it reflects a gradual evolution over time. Organizations, investors and policymakers have all grappled with the question of what truly constitutes responsible and sustainable business practice. In this

context, the integration of ESG principles into sustainable development represents a significant shift. It signals a growing global effort to engage with the increasingly complex set of environmental, social and governance challenges that organizations face today. This is not merely about rules or metrics. It is about how companies respond to real-world pressures and expectations often in ways that are far from straightforward. This literature review synthesizes current research on ESG. It traces the evolution of the concept, highlights its growing importance and identifies the key gaps that remain in our understanding.

1.1 The evolution of ESG

ESG considerations have become integral to contemporary corporate operations and investment strategies. Although the term “ESG” is relatively recent, the underlying principles trace back several decades, evolving from early practices of socially responsible investing into globally recognized frameworks for sustainable and ethical corporate governance. Understanding the historical development of ESG therefore provides valuable insight into its current relevance and its long-lasting influence on business practices and investment decision-making.

The intellectual foundations of ESG can be traced back to the 1970s, when *Socially Responsible Investing* (SRI) emerged as a practice through which investors began integrating ethical, social and environmental considerations into their financial decisions. Early SRI approaches typically involved screening out companies operating in controversial sectors such as tobacco, arms manufacturing, or environmentally intensive extractive industries. During the 1980s, investor activism gained significant momentum; the divestment campaigns targeting companies doing business in apartheid-era South Africa serve as a notable example. These campaigns demonstrated how financial capital can be mobilized as an instrument to encourage or pressure corporate actors to contribute to broader social and political change (Krantz, 2024).

In the 1990s were a decisive period in the conceptual development of ESG. From the beginning of the decade, organizations such as the Social Investment Forum in the United States documented growing interest in sustainable investment practices, indicating that ethical considerations were beginning to influence mainstream financial markets. In 1997, the *Global Reporting Initiative* (GRI) was established, providing a standardized framework for corporate environmental and social reporting. At the same time, John Elkington developed the *Triple Bottom Line* concept, emphasizing that corporate performance should be measured not only in financial terms, but also in terms of social and environmental impacts, an idea best summarized by the "people, planet, profit" paradigm (Krantz, 2024).

The early 2000s saw ESG evolve into a more structured global framework. The *Carbon Disclosure Project* (CDP) encouraged companies to report on their climate-related risks and impacts. In 2004, the term "ESG" was popularized in the "Who Cares Wins" report, which advocated integrating environmental, social and governance considerations into corporate strategy and investment analysis. Subsequently, various standardized frameworks, including the *Sustainability Accounting Standards Board* (SASB) and the *Principles for Responsible Investment* (PRI), provided methodologies for measuring ESG performance and integrating it into corporate and investment decision-making processes (Krantz, 2024).

The adoption of the United Nations *Sustainable Development Goals* (SDGs) in 2015 further reinforced the relevance of ESG, linking corporate practices to global social and environmental objectives. Regulatory developments, such as the European Union's *Corporate Sustainability Reporting Directive (CSRD),* have increased corporate accountability by requiring companies to provide transparent reporting on ESG-related impacts. Together, these initiatives illustrate the evolution of ESG from a voluntary ethical consideration into a standardized and increasingly mandatory component of corporate governance (Krantz, 2024).

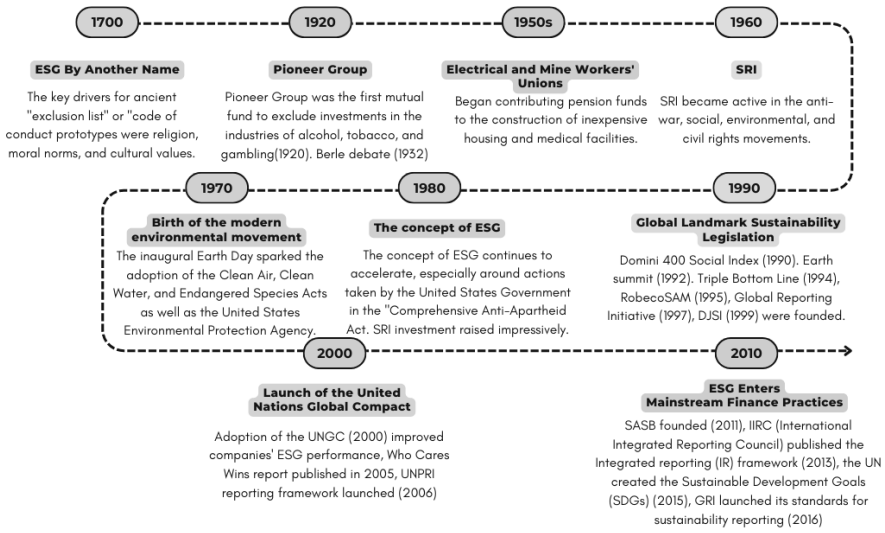

Figure.1
Timeline for the evolution of ESG

The historical evolution of ESG reveals how the concept has transformed from niche ethical investing to a robust, globally recognized framework that guides corporate behavior, investor strategy and regulatory oversight. ESG helps companies and investors balance financial performance with long-term environmental and social responsibility. Properly integrated ESG does more than just reduce risks and increase corporate transparency; it also aligns company operations with broader social objectives, reflecting a growing consensus that sustainability and business profitability are self-reinforcing, not mutually exclusive.

2 Definition of ESG

Companies all over the world adopt ESG measures in order to sustain themselves in today's dynamic environment. The concept of ESG has its origins in the financial world, with its beginnings tracing back to the 1970s when a small group of socially responsible investors expressed interest in the environmental and social practices of the firms in which they invested (Galbreath, 2012). "ESG" stands for the initial letters of the words Environmental - E, Social - S, and Governance - G, three elements that complement each other in measuring sustainability and the impact of an organization. ESG factors mean a group of non-financial performance indicators aimed at assuring the responsibility of the organization and may be subject to assessment by investors and other stakeholders (Kaźmierczak, 2022).

Dimension	Description	Key Elements	References
Environmental (E)	Demonstrates the corporation's commitment to ecologically sustainable operations.	Climate change, carbon emissions, deforestation, biodiversity, pollution, waste management, water usage	Dathe et al., 2024
Social (S)	Reflects the company's contribution to social justice and human capital.	Labor practices, diversity, human rights, pay equity, community relations, data privacy, health & safety, supply-chain ethics	Kolsi & Muqattash, 2020
Governance (G)	Covers the corporate leadership structure and integrity of management practices.	Board composition, executive compensation, anti-corruption policies, lobbying activities, regulatory compliance	Karim, 2024

Table.1

The most important trends shaping the ESG concepts

Environmental, Social, and Governance (ESG) is a broader concept to evaluate a company's sustainability and ethics in these three basic dimensions (EBA, 2021). Within this context, the Environmental („E") dimension captures a

firm's commitment to ecologically sustainable business practices. Key components encompass climate change, carbon footprint, deforestation, biodiversity, pollution, waste management and water-related impacts (Dathe et al., 2024).

The Social („S") dimension, reflecting a firm's contribution to social justice and human capital, encompasses labor relations, diversity and inclusion, human rights, compensation policies, community engagement, data privacy, health, safety and responsible supply-chain practices (Kolsi & Muqattash, 2020).

Governance („G") means corporate governance, composition of the board of directors, executive consideration, anti-corrupt policy, political activism, compliance with laws and regulations (Karim, 2024).

Although the concept of ESG is relatively recent, it originally developed from the principles of Socially Responsible Investing (SRI) (Li et al., 2021), which includes mission-related investment, impact investment and sustainability thematic investment (Caplan et al., 2013). Likewise, modern ESG investing seeks to balance risk management with the potential for value creation through sustainable growth. As such, it has become a benchmark for assessing a firm's potential contribution to society and the environment, alongside its long-term financial resilience. Investors today apply ESG criteria to evaluate a company's conduct in terms of corporate citizenship, environmental responsibility and prospective financial performance.

2.1. The Impact of ESG Ratings on Corporate Behavior

Wang et al. (2023) take what is basically a seminatural experiment to see whether ESG ratings nudge companies toward greener innovation. Higher ratings seem to give firms a little push toward developing cleaner technologies. However, the effectiveness of ESG evaluations largely depends on the reliability and consistency of the ratings themselves perhaps more than we might hope. In practice, these ratings are frequently not fully reliable and nor consistent. This inconsistency makes life difficult for investors. Chen et al. (2023) point out that different agencies apply different criteria, so they have strangely different assessments of the same company.

Ahmad et al. (2023), analyzing data from emerging markets, concluded that ESG activity in these regions may have a negative impact on the financial performance of companies. According to research, the cause of the phenomenon is the underdevelopment of the regulatory environment. As state and institutional systems do not yet reward or support the sustainability efforts, resources spent on the ESG will be merely a cost without providing a competitive advantage.

Trivellas et al. (2020) take a close look at ESG disclosures and how they play into companies valuation. Companies that make ESG a real priority seem to gain noticeable value in the market. It reinforces this growing sense I have had, and maybe others too, that investors are paying far more attention to sustainability than they used to. Some are thinking long-term risk, others just want to feel confident they are backing responsible firms. Higher ESG scores tend to pair with higher value, which makes transparent reporting feel less like an optional gesture and more like something companies genuinely rely on to signal stability.

Zheng et al. (2023) push the conversation in a slightly different direction. They argue that while ESG is clearly important, we still do not fully understand the mechanics behind its impact. Their study calls for deeper research, the kind that untangles how ESG efforts actually filter into performance and profitability. It is almost like saying, “We know it works, but not exactly why,” which feels honest. And maybe that uncertainty is what keeps this field moving forward.

Conclusions

The literature review shows that ESG factors have moved from a niche perspective on socially responsible investing to an overall framework that increasingly drives corporate strategy, investment decisions, and regulatory standards around the globe. This is a historical trajectory from the early ethical investing movements of the 1970s to globally recognized frameworks such as GRI, SASB, and the UN Sustainable Development Goals, underlining ESG's growing relevance both as a managerial and financial imperative.

ESG is much more than an abstract set of principles; it dynamically impacts corporate behavior, investor expectations, and market valuation. Firms embracing the integration of ESG practices not only reflect mitigation of risk and operational transparency but also conformity to social and environmental ambitions. However, the literature does note ongoing issues, which most significantly surround consensus and reliability in ESG ratings. The divergence in methodologies and contextual specifics, especially in emerging economies, can definitely reduce the effectiveness of ESG efforts and make the outcomes of these programs less certain regarding their practical influence on business performance.

Despite such challenges, ESG remains a key lens through which organizations, investors, and policymakers might pursue sustainable development. ESG acts both as a moral compass and as a strategic tool: it guides companies towards sustainability but also gives investors a framework for the evaluation of long-term value creation. Its continuous development is likely to play a role in creating a business environment that is economically resilient, socially responsible and environmentally sustainable.

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Examination of the Application of Marketing Controlling in Family Businesses

Ferenc Katona

Obuda University, Keleti Károly Faculty of Business and Management
katona.ferenc@kgk.uni-obuda.hu

Abstract: Family businesses play a significant role in the Hungarian, EU, and global economies. They also play an important role in income generation and employment. However, their performance lags significantly behind that of large companies. Using a questionnaire survey conducted among SMEs, primarily family businesses, I examined, among other things, what characterizes the marketing activities of these businesses and to what extent they use marketing planning, measurement, and analysis tools..

Keywords: family business, SMEs, marketing controlling, marketing planning

1 Definition of family business

The definition of family business is summarised in the European Commission (n.d.) as follows:

- the majority of the decision-making power is concentrated in the hands of the person who set up the enterprise or of a family member or relative who participates in the enterprise,
- the majority of the decision-making powers are exercised directly or indirectly;
- a family member or relative is formally involved in the management of the enterprise;
- if the company is listed on a stock exchange, the family owns at least 25% of the shares.

The factors that determine family businesses are (Tóth-Bordásné Marosi (2014) and Chua et al (2009)):

- Family ownership and control,
- Family ownership but not control by the family,
- family control, but the property is not family.

Family and non-family businesses follow different operational logics in several important respects. In terms of purpose, the primary objective of family businesses is to ensure the long-term survival of the company, while non-family businesses seek to maximise share price and short-term financial results. The corporate objectives also differ: family firms focus on preserving the assets and reputation of the company, while non-family organisations focus on meeting investor expectations. The belief system on risk-taking also differs: family firms focus on avoiding the negative effects of risk, while non-family firms see risk as an opportunity for higher profitability. In terms of strategic orientation, family firms tend to be more adaptable, pursuing a more cautious growth path, while non-family firms' main ambition is to expand continuously. The key stakeholders are also different: in family firms the focus is on customers and employees, while in non-family organisations the interests of shareholders and management dominate. In terms of management focus, family firms implement improvements in smaller incremental steps, while non-family firms place greater emphasis on innovation. In terms of perception of business, family firms often see themselves as a social, community institution, while non-family firms see the organisation as a business asset or a store of value. Finally, leadership and managerial roles also differ: in family businesses, the leader is often seen as a caring, patriarchal figure, while in non-family businesses the leader is often described as a charismatic, results-oriented manager (Thomassen, 2007).

2 The concept og marketing controlling

The complexity of the content of marketing, the multifaceted tasks of marketing management and the often complex marketing process require a system to support the preparation of decisions. Linked to this system are the tasks of planning, information gathering, analysis, monitoring and management, which together make up the activity of marketing controlling. Marketing controlling thus functions both as a subsystem of marketing management and as a boundary system of the corporate controlling system (Ehrmann, 1991).

Bruhn (1990) defines the main objectives of marketing controlling as follows:

- ensuring the long-term survival of the firm,
- to identify opportunities and threats, and to identify strengths and weaknesses at an early stage,
- managing marketing activities in a profit-oriented way,
- mitigating revenue risks,
- maintaining decision flexibility to support market behaviour.

The role of marketing controlling is to ensure that the marketing objectives set are met, taking into account efficiency and effectiveness. In this context, marketing controlling is responsible for producing, coordinating and managing the relevant information needed for decision-making. It operates as a cybernetic system that supports the interpretation and fine-tuning of processes through feedback and forecasting mechanisms. Marketing controlling is composed of three main subsystems: the information system, the planning system and the control system (Auerbach 2001).

The central task of marketing controlling is to increase the effectiveness of management by supporting the planning, control and information systems used in the company's marketing activities (Link & Weiser, 2006).

3 Methods and sample

The empirical study utilized an online survey as its primary data collection method. A total of 2,628 enterprises—predominantly small and medium-sized businesses, of which 89% were family firms—completed the questionnaire. The collected data were coded in Excel and subsequently analyzed using SPSS version 25. The sampling process followed a snowball sampling technique. As the sample is non-representative, the findings should be interpreted as valid only for the investigated respondent group.

The vast majority of the firms surveyed, 73.5%, are classified as micro-enterprises, i.e. employing 0-9 people. Small enterprises employing 10-49 persons account for 20% of the sample, while medium-sized enterprises (50-249 persons) represent only 5.5%. The share of firms in the large enterprise category with more than 250 employees is only 1%.

In terms of the distribution of the surveyed enterprises by activity, consumer services firms represent the largest share of the sample, with 34%. They are followed by industrial services with 19%. The share of firms producing consumer durables and the share of firms producing basic materials and components are both 12%. FMCG manufacturers account for 10% of the sample. The share of firms related to market production equipment is 3%. Enterprises classified in the other category and those that could not identify their field of activity both represent 5%.

In terms of the distribution of enterprises surveyed by economic sector, the largest share of enterprises is in the trade and repair sector, representing 27% of the sample. This is followed by agriculture, hunting, forestry and fishing, which accounts for 16% of respondents. Manufacturing represents 15% of the sample. Construction represents 8%, while the financial intermediation, real estate and business services sector accounts for 7%. Accommodation and food service

activities account for 6% and transport, storage, post and telecommunications for 5%. Other, smaller categories (e.g. education) also account for 5%. Electricity, gas, steam and water supply account for 3% and Public administration, defence and compulsory insurance for 1%. And mining has a 0% presence, i.e. virtually absent among respondents.

In the case of the regional distribution, the majority, 51%, operate in Budapest or Pest county, indicating a significant concentration in the capital and its agglomeration. The second highest proportion, 13%, is represented in the North-Hungary region. The North Great Plain and South Great Plain regions both account for 9% of the sample. The regions of Central Transdanubia and Western Transdanubia both account for 7%. The South Transdanubia region received the smallest share of 4%.

4 Results

Figure 1 shows the marketing planning tools used by the companies surveyed. According to the responses, the most commonly used method was SWOT analysis, mentioned by 13.9% of companies. It can be assumed that this is also the most familiar planning technique among family businesses. The calculation of the payback period came second with 10.3%, while benchmarking was the third most widely used tool (9.3%). This was followed by the use of the profitability index.

Responses indicated that the use of the internal rate of return (IRR) was at 7.2%, which is positive in itself, but still relatively low in the SME sector. Other tools used included product life cycle analysis (5.3%), GAP analysis (4.4%), net present value (NPV) method (4.5%), portfolio analysis techniques (4.1%), scenario planning (2.1%) and discounted cash flow analysis (1.9%).

Overall, the application rate of marketing planning methods is rather low. This suggests that the knowledge and use of strategic and financial analysis tools among SMEs, especially family businesses, still needs to be improved. This justifies further strengthening of the professional knowledge and management skills of entrepreneurs.

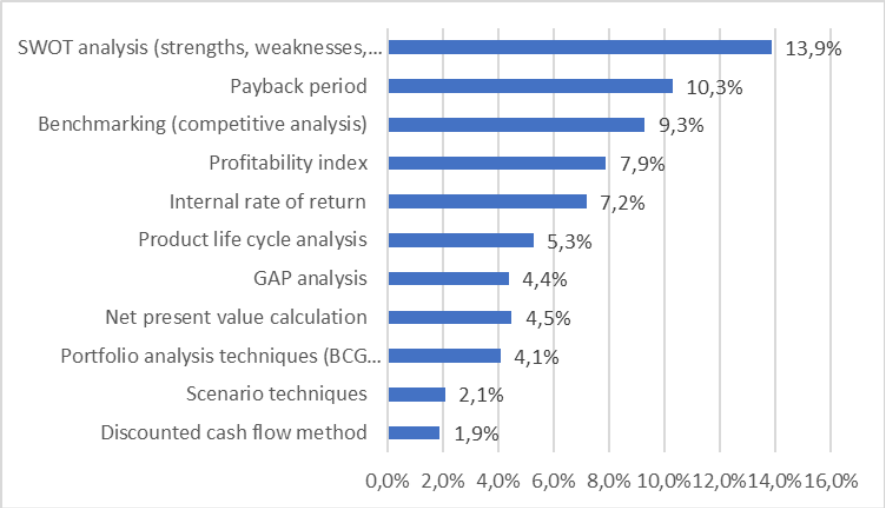

Figure 1
Marketing planning tools
Source: own research

My research also examined the performance indicators used by businesses to assess the effectiveness of their marketing activities. I used a total of 12 indicators in the questionnaire, and respondents could select more than one option depending on which indicators they used in their own practice.

The results presented in Figure 2 show that the most frequently used indicator is the increase in turnover, which was indicated by 30.2% of the enterprises. This is followed by an increase in customer satisfaction with 14.6%, while the third most cited indicators are an increase in profitability and an increase in company/product awareness, both with 12.3%. The fifth most cited indicator is growth in market share (9.5%), followed by change in customer attitudes (9.1%) and return on sales (ROS) (8.4%), then growth in brand loyalty (7.3%) and return on investment (ROI) (6.6%). Change in corporate or product image is ranked at the bottom with 5.1%, return on equity (ROE) with 3.3% and change in contribution margin with 2.5%.

The results show that companies rely mainly on short-term, financial indicators to assess marketing performance. The use of strategic and branding indicators is present but significantly less important, suggesting that companies' marketing activities are not yet fully integrated in the long-term process of creating value for the company.

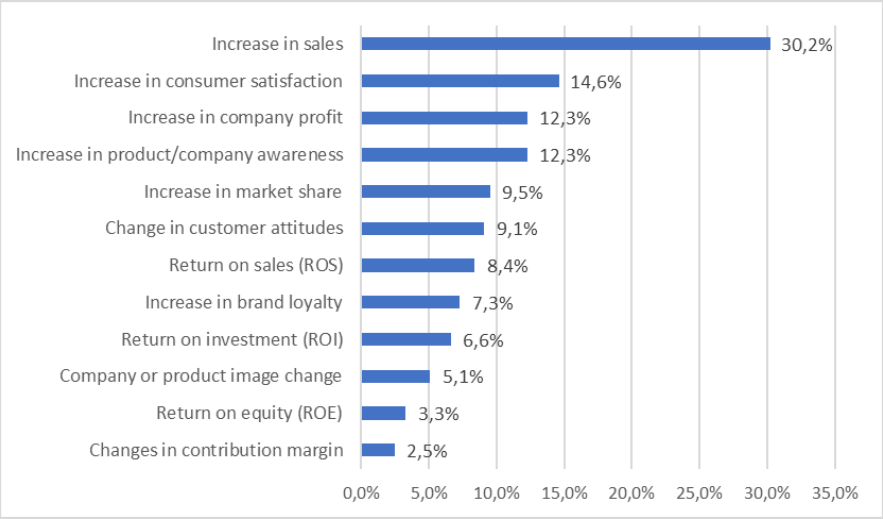

Figure 2
Indicators to measure the effectiveness of marketing actions
Source: own research

The research findings are in line with trends in the international literature, which suggests that marketing measurement practices in SMEs are still underdeveloped and based predominantly on short-term financial indicators (Ambler - Kokkinaki, 1997; Clark, 2001). Several studies emphasise that non-financial indicators such as brand equity, customer satisfaction or loyalty are more important for competitiveness in the long term, yet they are marginalised in the evaluation system of SMEs (Kaplan - Norton, 1996; Rust et al, 2004).

The literature also highlights that the majority of SMEs consider marketing as a supportive, non-strategic function, and therefore measurement systems are often ad hoc and not closely linked to corporate objectives (Simpson et al, 2012). In line with this, the results of my research suggest that the marketing performance evaluation of the enterprises studied is not yet mature: most of the indicators used are linked to revenue, while systematic monitoring of market position and brand equity is less common.

Overall, therefore, the practices of domestic SMEs do not differ significantly from international trends: the development of marketing measurement is still at an early stage, especially among family businesses.

Conclusions

The findings reveal that the surveyed enterprises exhibit a notably low level of adoption of marketing planning tools. Nearly 70% of small and medium-sized firms do not employ any formal marketing planning instruments at all. Even among those that do, the most widely applied tool is used by only 14% of respondents, while the utilization of two additional tools remains around 10%.Furthermore, more than half of the participating SMEs do not evaluate the effectiveness of their marketing activities. Among those that do, the most frequently applied metric is sales growth, reported by just over 30% of firms. The second most common indicator—customer satisfaction—was mentioned by only approximately 15%. Overall, only six performance indicators showed usage levels of around 10% or higher among the surveyed enterprises.

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The Possibilities of Artificial Intelligence in the Areas of Pension Security

Zsolt Mihály Szabó

Obuda University, Doctoral School on Safety and Security Sciences
szabo.zsoltmihaly@uni-obuda.hu

Abstract: The pension sector, whether public or private, is on the cusp of technological transformation. The artificial intelligence (AI) is beginning to transform the way pension systems operate, member engagement and investment management. The AI offers exciting opportunities, but its introduction must be approached with caution, responsibility and a commitment to protecting the future of members. According to analyses by pension professional bodies, AI is already having an impact in key areas, such as personalised communications and pension planning tools that help members make more informed decisions, and fraud detection and cyber protection that increase the resilience of pension systems. These innovations are not theoretical, they are already being piloted or implemented in various systems across the pension sector, and many experts predict that AI could become a standard feature of pension fund management in the future.

Keywords: pension security, artificial intelligence (AI), pension planning tools, cyber security, pension system resilience

1 Introduction

The world was shaken by three major explosions at the beginning of the 21st century: the population explosion, the longevity explosion and the information explosion (Iván, 2004). The population explosion is a rapid, rapid increase in population, which usually occurs when the birth rate is high, while the death rate is falling. This phenomenon can still be observed in developing countries, but the world's population growth rate is slowing down. Longevity means that we not only live longer, but also do so healthily and actively, i.e. we do not only add years to life, but also add life to years. It also includes increasing life expectancy and healthy life expectancy, which aims to improve the quality of life. The deteriorating demographic situation is typical of the countries of the European Union, including our country. The information explosion refers to the explosive growth in the amount of information, which has accelerated in the digital era thanks to the development of technology, the Internet and social

media. This phenomenon involves access to a vast amount of often unfiltered information, which poses challenges for people, such as brain adaptation pressures, communication bottlenecks and intergenerational alienation. Global demographic changes, ageing societies and sustainability challenges of financial systems are putting increasing pressure on pension systems (European Commission, 2024). The emergence of artificial intelligence (AI) offers new opportunities to improve pension security, manage risks and support individual decision-making. The application of AI in this area is not only a key factor in technological innovation, but also in terms of social and economic stability (OECD, 2025).

2 The basics of pension security

The social security is an unquestionable value of modern history. The social security system may consist of pension insurance, health insurance and social welfare system (Balogh, 1996). A pension system is a system designed according to a specific system, which ensures the livelihood of an individual who is unable to work due to old age (or disability) with regular financial support (pension benefits). Pension systems can be grouped, compared or contrasted according to their systems, sources and regulations. According to the Green Paper (Towards adequate, sustainable and safe European pension systems) prepared by the European Commission in 2010 (European Commission, 2010) and the White Paper (An Agenda for adequate, safe and sustainable European pensions) (European Commission, 2012) adopted in 2012, the fundamental objective of pension systems is to provide adequate retirement income, to ensure that older people live in decent conditions and in economic independence, and to play an automatic stabilising role in pensions. The function of the pension system is to provide income security in old age or in the event of the death of a close relative. In the state pension system, entitlement to benefits is based on the payment of pension contributions. The state guarantees the payment of pensions and ensures that the real value of pension benefits is preserved (Matits, 2016). According to the European Commission's 2015 Pension Adequacy Report (European Commission, 2015), EU pension systems can only be expected to provide an adequate level of pensions for future generations if Member States implement sufficiently strong policies to ensure that as many workers as possible remain active until they reach the official retirement age. Employment policies should offer older workers more opportunities to stay in the labour market for longer. At the same time, pension systems should also protect those who cannot stay in the labour market long enough to build up sufficient pension rights (European Commission, 2024).

The Organisation for Economic Co-operation and Development (OECD) is an international economic organisation based in Paris, of which Hungary has been a member since 1996. It is a global organisation whose aim is to help Member States' governments design and evaluate the best possible economic and social policies. According to the OECD, pension systems generally consist of "three pillars" (see Figure 1).

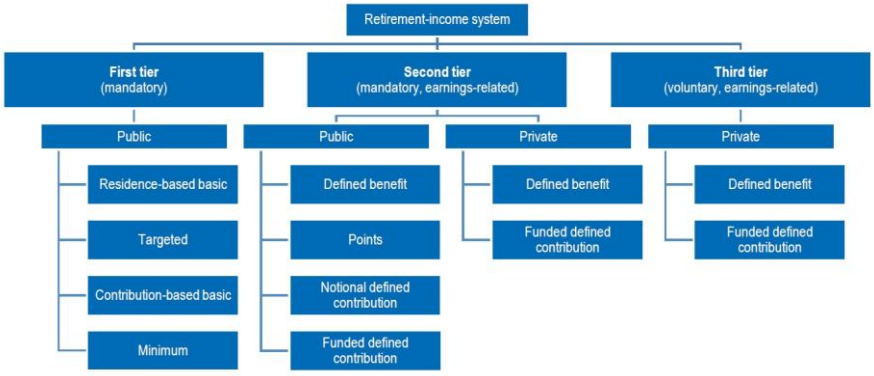

Figure 1

Summary framework of the various pension financing systems (OECD, 2021, 2025, Novoszáth, 2014, 2017, own editing, 2025)

The "first pillar" (state) pensions are statutory state pensions managed by the state, usually financed from social security contributions and/or general tax revenues on a pay-as-you-go (PAYG) basis. In some countries, individual schemes financed by law have been introduced alongside the first pillar. The "second pillar" (employer) pensions are private supplementary schemes linked to employment. Finally, the "third pillar" (personal) pensions are personal pensions, i.e. pre-funded private voluntary supplementary schemes in which contributions are invested in an individual account held by a pension fund or financial institution.

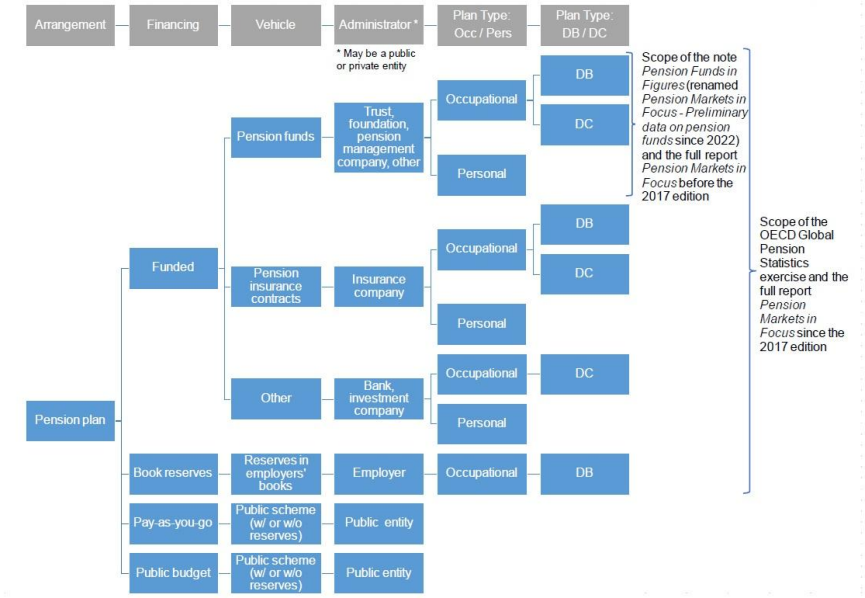

Figure 2

Pension plans (OECD, 2020, 2022, own editing, 2025)

In the following, I will review the factors that determine individual retirement security and our decision-making options related to them. Juan Yermo, in his publication "Established data on pension plans, pension funds and pension organizations" (Yermo, 2002), distinguishes between public and private pension fund pension schemes as follows:

- Public pension schemes: social security and similar schemes where the public sector (i.e. central, state and local governments, including social security institutions) arranges the payment of pension benefits. They aim to provide minimum (flat-rate and/or earnings-related) benefits at retirement for the entire population (or at least the formal sector). Public schemes are traditionally financed by PAYG, but some OECD countries partially pre-finance public pension liabilities or have replaced these schemes with private pension funds.

- Private pension scheme: a pension scheme in which the payment of pension benefits is arranged by an institution outside the public sector. Private pension schemes are managed by the employer, pension organisation or private sector service provider acting as the sponsor of the scheme. Private pension schemes can complement or replace social security schemes. In some countries, these may also include schemes for public sector employees. Private pension schemes are financed by OECD countries.

Regarding financial decisions related to pensions at the individual level, only in the case of private pension schemes (pension savings plans), public schemes exclude the possibility of such individual decisions. In the following, it is worth defining what we mean by pension savings. In the broadest sense, retirement savings can be understood as any long-term, voluntary or non-voluntary form of savings that is intended to provide financial security in later life and that does not come from state old-age pensions (i.e. not from the first pension pillar). In this case, retirement savings include classic voluntary savings products such as voluntary pension funds and pension insurance, as well as private pension funds. But in a broader sense, it also includes life insurance, real estate investment and all country-specific forms of retirement savings (pension bonds, special retirement accounts, etc.), even those with preferential taxation. The OECD uses the definition of a retirement savings plan (OECD, 2020, 2022), which includes all financial instruments that generate long-term payments (see Figure 2). These assets can be in pension funds (pension fund), pension insurance contracts (pension insurance), or other forms of savings (pension savings account). Thus, private pension fund accounts, which can be interpreted as the second pillar, are also classified as forms of pension savings, especially given that their presence is not evident among pension products in the four countries examined (in Hungary and Poland, after the redirection of private pension fund payments to the first pillar, the role of this form of savings for retirement purposes became very low (Vaskövi- Ráduly, 2022).

3 AI opportunities in the pension systems

Pension systems worldwide are under demographic and financial pressure. Artificial intelligence (AI) – including machine learning (ML) and generative AI – offer promising tools to improve the coverage, efficiency, equity and resilience of schemes. According to the OECD 2025 review (OECD, 2025), client support, automation of back-end processes and error/fraud detection are already widespread in social protection; the next leap is towards predictive analytics and personalised interventions. Pension industry-specific analyses show that AI can deliver measurable results across the entire value chain – from enrolment to payout – but strong governance, transparency and member trust are needed. OECD governments are increasingly using advanced data and technology to improve the coverage, efficiency and effectiveness of social programmes, but they are also cautious about introducing artificial intelligence (AI). Common uses of AI in social protection include customer support, automation of back-office processes and fraud detection. Looking ahead, AI has significant potential to improve the performance of social programmes – including through predictive analytics, increased awareness and more tailored

interventions – but governments need to continue to build trust and promote transparency in the use of AI.

Recommendation	Description	Pension-specific example
Human-centric, trustworthy AI	AI serves people, providing decision support; in particularly sensitive life situations (widowhood, orphanhood, disability), human supervision is mandatory.	Pre-screening for eligibility for care with AI, but final decision with an administrator; humane handling of individual equity cases.
Transparency and explainability	Communicating the role of AI; justifying decisions and displaying "reason codes".	Publishing factors behind eligibility scores; decision-support explanation on the client portal.
Data protection and security (GDPR)	Data minimization, access control, logging; risk management of the use of generative AI.	Pension dashboard: strong authentication, contribution management and logging; protection of sensitive documents.
Fairness and bias reduction	Incorporation of data cleaning, representativeness, bias tests and fairness audit.	When detecting payment anomalies, demographic parity analysis (age, gender, region).
Pilot → scaling	Learning from small pilots, gradual national expansion after measurable KPIs.	Pension chatbot pilot in one region, then scaling to national customer service.
Algorithmic accountability and audit	Independent verification, audit trail, traceability; complaint handling and correction.	Full logging for automated decision support; annual independent audit.
Customer-centric service design and engagement	Co-design by life stages; understandable communication; accessibility (A11y).	Voice-based channels for older customers; simple forms.
Responsible use of predictive analytics	Validation, drift monitoring, human review; risk communication.	Forecasting payment peaks and customer traffic for capacity planning.
Fraud/abuse monitoring with AI	Anomaly detection, real-time alerting; ethical thresholds and human verification.	Identify suspicious payment patterns and identity fraud.
Digital architecture and interoperability	Unified identification, consent management, standardized data exchange (API, SLA).	"Pension overview" dashboard ecosystem with provider integrations.
Skills development in the public sector	AI literacy at all levels; advanced/specialist competencies; ethics.	Agents use genAI tools for summarization and knowledge discovery.
Impact assessment and monitoring	Continuous performance and risk monitoring; measurement of public service value.	Tracking AI KPIs and public service outcomes in pension administration.

Table 1

OECD recommendations on the possibilities of AI in the pension system (OECD, 2025, own editing, 2025)

The OECD outlines key opportunities and recommendations for the application of AI in pension systems, which are summarised in Table 1 with descriptions and pension-specific examples. The OECD recommends the application of AI in pension systems by implementing tools that support clients, make

administration more efficient, improve fraud protection, cybersecurity, data protection, facilitate personalised interventions and expand access to services. It places this behind sound regulatory, governance and human capacity-building measures, fully in line with the OECD's "Trustworthy AI" principles (OECD, 2025). Hungary's 2020–2030 AI Strategy promotes a "data-driven service state" and trustworthy AI applications, and an updated version was published in 2025 with a promise of an annual review, with a focus on social applications (education, healthcare, public services). The strategy focuses significantly on the development of public services, but does not highlight the pension system as a separate sectoral target area. The strategy does not specifically address the pension system, however, the digitalisation of public services and data wallet-based services can offer indirect benefits to the pensioner generation, such as automated administration can facilitate online pension-related applications and data changes, and the use of the data wallet can enable personalised administration, such as easy updating of pension calculation data. Increased digitalisation in e-government can also be beneficial by reducing the digital gap between generations (NGM, 2025).

4 AI opportunities in pension plans and self-care

According to forecasts, the number of pensioners is increasing drastically, and this cannot be changed in the short term (OECD, 2021, 2025, Europian Commision, 2024). The Hungarian pension system currently rests on two pillars. Pillar I: the state pension system operates on a pay-as-you-go basis and Pillar II, which operates on the principle of capital funding (Novoszáth, 2014). In the current pension system, choosing a voluntary pension fund can be an additional element of ensuring livelihood in old age. A voluntary pension fund can enable us to maintain the standard of living we have become accustomed to during our active years upon retirement. These institutions complement other retirement savings, such as pension insurance. In the general public perception, a pension is the pension that a country's elderly citizens receive on a subjective basis, i.e. not on the basis of need. Its amount depends on the length of service, i.e. the number of years spent working (earnings) and previous income (Matits, 2016). This definition reflects the public opinion, according to which the concept of pension is exclusively related to social security benefits. However, a pension can be considered any regular old-age income to which we are entitled during our active years. Thus, retirement income from some retirement savings can or may be a pension. It must be made aware that there is no and cannot be a state benefit that can promise everyone an adequate pension in all cases. In other words, if we really want to be secure in our old age, we have to do a lot for ourselves. In addition to increasing taxes and contributions and extending the retirement age, there is also a more effective and sustainable solution, which

is called self-care. This means that people create a private pension fund for themselves that allows them to live a full life in old age. This also relieves the burden on the state, because they set aside money for private purposes, although with state assistance. They manage their own assets and do not pay more into the common fund. There are many ways to save for retirement.

Recommendation	Description	Hungarian practice
Individual pension dashboard (multi-source)	A personalized online interface that automatically brings together legal relationships and savings from multiple sources (state, employer, voluntary); interactive overview and action suggestions.	There is no national pension dashboard integrated from multiple sources. E-administration in the SZÜF/Ügyfélkapu+ framework; thematic pages on the MÁK website.
Interactive 'what if' calculators	User-modifiable parameters (deposit, trajectory, yield), instant forecasts and decision suggestions to support planning.	MÁK Self-service pension calculator (based on service time/earnings); calculator for several voluntary pension funds (ÖPOSZ, OTP).
Payout phase planners	Comparison of payout alternatives (annuity, periodic annuity, lump sum); payout strategy tailored to individual needs.	Annuity calculators are available from voluntary funds (e.g. Erste). On the state side, the focus on determination dominates, and uniform payout planning is less supported.
Communication and education (OECD/INFE)	Plain language guides, financial education built into the interface; measurement with OECD/INFE questionnaires and competency framework.	Strong educational ecosystem (PÉNZ7, Pénziránytű, MNB). The level of knowledge is outstanding, but financial behavior and practical application need to be improved.
Risk/return visualisers	Portfolio recommendations and market simulations based on risk profile; transparent return communication on the dashboard.	Voluntary funds have yield simulators (OTP, Aranykor). There is no uniform yield/risk illustration on the state platform.
Automatic data interoperability	The key to a dashboard is data connectivity, real-time updates, and auditability – integrating multiple sources according to standards.	This identification works (Customer Portal+ / DÁP), but multi-source pension consolidation is not common.
System statistics in individual view	Combining macro indicators (average, median, regional breakdown) and individual context in decision support.	KSH STADAT detailed pension statistics (average, median, regional breakdown) are available, but are not integrated into personalized interfaces.
Action-oriented 'nudge' functions	Reminders, goal tracking, automatic deposit increases, and decision guides to encourage actual savings steps.	These administration and fund campaigns are available, but system-level nudge frameworks are not common on the pension platform.

[15] Table 2
OECD recommendations on the application of AI in pension plans and self-care (OECD, 2025, own editing, 2025)

The OECD outlines key opportunities and recommendations for the application of AI in self-care and decision support for individual retirement savings, which are summarized in Table 2 with descriptions and Hungarian implementation practices. The OECD recommendations build support for individual retirement savings on a comprehensive, multidimensional approach. Together, these elements increase financial awareness, help make more informed decisions, and thereby improve the quality of life of people of retirement age (OECD, 2025).

Conclusion

An ageing population, increasing life expectancy and changing employment structures are undermining the balance of pay-as-you-go models, while market volatility and inflation are challenging funded systems. AI is already a proven performance-enhancing technology in government and financial services, especially when combined with sound governance. In most EU countries, public systems play a central role in enabling people to maintain their standard of living in their working years and beyond. The challenge for pension policies in Member States is to create systems that are financially sustainable in the long term and that meet the fundamental objective of pension systems, namely to provide an adequate income and standard of living for older people and ensure their economic independence. To create an institutional framework that can provide sufficient coverage in the long term to ensure the security of a retired society. Artificial intelligence has significant potential in the field of pension security, especially in the areas of forecasting, personalized advice, administration and risk management. However, the introduction of the technology requires responsible regulation, ethical considerations and social dialogue. In order for Hungary to have an economy that adapts to inevitable demographic processes, a major paradigm shift and the inclusion of new technologies – such as artificial intelligence – are needed in terms of the sustainability of the economic environment and pension security.

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A Literature Review on the Evolution of Competence Matrices and Workforce Resilience in Industry

Zoltán Váradi

Obuda University, Doctoral School on Safety and Security Sciences
varadi.zoltan@kgk.uni-obuda.hu

Abstract: Competence matrices are widely recognized as effective tools for visualizing and managing workforce capabilities in alignment with operational requirements. This structured approach facilitates the systematic evaluation, documentation, and allocation of employee skills according to production needs. Within the context of standardized work, competence matrices serve to identify areas for improvement, decrease process variability and ensure the consistent application of best practices. This study presents a comprehensive literature review on the development and industrial implementation of competence matrices, with an emphasis on lean manufacturing principles. The analysis examines how competence mapping supports workforce allocation, identifies training needs, and aids in the development of balanced competence portfolios that improve substitutability among workers. By integrating competence management with continuous improvement practices, the paper demonstrates how competence-based allocation contributes to operational stability and adaptability. Competence matrices provide a strategic advantage in managing workforce fluctuations, allowing companies to respond swiftly to employee turnover or absences. Their implementation enhances process resilience by ensuring critical tasks remain covered, thereby preserving workflow continuity even during disruptions. The findings emphasize that maintaining clear and up-to-date competence records enables organizations to effectively plan for employee interchangeability and sustain production performance under dynamic conditions.

Keywords: Competence matrix, skill mapping, workforce flexibility, manufacturing systems, lean management, standardized work

1 Introduction

Contemporary production systems operate under pressure originating from both market forces and internal corporate requirements. Market-side expectations typically bring tight cost targets, delivery pressure, and consistently high quality levels, while corporate stakeholders simultaneously demand regulatory compliance and sustainable profitability. These concurrent pressures emphasize firms' vulnerability to workforce-related disruptions, including employee

absences or shortages of adequately skilled workers. The heterogeneity in human skills, competencies and behaviours often translates directly to process variability, as best demonstrated work practices are applied inconsistently across shifts and workstations (Misiurek, 2016). The human-induced variability can manifest in operational and economic consequences such as bottlenecks, increased defect rates, missed delivery commitments, and frequent need for overtime or other costly countermeasures.

Operational resilience and adaptability have become critical management priorities, as recurring disruptions highlight how rapidly performance can degrade when processes and roles are not robustly designed. Organizations that lack structured mechanisms for absorbing shocks and restoring normal operations are more prone to cascading effects from relatively minor disturbances, resulting in instability, reactive firefighting, and deteriorating customer satisfaction. A key managerial challenge is the robust allocation of workforce to workstations and tasks so that critical operations are fully covered, and targeted throughput levels can be sustained even under workforce-related disruptions.

Lean management principles propose several countermeasures, with a strong emphasis on the reduction of variability, referred to as the waste of “mura”, which in turn contributes to the reduction of the more visible forms of waste known as “muda” (Womack & Jones, 2003). Standardized work provide complementary managerial frameworks for addressing these issues by establishing a stable operational baseline and embedding structured mechanisms for continuous improvement. Standardized work reduces variability by defining the best currently known method, sequence, and timing for each task, while lean manufacturing principles guide the systematic elimination of waste, thereby supporting both short-term process stability and long-term organizational adaptability (Liker, 2013).

Workforce is regarded as an integral part of lean manufacturing, where the development of standardized work both facilitates and at the same time requires repeatable human performance. Effective task execution depends on the worker’s portfolio of knowledge, skills, competencies, and practical experience. Although the term “competence” is used in many different contexts (Hegyi, 2012), this study applies a task-focused definition: a worker is considered “competent” if he or she is capable of performing the required task to the expected standard (Weerasombat & Hampson, 2012). In a lean context, competence management should support continuous improvement, as competence information should reveal training needs and improvement opportunities, rather than serve only as a static documentation.

Many manufacturing companies operate within an audited quality management system certified to ISO 9001:2015. These firms must repeatedly demonstrate

during internal and external audits that their documented processes, records, and practices comply with the requirements of the standard. In particular, ISO 9001:2015 explicitly links personnel competence to the performance and effectiveness of the quality management system, making competence management simultaneously a quality issue and a regulatory compliance obligation. Clause 7.2 of the standard (ISO/TC 176/SC 2, 2015) requires organizations to regularly and systematically evaluate the knowledge, abilities, skills, and experience of their personnel, commonly referred to with the broad but widely adopted term “competence”, while considering multiple factors such as job requirements and risks. Employee competences must be consistent with the level of knowledge and experience needed for the activities they perform, which implies that organizations should define clear competence criteria for each role and function. In details, Clause 7.2 expects organizations to define the competencies required for each role, including technical skills, process knowledge, and understanding of relevant quality standards. Employee competence should then be evaluated on a regular basis, for example through performance reviews, tests, or structured on-the-job observations, to verify whether individuals meet these predefined requirements. When gaps are identified, managers should provide targeted training or development programs so that employees can reach the required competence level and progress in their roles. It is also necessary to keep documented evidence of competence-related activities, such as training records, assessment results, and corrective actions taken, as these documents are essential for audits and for demonstrating compliance with ISO 9001:2015 expectations (BPR Hub, n.d.).

To fulfil these requirements, organizations can already assess relevant competences, skills, and qualifications during recruitment and selection, and subsequently provide structured, job-specific education and training to develop the competence profile required for each position (Bencsik, 2016). An employee may be authorized to work independently at a given workstation only when the necessary knowledge and experience have been demonstrated, preferably against predefined and documented criteria. From a managerial perspective, it is therefore useful to catalogue and classify the competences required at each workplace and to specify minimum acceptable competence levels in advance, as this supports systematic competence assessment, targeted development actions, and transparent deployment decisions.

Managerial decisions about allocating competent workers to workstations raise several questions about coverage, flexibility, and risk. Managers need to know whether all workstations can be staffed even when key workers are absent, how workflow continuity can be maintained during absences or turnover, and what level of coverage can be achieved under realistic constraints. Managers also need to know whether any backup options exist for each critical task, for example through cross-trained, multi-skilled or polyvalent workers who can

step in without compromising safety, quality, or throughput. Addressing these questions goes far beyond simple yes–no allocation decisions by the team leader, and instead requires a more systematic approach supported by competence or skills matrices, scenario analysis, and explicit resilience targets for the production system. A binary evaluation of worker capability is simple and fast to use as an input for substitutability decisions, but it does not provide sufficient detail to support truly optimal allocation of personnel to workstations. In industrial practice, multi-level competence scales in skills or competence matrices are widely used, typically distinguishing several proficiency levels (for example, from novice to expert or trainer) to better capture differences in operator capability and flexibility.

Beyond such discrete rating schemes, various continuous scales are also used in practice to quantify workers' capabilities, for example by incorporating observed operation times, speed, or delay patterns into performance indices (Szilagyi, 2015). In parallel, fuzzy-logic-based evaluation approaches have been introduced to capture uncertainty and gradual differences in human skills more realistically, thereby enabling more nuanced workforce allocation and management decisions in manufacturing systems (Váradi, 2025).

Inventories of knowledge elements and skills are often mapped and visualized in simple, easy-to-use formats, such as skills or competency matrices (Bencsik, 2016), to make capability information accessible for managers and team leaders. These visual tools help to summarize who can perform which tasks, at what proficiency level, and where gaps exist, thereby supporting everyday assignment decisions and targeted development planning. The matrix representation as shown in Figure 1 supports day-to-day allocation decisions on the shop floor by making the distribution of competencies across workers and workstations transparent. At the same time, it provides a structured data basis for further analysis, such as identifying skill gaps, planning cross-training, and evaluating the robustness of workforce coverage under different disruption scenarios (Váradi, 2023).

	Skill1	Skill2	Skill3	Skill4	Skill5	Skill6	Skillset #
Name1		1					1
Name2	1						1
Name3	1	1	1				3
Name4			1				1
Name5					1	1	2
Name6			1		1	1	3
Name7	1		1	1	1		4
Name8			1	1			2
Name9			1	1		1	3
Name10	1						1
Name11	1			1	1		3
Name12					1	1	2
Name13			1	1	1		3
Name14						1	1
Name15	1		1			1	3
# of people trained	6	2	8	5	6	6	

Figure 1

An anonymized example of a competence matrix, and bundary distributions for analysis

Source: the author's own edition based on (Váradi, 2023)

2 Method

The research questions guiding this study are twofold. First, how can a competency matrix be systematically designed and implemented as a visual tool that supports managerial decision-making in areas such as workforce allocation, competence management, and operational resilience? Second, what additional applications and documented uses of competency and skills matrices are reported in the literature specifically for industrial practice, for example in skills planning, targeted training design, succession planning, and resilience analysis of manufacturing systems?

The development of ideas to address the research questions was supported by generative AI tools used for idea generation and refinement. An example prompt for keyword generation was formulated as follows: "Act as a researcher in the field of industrial competency management, aiming to summarize the literature on the use of competency matrices or skills matrices. Using the block method, suggest a set of main keywords to search for, and construct a corresponding search string suitable for use in the Scopus database." The outputs were critically reviewed and validated by the author to ensure accuracy and adherence to academic standards.

An example output for search string for use in the Scopus database was structured as follows, combining the main concept blocks with Boolean

operators and field codes: (TITLE-ABS-KEY("competence matrix" OR "competency matrix" OR "skill matrix" OR "competence mapping" OR "skill mapping" OR "competency management" OR "competence portfolio")) and (TITLE-ABS-KEY(industry OR industrial OR manufacturing OR "workforce management" OR "employee allocation" OR "workforce allocation" OR "human resources")) and (TITLE-ABS-KEY("workforce resilience" OR "workforce flexibility" OR substitutability OR "employee turnover" OR "workforce fluctuations" OR "employee interchangeability" OR "operational stability" OR "workflow continuity")).

The search strings were subsequently simplified in order to broaden the query and increase the number of relevant results retrieved from the database. Similar queries were submitted to ResearchGate, and findings were added to the list.

In addition, web search engines, especially Google and Perplexity were used to identify examples of publicly available industrial applications of competence-matrix tools and related online resources, such as templates, software solutions, and implementation guides.

Parts of this paper were developed with the assistance of generative AI tools, including Perplexity, DeepSeek, Scopus AI, and LitMaps, which were used to support idea generation, enhance visualisation, and refine language use. All generated content was critically reviewed, edited, and verified by the author to ensure accuracy, originality, and compliance with academic integrity and ethical research standards.

3 Results

The origins of competence management can be linked to early work on the psychological properties of group versus individual learning, such as the experiments of Ghiselli on group performance in complex coordination tasks. In these studies, multiple groups were compared with individuals, and the findings suggested that group-level psychological characteristics, including openness and stability, play a critical role in explaining group learning performance, whereas individual traits alone are poor predictors of collective outcomes (Ghiselli, 1966).

McClelland proposed a different approach by arguing that traditional intelligence and aptitude tests are weak predictors of job performance and life success. Instead of relying on IQ scores, he advocated a shift toward testing for competencies, focusing on characteristics that are directly linked to effective behaviour in real work settings. In his paper, he fundamentally criticized IQ testing as the main selection tool and suggested that society should identify and measure specific, teachable competencies that predict real-world success, using

assessment methods closely related to actual job demands. In this context, competence was defined as an underlying characteristic of an individual, such as a motive, skill, self-concept, or body of knowledge, that enables effective performance in a particular role or situation (McClelland, 1973).

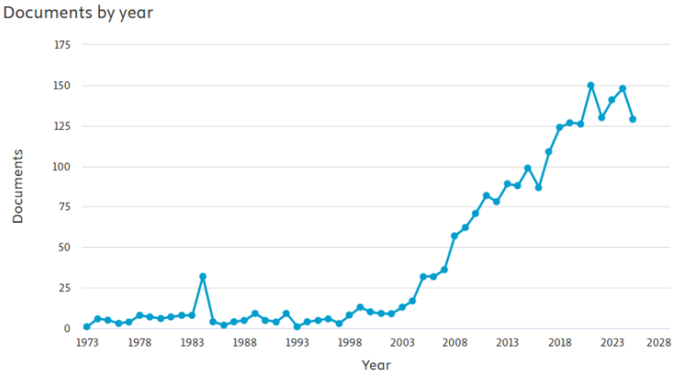

Figure 2

The evolution of annual citation count for McClelland's seminal work (McClelland, 1973)

Source: graph created with Scopus Citation overview function

McClelland's article has attracted substantial academic attention, accumulating 2239 citations by 2025 and gaining marked traction in the years following the millennium, as illustrated in Figure 2. The interrelationships among the top 100 most influential citing articles are visualized in Figure 3, highlighting how his original work has become a central reference point in the development of competence-based approaches in psychology, education, and human resource management.

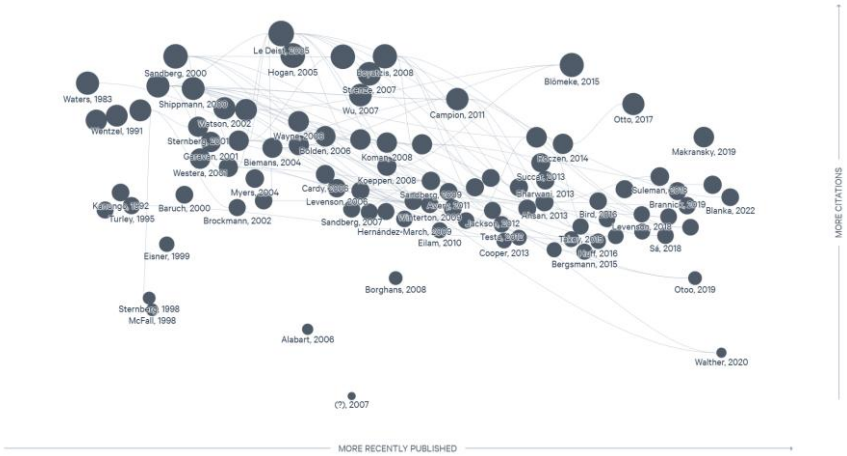

Figure 3

The top 100 most influential citing articles of McClelland's seminal work (McClelland, 1973)

Source: graph automatically created by LitMaps using .ris export of Scopus search results

After further restricting the Scopus search to industrial and manufacturing contexts, and excluding educational, healthcare, governmental, and other non-industrial applications, only a single paper was identified that explicitly addressed competency or skills matrices in a comparable way. In their study, Nizam et al. examine and further develop a skills-matrix system tailored to ready-made garment factories (Nizam et al., 2022). Their starting point is the observation that companies in this sector rarely use formal skills matrices and that existing evaluation practices are often manual, inaccurate, and insufficiently transparent to workers, which contributes to mistrust and dissatisfaction. The analysis focuses on three types of skills-matrix systems: manual (paper-based), semi-automatic (typically Excel-based), and fully automatic (software-based) solutions. The authors compare these variants using criteria such as time required and accuracy of feedback, ease of updating records, the granularity of the grading policy, and the transparency of managerial decisions and their impact on worker motivation and perceived fairness. They conclude that fully automatic, integrated systems enhance productivity and enable more precise evaluations through automatic calculations and data processing. This study pays relatively little attention to how such matrices can support day-to-day allocation decisions on production lines.

The research methods of Nizam et al. also include collecting data from diverse sources such as internet materials, blogs, books, and research reports (Nizam et

al., 2022). A similar multi-source approach is applied in the present study, which likewise integrates literature with practitioner-oriented and online resources to capture both academic and industrial perspectives. Randomly selected online materials, including blogs, consultancy white papers, and documentation from software solution providers appearing among the top Google search results, were also reviewed.

The simplest and freely accessible solutions typically offer Excel-based templates together with easy-to-follow instructions for constructing a basic competency or skills matrix on a really practical way (Miller, 2017). An additional advantage of such blog-based resources is that users and followers can comment on the posts, share questions or practical experiences, and thus collectively refine the proposed templates, methods and usage practices over time. Very similar description in various level of detail is posted in various internet sources, e.g. (Raoult, 2023), (Pritchard, 2022), and (Tamás, 2023). Some webpages offer a downloadable template at no cost, or after registration.

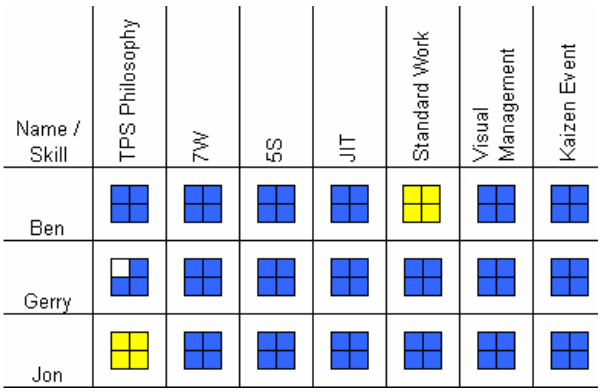

Figure 4
An example of a skill matrix with 5 levels of rating
Source: (Miller, 2025)

Apparently, various websites offer compiled material on competence or skills matrices for a small or no fee, including presentation-sharing platforms such as SlideShare. The content of these randomly selected sources is usually not verified with scientific rigor and often reflects only the specific industrial experience and practice of the individual authors, they might contain practical information.

Certain authors present case studies and applications of competency matrices outside industrial contexts, for example setting up team for a project (Furlan, 2023) (Tamás, 2023). Other applications are in high value adding activities, such as in healthcare, education, public administration, and non-profit

organizations. These works typically use competency matrices to support curriculum design, role profiling, governance, and succession planning rather than day-to-day shop floor allocation decisions. Many of these web sources also include a notable element of marketing, as they promote the authors' own consulting services, software products, or template packages alongside the conceptual discussion of competency matrices.

Following the preference for more complex software solutions noted by Nizam et al. (Nizam et al., 2022), an additional web search was run to identify representative providers of competence-matrix and skills-management systems. These vendors typically illustrate the practical use of their own solutions through detailed examples and offer extensive information packages on competencies, including predefined role profiles, grading scales, and reporting options.

A very compex guide to competency matrices is provided in two parts at ThinkEleven (Race, 2025). The article explains how competency matrices provide a structured way to map employees' skills, knowledge, behaviours, and proficiency levels to organisational goals, making them a central tool of competency management. It distinguishes between a skills matrix, which lists specific task-oriented abilities, and a broader competency matrix that also includes knowledge, behaviours, and attributes aligned with strategy. The matrix is presented as a practical instrument for finding skill gaps, planning resources, tracking performance, succession planning, and supporting workforce planning and productivity. Technology and dedicated competency management systems are highlighted as enablers for real-time updates, analytics, scalable assessments, and faster training needs analysis. The article also links competency matrices with tailored training, role definition, capability matrices, and employee engagement, arguing that together these elements maximise workforce potential and long-term organisational performance.

A solution specific to the manufacturing industry is provided by Cloud Assess, acompanied with an article (Gordon, 2025) that explains how a well-maintained matrix improves employee management, supports ISO-aligned compliance, enables early identification of technical skill gaps, and underpins continuous professional development and career progression . It outlines a practical, step-by-step approach to building a matrix: define key roles, list required competencies, assess current levels, highlight gaps, and create personalised training plans, with regular review and updates. Digital tools and integrated platforms are highlighted as essential for automating tracking, providing real-time dashboards, and turning skills data into strategic insights that strengthen workforce planning and operational resilience.

4 Discussion

Early work by Ghiselli and McClelland shifted attention from general intelligence tests to job-relevant competencies and group capabilities, creating the conceptual basis for later task-focused competence definitions and assessments in industrial environments. Over time, these concepts were translated into competence and skills matrices that show who can perform which standardised tasks and at what proficiency level, consistent with lean management's aim to reduce variability and with ISO 9001:2015 requirements to define, assess, and document personnel competence.

Across academic and practitioner sources, three patterns are visible: everyday practice is still largely dominated by simple Excel-based matrices and downloadable templates; there is a growing movement toward software-based, integrated competence-management solutions promoted by commercial providers and exemplified in work such as Nizam et al. and industry platforms like ThinkEleven and Cloud Assess; and, despite the broad uptake of these tools in industry, formal peer-reviewed research on competence matrices in industrial manufacturing remains limited, with only a single closely comparable Scopus-indexed study identified in the domain.

In this paper, workforce resilience means the ability of a production system to maintain required throughput, quality, and safety levels under common disturbances such as absences, turnover, and short-term changes in demand or product mix, and to restore performance quickly when critical operators are missing. Well-designed competence matrices support this resilience by using multi-level proficiency scales instead of simple binary "can/cannot" ratings, by making the depth of cross-training and the coverage of each workstation visible and measurable, and by enabling scenario analysis of substitution options (who can replace whom, and how many simultaneous absences the system can tolerate without violating key constraints). When embedded into lean and standardised work practices, these design choices help reduce mura by stabilising how standard work steps are staffed, provide a more robust basis for line-up and job-rotation decisions, and contribute to more stable, predictable operations even under fluctuating workforce conditions.

Managers should first define clear competence criteria and multi-level proficiency scales for each role or workstation, and maintain an up-to-date competence matrix at team level as a routine planning tool rather than a static document. They should embed the matrix in daily and weekly management routines by using it for line-up decisions, cross-training and job rotation planning, succession planning, and prioritising training investments, instead of consulting it only before audits. Where operations span multiple lines, shifts, or sites, managers should progressively adopt digital solutions that automate updates, reporting, and scenario analysis, while recognising that a

well-structured spreadsheet-based matrix can be an effective starting point in less complex environments.

Conclusions

The paper presents a literature-based overview of how competence matrices have evolved from early competence concepts into practical tools for visualising and managing workforce capabilities in industrial settings. Particular emphasis is placed on their role within lean manufacturing and standardized work, and on how well-designed matrices contribute to workforce resilience by supporting robust, flexible allocation of employees under disruptive conditions. The review highlights that competence matrices are widely used in industry and closely link lean principles, standardized work, and ISO 9001:2015 competence requirements, yet they remain surprisingly under-researched as formal management tools. It also shows that everyday practice is dominated by simple spreadsheets and commercial software solutions, while robust empirical evidence on their design choices and performance impact is scarce, even though multi-level, regularly updated matrices clearly offer greater workforce flexibility and resilience than static, binary or purely document-oriented approaches.

Although the practitioner-oriented web ecosystem offers a rich set of examples and templates for competence and skills matrices in addition to practical guides, the formal, peer-reviewed literature on this topic in industrial contexts remains surprisingly limited, indicating a research gap in linking practice to scientific evidence. Promising future research directions include quantitative studies that relate specific matrix characteristics to resilience indicators such as downtimes, bottlenecks, and recovery times after disruptions. Another potential research direction may study optimization and modelling approaches that use refined competency evaluations as input data for optimization or simulation models supporting robust workforce allocation and scheduling under uncertainty.

Possible future research includes comparing manual and software-based competence matrices in small and medium-sized companies and in large enterprises. Such studies could focus on how easy the tools are to use, how reliable the data are, and how they support management decisions. Another important direction is to study how employees feel when competence matrices are used for evaluation, promotion, and pay decisions. Empirical research could examine their perceptions of fairness, transparency, and motivation, and how these perceptions influence behaviour and performance.

This review has several limitations that should be acknowledged. It relies primarily on a single major scientific database for the formal literature search, and focuses deliberately on industrial and manufacturing contexts, rather than other sectors, and supplements academic sources with practitioner-oriented web

materials and vendor documents that are not peer reviewed and may contain unverified or marketing-driven claims or statements.

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