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The Transformation of Family-Owned Enterprises into Design-Intensive Firms

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Abstract

This study examines how family-led small and medium-sized enterprises (SMEs) with little or no design experience are transforming into design-intensive firms. Extant research allows us to understand the distinct capabilities of design-intensive firms. This study defines the capabilities of new design leadership, including the unique capabilities of design-intensive firms, to assist SMEs in their transformation to design-intensive firms. Furthermore, this study empirically evaluates the influence of individual family CEOs' characteristics and industrial structural factors on the design leadership capabilities in family-led SMEs. The findings show that the efficiency of developing design leadership capabilities is influenced by the family CEO's awareness of traditional design identity, and designers assist family CEOs in building a new network with interpreters and managing their knowledge of sociocultural models. A family CEO's exploitation of traditional design identity and designers' exploration of design renewal must be managed as a portfolio to transform a traditional SME into a design-intensive firm. This study has critical implications for family-led SMEs as it emphasises the importance of passing on a firm's traditional design identity and design renewal as a portfolio to the next generation of CEOs for the firm to transform into a design-intensive firm.

Key words

design-intensive firms, collaborative innovation, family businesses, small and medium-sized enterprises, design leadership capabilities, absorptive capacity.

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Introduction

Recent research has illustrated that design-intensive family-led firms and small-medium enterprises (SMEs) gain a significant competitive advantage through collaborative innovation with external professionals (Dell'Era & Verganti, 2010; Magistretti et al., 2019, 2020; Verganti, 2008). A design-intensive firm is one in which “design is not a complementary element but the focus of their activities” (Magistretti et al., 2020), and one in which designers are not only used for styling and problem-solving, but also play a role in leading the co-evolution of problem finding and problem-solving (Dell'Era et al., 2018). Design-intensive firms also have a complex network of external interpreters to balance their traditional design identity and design renewal (Dell'Era & Verganti, 2010; Verganti, 2017; Magistretti et al., 2019). The interpreters identify weak signals of change in sociocultural models and contribute to developing novel visions that become future trends (Dell'Era & Verganti, 2010; Verganti & Öberg, 2013; Verganti, 2008). Design-intensive firms use design as a collective of knowledge from the external designer and the interpreters.

Collaborative innovation is practical as it compensates for SMEs' limited resources (Diéguez-Soto et al., 2018; Feranita et al., 2017). Collaborative innovation is “a form of inter-firm relationship that involves exchanging and sharing resources such as financial capital, information, knowledge, and technology with external parties to achieve innovation” (Feranita et al., 2017). Rather than being planned, learning in SMEs is temporal and contextual, and is implemented through social relationships (Fernández-Mesa et al., 2013; Pittaway & Rose, 2006). Although collaboration with the external designer can provide a significant competitive advantage for family-owned SMEs, most still need to make design a core part of their business activities. Bringing in external design expertise requires the ability to identify the appropriate design expertise to bring in, which SMEs with little or no design experience lack (Acklin, 2013; Berends et al., 2011; Bruce et al., 1999; Chiva & Alegre, 2007). SMEs rarely have an in-house design department and lack a basic understanding of design (Berends et al., 2011), and designers are often viewed as a variable cost hired on a project-by-project basis (Berends et al., 2011; Bruce & Morris, 1994). Given that there are very few family-led SMEs that are design-intensive firms, understanding how family-led SMEs with little or no design experience transform into a design-intensive firm is critical. Hence, the research question of this study is to identify how a family CEO with little or no design experience absorbs external knowledge from collaborative innovation to transform into a design-intensive firm. A family CEO absorbing design capabilities is the first step in the transformation to design-intensive firms (Acklin, 2010, 2013). A family CEO is responsible for unifying ownership and operation in family-owned firms (De Massis et al., 2013). Therefore, corporate activities can be changed quickly and flexibly when the family CEO understands design and builds design capabilities. Design leadership capabilities have received extensive research attention as an absorptive capacity (ACAP) for design (Acklin, 2010, 2013). According to Acklin (2013), design leadership capabilities include formulating design strategies and new business hypotheses, bringing external design expertise into the firm, and allocating resources. Developing design leadership capabilities, however, does not enable family-led SMEs to transform into design-intensive firms as it excludes the distinctive capabilities of design-intensive firms. Therefore, this study defines new design leadership capabilities as a theoretical framework for family-led SMEs transitioning to design-intensive firms.

The remainder of this paper is organised as follows: Section 1 reviews extant literature on collaborative innovation with designers in SMEs, design-intensive firms and propose a theoretical framework regarding design leadership capabilities. Section 2 describes the methods used in this study. Section 3 presents the study's empirical findings, focusing on the relationship between the collaborative innovation process and design leadership capabilities. Finally, Section 4 discusses this study's theoretical and managerial implications and limitations.

1. Literature review

1.1. Collaborative innovation with external designers

Before the concept of open innovation was proposed, research on collaborative innovation has been discussed from resource-based, transactional, and relational perspectives, primarily as innovation is achieved by collaboration with external parties (Feranita et al., 2017). The concept of open innovation has led to a significant development in the debate over collaboration as a source of competitive advantage (Chesbrough, 2003). Open and collaborative innovation research in SMEs has primarily focused on technological innovation, its performance, technology transfer, resource limitation for R&D, and external collaborator networks (Feranita et al., 2017; Hossain & Kauranen, 2016; Usman et al., 2018; Diéguez-Soto et al., 2018). Conversely, innovation scholars have also focused on design-intensive industries as a collaborative innovation with external designers (D'Ippolito, 2014; Dell'Era & Verganti, 2010; Magistretti et al., 2019; Magistretti et al., 2020).

Since SMEs rarely have in-house design departments, collaborations with external designers are more common. A company's design processes are divided into two categories: collaborations with

internal design departments and collaborations with external design firms (Chiva & Alegre, 2007). External designers' participation in new product development enables SMEs to achieve problem-finding and problem-solving co-evolution through an iterative process of divergence and convergence (Berends et al., 2011). However, since SMEs lack a basic understanding of design and have limited access to design resources, using design effectively is a challenging task for such firms (Berends et al., 2011; Fernández-Mesa et al., 2013; Moultrie et al., 2007; Oakley, 1982). According to Bruce et al. (1999), design project failures can be attributed to: "lack of senior management commitment to design," "poor financing of projects," "incomplete design brief," and "inappropriate sourcing of design competencies." Combining a firm's design knowledge with knowledge gained from previous collaborations with designers is critical (Simoni et al., 2019). According to Bertola and Teixeira (2003), designers in Italian SMEs serve as 1) "knowledge integrators," facilitating the flow of technology between companies and integrating it into products, and 2) "knowledge brokers," internalising knowledge shared within the supply chain and local communities, including users. Collaborations with designers allow SMEs to absorb design expertise from external sources (Acklin, 2010). However, collaborating with external designers necessitates the ability to identify appropriate design expertise to be introduced in the firm. Therefore, examining how SMEs with little or no experience acquire design expertise from external sources (Dell'Era et al., 2018; Fernández-Mesa et al., 2013) is critical.

1.2. Design-intensive firm

Previous studies on design-intensive firms have primarily focused on SMEs in the Italian furniture and lighting industries. Dell'Era et al. (2018) discovered that 80% of products in design-intensive firms in the Italian furniture industry are developed in collaboration with external designers, and the ratio of collaborating with external designers to employees is as high as 16%. Design-intensive firms do not hire external designers on a project-by-project basis, but rather manage them as a complex portfolio of designers (Dell'Era & Verganti, 2010; Magistretti et al., 2019). Interpreters who analyse the sociocultural model and identify weak signals of change are also part of the collaboration (Verganti, 2008, 2017). Dell'Era et al. (2018) discovered that design-intensive firms have a "technological gatekeeper of cultural production" that brings knowledge held by external interpreters into the firm.

Verganti (2009) highlighted that top management plays a critical role in managing the complex portfolio of interpreters and the dialogue with them. The dialogue aims to create future scenarios, lifestyle propositions, and a strategic vision for a new product (Dell'Era et al., 2018). According to these studies, in family-led SMEs with little or no experience, a family CEO serves as a gatekeeper and a key to acquiring external knowledge from interpreters and blending the firm's knowledge from previous collaborations.

1.3. Theoretical framework: Design leadership capabilities

Acklin (2013) developed the design management absorption model (DMAM) as a process by which SMEs with little or no design experience could develop absorptive capacity (ACAP) for design practice. Previous studies on absorptive ACAP have examined knowledge acquisition from a firm's external network (Cohen & Levinthal, 1990; Zahra & George, 2002). The DMAM emphasises the importance of a family CEO's design leadership capabilities early in the process. Design leadership capabilities refer to capabilities in acquisition and assimilation as potential ACAP (PACAP) (Zahra & George, 2002). According to Daspit et al. (2019), the survival of a family firm is dependent on PACAP as the breadth of family members' knowledge is limited.

As stated previously, this study defines alternative design leadership capabilities that can assist a traditional firm in transforming into a design-intensive one. Verganti (2009) stated that the top management in design-intensive firms is a leader and provides a vision and direction for innovation. The top management is also responsible for directly engaging in a dialogue with external interpreters. Therefore, new design leadership capabilities required to transform a traditional family-owned SME

into a design-intensive firm include 1) the ability to build and manage a network of external collaborators, 2) the ability to formulate a design strategy by envisioning potential future scenarios, 3) the ability to identify new business opportunities, 4) the ability to source design expertise and combine it with the expertise of in-house employees, and 5) the ability to allocate in-house resources in the assimilation (Table 1).

Table 1. Comparison of design leadership capabilities.

	Design leadership capabilities for transforming into a design-intensive firm	Design leadership capabilities (Acklin, 2013)
Acquisition	To build and manage a network of external collaborators To formulate a design strategy by envisioning potential future scenarios To define hypotheses for new business opportunity	- To formulate a design strategy To define hypotheses for new business opportunity
Assimilation	To source design expertise and combine it with in-house team expertise To allocate in-house resources	To source design expertise and combine it with in-house team expertise To allocate in-house resources

Source: created by authors.

To summarise, a family CEO's acquisition of design leadership capabilities is critical to transforming SMEs with little or no design experience into design-intensive firms. Existing research, however, has not yet clarified how design leadership capabilities are acquired.

2. Methodology

2.1 Research design

The main objective of this study is to understand how a family CEO with little or no design experience can develop design leadership capabilities through collaborative innovation. The study investigates how collaborative innovation with external designers and interpreters can help family CEOs in small and medium-sized enterprises (SMEs) develop design leadership skills. To achieve this, an exploratory case study methodology has been adopted. This does not aim at statistical generalization, but rather at analytical generalization (Yin, 1984). The case study approach is ideal for understanding the dynamics of the process (Yin, 1984). Since there is a lack of research on how family-led SMEs with little or no design experience can transform into design-intensive firms, this study has chosen a critical case for analytic generalisation. The research strategy used in this study will help reveal the family CEO's black box between collaborative innovation and design leadership capability.

2.2 Empirical settings

This study focuses on FUXION, a design implementation support program launched by the Nagoya City government in Japan in 2020. The program aims to assist SMEs with little or no design experience. It includes a seminar that provides an overview of design fundamentals, which is conducted by Mitemo Co. Ltd. This professional consulting firm has been contracted by the Nagoya government to support the implementation of design management. Following the seminar, SMEs participate in collaborative workshops facilitated by the consulting firm, with the assistance of interpreters from various industries and professional designers. These external collaborators are recruited by Nagoya City through an open call for applications and then matched with SMEs by the consulting firm. Each team is comprised of four or five members, with the interpreters and designers supporting each team.

Table 2 presents the whole program. The first phase comprises a program with 7.5 hours of design, design methodology, and design management lectures. This phase encourages family CEOs to understand the general design process, design methods, and tools to broaden their knowledge before implementing collaboration. The second phase aims to develop design leadership capabilities required

for the firm to transform into a design-intensive one through pilot projects in which a family CEO collaborates with interpreters. The phase consists of four days of four-hour workshops, which include 1) the development of a vision based on the company's traditional identity and technology to identify a target user; 2) an iterative process of user observation, ideation, and rapid prototyping to establish and validate new business hypotheses; and 3) implementation of a solution and brand communication design.

Table 2. The collaborative innovation process in FUXION.

Phase	1	2
	Learning of • design process • design method • design tools	To develop a vision based on the company's traditional identity and technology to identify a target use
		An iterative process of user observation, ideation, and rapid prototyping to establish and validate new business hypotheses
		Implementa- tion of a solu- tion and brand communication design
PCACP	Prior knowledge of design (Ante- cedent of PCACP)	Acquisition
		Assimilation
Design leadership capabilities to transform into a design-intensive firm	Building and managing a network of external collaborators Formulating a design strategy by envisioning potential future scenarios Defining hypotheses for new business opportunities	Sourcing design expertise and combining it with in-house team expertise Allocating in-house resources

Source: created by authors.

In this study, two embedded subcases in which family CEOs participated in a pilot project were selected using replication logic (Yin, 1984). Table 3 presents an overview of the two family-led SMEs involved in the FUXION program that were selected for the study. These two CEOs were theoretically selected as cases in which design leadership capabilities were acquired efficiently through the process and cases in which they were not. By comparing the acquisition processes of these two CEOs, we discover the contextual factors that influence the efficiency with which design leadership capabilities are acquired.

Table 3. Case overview.

	Company A (Team A)	Company B (Team B)
Industry	Manufacturing	Manufacturing
Product	Rainwear	Wooden sofa frame
Year of establishment	1921	1976
No. of Employees	17	9
Generation of family CEO	3rd	2nd

Source: created by authors.

2.3 Data collection and analysis

This study gathers both primary and secondary data (Table 4). For primary data, semi-structured interviews lasting 45 to 60 minutes were conducted through ZOOM Videoconferencing platform between February 2022 and May 2022. In addition to the CEO, the interviewees were the designers who participated in each team and the experts and facilitators who participated in both teams for the triangulation.

Table 4. Data collection.

Source	Type of data	Evidence	Use in the analysis
Primary	First round: Semi-structured interviews	Two interviews with two CEOs 110 minutes 25 pages of transcript	Data on self-assessment of design process and design leadership capability
	Second round: Semi-structured interviews	Four interviews with the facilitator, the designers, and the interpreter 205 minutes 47 pages of transcript	Triangulating information from two CEOs.
Secondary	Miro, an online whiteboard	Two boards	Triangulating CEOs' self-assessment of design processes

Source: created by authors.

Table 5 presents the respondent profile. The criteria for developing design leadership capabilities were included in the questions. The facilitator, designers, and interpreters, as well as the family CEOs, were all interviewed. As secondary data, we examined Miro, an online whiteboard used by each team to conduct their online work. The data were used to verify project progress and to triangulate informants.

Table 5. Interviewees.

Participant ID	Role in FUXION team	Expertise
A	Facilitator	Design consultant
B	Leader in team A	Family CEO of Company A
C	Leader in team B	Family CEO of Company B
D	Collaborator in team A	Architect, Business consultant for SMEs
E	Collaborator in team B	Designer
F	Collaborator in teams A and B	Engineer

Source: created by authors.

3. Research results

3.1 Case description

Company A

Company A, which has extensive experience in the B2C industry, manufactures rainwear primarily for general consumers and firefighters. The desire to join FUXION stemmed from the family CEO's passion for reviving a traditional product, rainwear, for the fishing industry. According to the CEO,

"The reason why I joined FUSION this time is because it is the 100th anniversary of the company's establishment... I think one of the reasons is to go back to the basics again." (Participant ID:B)

At the beginning of the process, the designer took the lead in envisioning based on the company's traditional identity and technological advantages without the entrepreneur's passion. The vision matched the family CEO's passion, and the team discovered a meaningful direction for their new business in rainwear for the fishing industry. Collaborator D described this process as follows:

"At the time Fusion started, the family CEO originally said he wanted to make that fisherman's rainwear... The rainwear for fishermen is quite compatible with our new vision, so we thought it would be a good idea to develop rainwear for fishermen." (ID:D)

The team then attempted to develop a solution for fishermen's rainwear, but the facilitator recommended that they stop their development process and conduct a user observation instead. Facilitator A described this process as follows:

"From there, they were already trying to create some kind of solution, and I stopped them... Don't take anything with you, just observe. And then the rest of the time, you can go to the site and see what's not related to that, like what they're using, what they're talking about, what kind of work they're

doing, not how the rainwear is used, but how they're living, how they're working, what they're talking about while they're working. I told them to observe.” (ID:A)

As a result, the team developed a new business hypothesis based on user observations at three different sites. Furthermore, the team tested the hypothesis iteratively by building prototypes and showing them to customers while continuing to observe them. According to collaborator D,

“We have been making concept catalogues, which show the concept of the business we are considering, and then showing them to various clients to elicit their specific requests.” (ID:D)

Concurrent with user observation, technical solution development and cost simulation were carried out within a short span of time. This was also an iterative process.

“We have been working on verifying the technical issues. ...We have made an income/expense simulation, showing the cost of production and SG&A expenses. We also examined whether or not the fabric lots would actually go into production, whether or not too much inventory would be produced, and discussed how much we should set the selling price. Well, it was like this was repeated over and over again.” (ID:D)

Company B

Company B is a subcontractor that manufactures wooden sofa frames for furniture manufacturers. The company has been in the B2B industry and has no products sold directly to consumers under its own brand. While the company had technological advantages in manufacturing processes, it was unaware of the importance of the traditional identity that had been cultivated. Even the CEO of the company did not have much design experience and did not understand the importance of envisioning. According to the CEO,

“To be honest, as a subcontractor for a manufacturer like ours, I never have the opportunity to work with or talk to designers. So, I really only have a vague idea of what a designer does.” (ID:C)

In contrast to Company A, Company B did not decide what direction to take during the envisioning stage based on the family CEO's passions and the company's traditional identity. Instead, the family CEO of Company B asked the company's team members to be creative. As a result, only technical constraints were considered, solution development was initiated, and ideas diverged. Collaborator F described this process as follows:

“It started with an idea that I liked and that someone would be happy if I made something like this or something like this.” (ID:F)

Due to a lack of direction for ideation, the collaborators were forced to rely on their inherent ideas, and their respective expertise was underutilised. As a result, ideas diverged without any selection criteria, and time passed without a user setting for observation. During the ideation phase, the FUXION process was recommended for conducting user observation and iteratively establishing and testing business hypotheses. However, because no user observations were conducted, the validity of the emerging ideas was not verified, and a lack of vision also prevented idea convergence. Facilitator A described this process as follows:

“The FUXION workshop was designed to ask the participants to use the company's resources to find users who might be able to provide the product, but he did not take that action at that point. Well, without being able to make a decision, the idea just kept spreading...Teams that are successful in design thinking...have learned from observing their customer. Teams that are not driven by design thinking end up building a castle in the air or discussing within the team. In this way, the direction of the project is not determined at all.” (ID:A)

Time constraints prompted the convergence of ideas and forced the team to narrow down its product offerings, as FUXION had set a goal of exhibiting at the show. Therefore, CEO B revealed to the team his intrinsic ideas, which he had concealed during the process. In the words of collaborator F:

“Everyone was getting more and more attached to their own ideas, and I thought it would be difficult to come to a consensus, but in the end, during the discussion, he [family CEO B]...had this idea

before the FUXION started. And he disclosed it to us. ...We decided to adopt the president's idea because we had to get results in the first three months.” (ID:F)

The team received much positive feedback from users after deciding on and exhibiting the idea at the show. As a result, family CEO B realised the importance of taking an experimentalist approach to the process and learning from failure. Through a series of FUXION experiences, family CEO B understood that vision determines the direction of subsequent product ideation and brand communication. In other words, he learned the process of strategically using a design from the failure of this design process. Family CEO B and team member F described the importance of iterative processes as follows:

“After I decided that I wanted to submit my work to an exhibition and started preparing for it, I realised that direction is important, and that's what I realised, so that's the biggest lesson for me.” (ID:C)

“We might have learned a little more if we had done it once, failed, and repeated the process twice.” (ID:F)

3.2. *Design leadership capabilities*

Table 6 presents how far the family CEOs have progressed in their design leadership capabilities. FUXION enabled family CEO A to understand and practice design leadership capabilities step-by-step throughout the process, whereas family CEO B, who did not follow the program, understood the significance of design leadership capabilities after the entire process was completed through introspection.

Building and managing a network of external collaborators

Company A had previously participated in several collaborations. However, most of these collaborations were for marketing existing products or developing manufacturing solutions. Therefore, the company had no experience in design-intensive collaborations. Company B was also a subcontracting business with little opportunity to design its own products as customers provided the necessary specifications. Both family CEOs did not fully understand the design practice in a single process due to practising design through the process. They described their understanding of design as follows:

“I think the designer's presence was probably more important in the FUXION, but to be honest, I could not utilise the designer to that extent.” (ID:B)

“Through FUXION, I think I have gained a vague idea of the wide variety of fields in which designers work. I haven't actually done the actual work that many times, so there are still things I don't understand, but I think I clearly understand better than I did before I participated.” (ID:C)

Due to a lack of a deep understanding of design, the family CEOs could not acquire the capability to build and manage a network of external collaborators on their own.

“I believe that we cannot survive unless we collaborate with outside designers and brand ourselves, and I intend to do so, but I am not sure I have quite figured out how to work with them yet.” (ID:B)

“I think it would be difficult.” (ID:C)

Family CEO B, a subcontractor, had a lower efficiency in acquiring new knowledge due to the narrower breadth of previous knowledge. Because product specifications are specified by the customer for subcontractors, acquiring limited technical information for developing solutions takes precedence over acquiring broad domain knowledge on a daily basis. According to designer E,

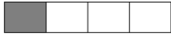
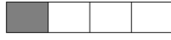
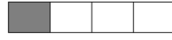
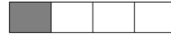
“Putting it simply, it may be that overwhelming lack of knowledge. Since he [family CEO C] keep on subcontracting. I think maybe there were times when he didn't know where to go, and even if he did go, he did not know what to ask.” (ID:E)

In contrast, the following references clarify that both family CEOs developed the capability to build and manage a network of external collaborators indirectly through the presence of designers as intermediaries.

“Our team was fortunate to have the designer as the team leader, who facilitated the team well, and I feel that we were able to draw out the knowledge of each member.” (ID:B)

“The designer is good at involving various people in his work, and we are still asking for his support... I think it would be good for small businesses to work in that way.” (ID:C)

Table 6. Evaluation of design leadership capabilities.

PACAP		Acquisition		Assimilation	
Design leadership capabilities	Building and managing a network of external collaborators	Formulating a design strategy by envisioning future scenarios	Defining hypotheses for new business opportunities	Sourcing design expertise and combining it with in-house team expertise	Allocating in-house resources
Family CEO A	Capability understanding is achieved. Practice is possible with an intermediary and successful.	Capability understanding is achieved. Practice is possible and successful.	Capability understanding is achieved. Practice is possible and successful.	Capability understanding is achieved. Practice is possible and ongoing.	Capability understanding is achieved. Practice is possible and successful.
Progression bar					
Family CEO B	Capability understanding is achieved. Practice is possible with an intermediary and successful.	Capability understanding is achieved. Practice fails.	Capability understanding is achieved. Practice fails.	Capability understanding is achieved. Practice is not started.	Capability understanding is achieved. Practice is not started.
Progression bar					

Source: created by authors.

Formulating a design strategy by envisioning future scenarios

Before joining FUXION, both companies considered design to be an add-on to product development rather than a core corporate activity. FUXION enabled both family CEOs to fully comprehend the significance of creating and instilling a vision within the company to strategically create and execute new businesses. Both family CEOs described their design strategies as follows:

“Design management is similar to visionary management based on vision. The vision is drawn by design. Working for a company that develops rainwear is not primarily about making money, but about solving social issues in the world by achieving the vision we have created.” (ID:B)

“I need to be more clear about which direction I am going in, or I will not be able to set a direction for my exhibition preparations. I realized at the time of the exhibition that I should have decided on my vision at an earlier stage.” (ID:C)

Family CEO A was also successful in strategically incorporating the company’s vision into the core of its activities, and even reviewed existing businesses that were not aligned with the design strategy. In the words of collaborator D,

“I think that he was able to understand the importance of vision tremendously... I got a bit of an impression that the idea that business strategies should be followed accordingly is something that was naturally acquired.” (ID:D)

Conversely, Family CEO B went into ideation without envisioning, resulting in many ideas. His team repeated the process of creating and testing several prototypes. As a result, too much time was spent on the prototyping cycle rather than implementing a vision-based strategic process. Family CEO B describes this as follows:

“Now, I understand now that it would be difficult in terms of resources to make this and that, and to attempt to research this and that on-site, but when we started, I thought that maybe we should try making just a little bit of everything and sell them all.” (ID:C)

He did not develop the capability within the process to the point where he could put it into practice, as he understood the importance of strategy much later, after the ideation process had failed without an appropriate vision.

“If there is no one who agrees with the same kind of great vision, such as issues that I want to solve for the future that I want to achieve with them, telling you that they want to do it together with you—an established mechanism like that, then the team wouldn't function. This is what has been really bothering me the most about the team at this point.” (ID:C)

Defining hypotheses for new business opportunities

Family CEO A had previously developed business hypotheses based on intuitive ideas, with no user observations or socio-cultural model analysis. According to facilitator A,

“They said, ‘We're going to make a product, take it to the customer, and get feedback from the customer.’ And I said, ‘Well, no. ...Don't take anything with you, just observe.’ I told them to observe how they live, how they work, what they talk about while they work.” (ID:A)

As a result, family CEO A recognised the significance of beginning with user observations when developing a new business hypothesis. In the words of the CEO,

“What I learned from going to the field was that ... what kind of problems do fishermen have besides rainwear ... what is their daily schedule, etc.? When we go fishing together on a fishing boat, there is a lot of time spent not fishing. We can talk about a lot of things at these times.” (ID:B)

In contrast, Family CEO B could not identify a targeted user and conduct user observation based on their vision. Therefore, new business hypotheses were developed under time constraints rather than user constraints. However, with the facilitator's continuous support, they understood the importance of taking an experimental approach and learning from mistakes while developing new business hypotheses. According to the facilitator,

“In his case, he still wants to be convinced and move forward. So, in order to be convinced, he first sold the product experimentally to see how users reacted. He tried to see the reaction of who would be interested and then approach them. A change in him occurred, like he would move forward even slightly.” (ID:A)

Sourcing design expertise, combining it with in-house team expertise, and allocating in-house resources

Both family CEOs recognised that their current organisational structures are incapable of incorporating design into the core of their operations. This has prompted them to work on specific organisational reforms.

“Engaging in new innovation activities while conducting sales for existing customers would be best if we could do that, but I think it would still be a bit difficult. We were inevitably overwhelmed by the need to deal with conventional customers, so we created a section dedicated to innovation to prevent this from happening.” (ID:B)

“One thing I am considering is to completely separate the new business development organization from the company...I think it would be easier for the time being if the new business development organization were to be completely separated from the company...if it were to become a sales, marketing, and development company, and manufacturing were to be outsourced from there.” (ID:C)

Both CEOs recognize that employees involved in design activities must break away from the routines of their current businesses to make design strategy the core of their activities. Family CEO A has already established a specialized department and has begun to develop new businesses with design at their core. Following the completion of the process, the newly acquired external knowledge in the department is shared with other departments, resulting in improved internal performance. In the words of the facilitator,

“By giving feedback to the sales department about the opinions we have heard from outside, in order to make them understand, perhaps it will lead to achievements after a while.” (ID:A)

4. Discussion

This study aimed to investigate how a family CEO with little or no design experience builds design leadership capabilities from collaborative innovation. The findings revealed that the efficiency of developing design leadership capabilities is likely to be influenced by a family CEO's awareness of their firm's traditional design identity, which refers to an attempt to increase the market recognition of a traditional product long-term collaborations with existing interpreters (Magistretti et al., 2019). During collaborative innovation, Family CEO A successfully developed design capabilities and practiced design-intensive collaborations, whereas family CEO B understood the significance of the capabilities through introspection much after the completion of the entire process. A traditional design identity works as a problem search frame, defined as “the boundaries of the interest of firms and individual innovators to shape and direct problem-finding activity” (Garbuio & Lin, 2021, p. 706). Ideas become overcrowded because the constraints that determine the meaningful direction of ideas do not exist without a problem search frame (Verganti, 2017). Family CEO B, amid a proliferation of ideas, could not determine which knowledge was critical to his company. Given that acquisition is influenced by the perceived value of externally imported knowledge, traditional design identities influence the perception of whether new knowledge from external collaborators is helpful for the company (Todorova & Durisin, 2007). The awareness of traditional design identity, being internal awareness (Cohen & Levinthal, 1990; Saad et al., 2017), enabled family CEO A to blend the firm's existing knowledge with the knowledge gained from collaborations with the interpreters within the process. This may demonstrate that awareness of traditional design identity improves the efficiency with which CEOs acquire relevant knowledge from the interpreters, and it positively impacts the development of design leadership capabilities. Meanwhile, adhering to traditional design identities impedes acquiring new, broader knowledge. The two family CEOs' practices revealed that the ability to build and manage a network of external collaborators is only acquired through intermediaries. Due to their limited knowledge breadth, both the family CEOs failed to recognise the value of the interpreters' knowledge regarding sociocultural models unrelated to the traditional design identity without the intermediaries. According to Rondi et al. (2019), family-led SMEs are traditional and conservative, and their acquisition capability is influenced by their existing knowledge and experience (Boyd & Hollensen, 2012; Zahra & George, 2002). The findings of this study suggest that design renewal, defined as the ability to continuously refresh a network with interpreters (Magistretti et al., 2019), depends on collaboration with an experienced designer in family-led SMEs with little or no design experience. While design renewal works as external awareness (Cohen & Levinthal, 1990; Saad et al., 2017), the designers serve as knowledge transfer agents and integrators across industries (Bertola & Teixeira, 2003; Hargadon & Sutton, 1997), helping family CEOs to build a new network with interpreters and manage their knowledge of sociocultural models. Thus, this study demonstrates that, in family-led SMEs with little or no design experience, the exploitation of traditional design identity by a family CEO and exploration of design renewal by the designers must be managed as a portfolio to transform the firm into a design-intensive organisation (Magistretti et al., 2019; Magistretti et al., 2020; Dell'Era & Verganti, 2010). The portfolio construction, however, depends on the long-term accumulation of multiple collaborations. In this regard, it is critical for a family-led SME to pass on its traditional design identity and design renewal as a portfolio to the next generation of CEOs to transform the firm into a design-intensive one. According to several major studies on succession, there is limited research on the intergenerational management of the portfolio of traditional design identity and design renewal (Fletcher et al., 2012; Handler, 1994; De Massis et al., 2008). In their seminal study, Magistretti et al. (2019) discovered that the balance of traditional design identity and design renewal differs depending on the

type of family involvement. Magistretti et al. (2020) also found that when family-based ownership transitions to a fund-based one, the balance of design tradition intensity and depth shifts. Thus, future studies must examine how to build and manage the process of intergenerational portfolio succession of family-led SMEs with little or no design experience, as succession in SMEs is a process that must be planned systematically (Le Breton-Miller et al., 2004; Sharma et al., 2003; Umans et al., 2021).

Another finding of this study is that when the envisioning process is inefficient, time constraints become critical to the design process. Other constraints for idea convergence are required without constraints from traditional design identity. In such cases, DT strategically employs user observations to determine the direction of ideas. However, subcontractors with no design experience cannot identify a target user based on their traditional design identity. Although extant research on DT elucidates the challenges of implementing DT with a determined user (Carlgren & BenMahmoud-Jouini, 2022; Carlgren et al., 2016), the problem of being unable to identify users has not been examined. Hence, this study concludes that one of the most critical challenges in the transformation of SMEs without design experience into design-intensive firms is determining what constraints to use to identify users without a traditional design identity. Previous studies have found that time constraints positively impact design creativity (Mehta & Zhu, 2016). According to April et al. (2019), when there is sufficient time, there is more flexibility in idea generation, allowing for exploration and experimentation; however, when time is limited, disciplined and focused actions are implemented.

Nevertheless, as highlighted by Verganti (2017), ideation without a vision eventually results in the overcrowding of ideas that cannot be converted into meaningful business plans. Hence, DT conducts observations to select ideas relevant to the user. Therefore, it is critical in the design practice of a subcontractor SME with no design experience to actively set time constraints from the beginning to elicit disciplined and focused action rather than disordered divergence of ideas.

Conclusions

This study has significant managerial implications for CEOs of family-owned SMEs as it emphasises the importance of developing a vision and design strategy based on a firm's traditional design identity, while leaving the building and management of an external collaborators' network, as well as design renewal, to an experienced designer. Because the design strategy is based on a traditional design identity dependent on the family's distinctive resource, it is relatively easy for family CEOs with no or little design experience to gain capability in design strategy. However, given that the ability to build and manage a network with external interpreters is dependent on the broader knowledge gained from design practices in various industries, it is difficult for family CEOs to develop this capability in a short duration as family-owned SMEs are conservative and traditional (Rondi et al., 2019). Since family influences in family-owned SMEs have advantages and disadvantages (Zellweger et al., 2010), CEOs must focus on the advantages derived from the firm's traditional design identity, allowing experienced designers to compensate for the disadvantages.

Furthermore, government agencies and design consultant firms that support SMEs must strive to match SMEs with experienced designers capable of building and managing an external collaborators' network and building a portfolio of traditional design identity and design renewal. The portfolio is built through the accumulation of multiple design projects rather than short-term initiatives. This study aimed to provide family CEOs with a short-term experience of a design-intensive firm's design process. However, SMEs lack access to design resources and skills to identify the appropriate design expertise to hire (Berends et al., 2011; Fernández-Mesa et al., 2013; Moultrie et al., 2007; Oakley, 1982). Therefore, in addition to providing short-term assistance, government agencies must foster long-term collaborations between skilled designers and SMEs to assist family CEOs in building and managing their portfolios in the long run.

This study has certain limitations. First, this study does not clarify how to make envisioning work when the envisioning process fails in the absence of a company's traditional identity. The case study in this study demonstrates how time constraints can act as a catalyst for idea convergence and promote a user-centred design thinking process. However, as in the inside-out process of Verganti (2017) and the outside-inside-out process of Goto et al. (2020), envisioning can be implemented without relying on the traditional identity and by using the intrinsic values of individuals as well as team and external interpreter criticism. The next challenge for future research is to integrate these various envisioning processes into the process and evolve it into a flexible program capable of responding flexibly to SMEs while considering the structural factors of their industries.

Second, the process of collaborative innovation, in this case, is yet to enable family CEOs to develop the capability to build and manage a network of external collaborators and a portfolio of traditional design identity and its renewal. The portfolio is constructed based on previous design practice, and it is impossible to construct a portfolio solely from short-term projects. Therefore, this study suggests that SMEs with no design experience can compose their portfolios by hiring designers with extensive design experience as intermediaries and substituting their portfolios. This proposal opens up new research avenues. Theoretical issues concerning the matching of designers and SMEs, such as what types of designers can assist SMEs in composing their portfolios, should be addressed by future studies.

Third, the case study tested the theory of design leadership capabilities for the aim of analytical generalization. Design thinking is becoming more widespread in SMEs, but cases of attempted transformation to design-intensive firms are still rare. Hence, it is a limitation that this study has not yet been able to be followed up with replication logic. However, as a first step, this study will contribute to the expansion of workshops for acquiring design leadership capabilities and attempts to transform the firm into a design-intensive firm. In the future, we will test the validity of the theory by following up the case with replicated logic.

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Does Domestic Investment Have a Role in An Economy? An Analysis of the Connection Between CO₂ Energy and Growth in the US and Canada

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Abstract

This study examines the relationship between domestic investment, economic growth, and carbon dioxide (CO₂) emissions in the United States and Canada from 1990 to 2021 using ARDL bound testing. The findings reveal a long-run relationship between the variables in both countries. In the US, short-run results show a positive link between domestic investment and CO₂ emissions, while economic growth has no significant impact. In the long run, only domestic investment positively influences CO₂ emissions. Other factors such as trade openness exhibit positive short-run effects but long-run negative relationships with CO₂ emissions, while fossil fuel consumption positively impacts emissions. Granger causality tests reveal bidirectional links between fossil fuel consumption and CO₂ emissions, and a unidirectional causality from trade openness to CO₂ emissions in the US economy. In Canada, positive short- and long-term connections exist between domestic investment and CO₂ emissions. FDI and economic growth exhibit mixed short-run effects on emissions but positive long-term impacts. Fossil fuel consumption negatively affects emissions in both the short and long term, while trade openness shows a positive long-term effect. The findings stress the need for targeted policies to balance economic growth, investments, and environmental sustainability, including promoting renewable energy, sustainable trade, and clean technologies.

Key words

CO₂ emissions, economic growth, domestic investment, fossil fuel, FDI.

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Introduction

Carbon dioxide (CO₂) emissions have emerged as a critical global challenge with profound implications for environmental sustainability, public health, and economic development. As the primary greenhouse gas responsible for trapping heat in the Earth's atmosphere, CO₂ emissions play a significant role in driving climate change, contributing to rising global temperatures, melting ice caps, sea level rise, and extreme weather events (Blunier and Brook, 2001). The escalating levels of CO₂ emissions are primarily attributed to human activities, particularly the combustion of fossil fuels for energy production, industrial processes, and transportation (Carl-Friedrich et al., 2022). Recent scientific evidence emphasizes the urgency of addressing CO₂ emissions to mitigate the worst impacts of climate change and safeguard the planet for future generations. The Global Carbon Project reported

a record high of 36.4 billion metric tons of CO₂ emissions in 2019, predominantly originating from the energy sector (Corinne et al., 2020). This relentless increase in CO₂ emissions poses a significant challenge to international climate goals, such as those outlined in the Paris Agreement, which aims to limit global warming to well below 2 degrees Celsius above pre-industrial levels (Joeri et al., 2016). The impact of CO₂ emissions extends beyond environmental concerns to encompass social and economic dimensions. Climate change induced by CO₂ emissions exacerbates existing vulnerabilities, disproportionately affecting marginalised communities and exacerbating social inequalities (Blunier & Brook, 2001). Moreover, the economic costs of climate change, including damage to infrastructure, disruptions to supply chains, and increased healthcare expenses, pose significant risks to global prosperity (Solomon, et al., 2017). Recent advancements in scientific research have provided details into the complexity of CO₂ emissions and the challenges associated with mitigating them. Studies have examined the drivers of CO₂ emissions, including population growth, economic development, energy consumption patterns, and technological advancements (Davis, 2018). Additionally, research has explored the effectiveness of various mitigation strategies, such as renewable energy deployment, energy efficiency improvements, and reforestation efforts, in reducing CO₂ emissions and transitioning to a low-carbon economy (IEA, 2020; Felix et al., 2019). Moreover, energy transition efforts in regions such as the European Union, as highlighted in the energy transition in the EU briefing by the European Parliament, exemplify concerted efforts towards achieving climate neutrality by 2050, aligned with the European Green Deal. The briefing emphasises the significance of transitioning the energy sector, the largest source of greenhouse gas emissions in the EU, towards a net-zero economy. The economies of the United States and Canada are deeply intertwined with the issue of CO₂ emissions, given their significant contributions to global emissions. Both countries rely heavily on fossil fuels for energy production and transportation, leading to substantial carbon footprints. Recent studies have shown that the United States and Canada are among the world's largest emitters of CO₂ per capita, highlighting the magnitude of their impact on global emissions (World Bank, 2021). The extraction, production, and consumption of fossil fuels not only drive economic growth but also generate CO₂ emissions, posing a complex challenge for policymakers seeking to balance economic development with environmental sustainability (EPA, 2021). Despite the importance of domestic investment, economic growth, and environmental sustainability, there is a lack of comprehensive research that simultaneously examines the interactions among these factors, particularly within the specific contexts of the US and Canada. Given the significant economic and environmental implications of these countries' policies and practices, there is a pressing need for empirical studies that shed light on the complex relationships between domestic investment, economic growth, and CO₂ emissions. The research problem lies in comprehensively examining the relationship among domestic investment, economic growth, and CO₂ emissions in the US and Canada. The study seeks to answer the following research questions: What is the causal relationship between domestic investment, economic growth, and CO₂ emissions in the US and Canada? How do variations in domestic investment patterns impact economic growth and CO₂ emissions differently in the US and Canada? The study answers these questions through the Autoregressive Distributed Lag (ARDL) method, which helps to capture the short-and long-run relationships among these variables. This study's findings seek to provide valuable insights for policymakers, businesses, and civil society stakeholders to help them design strategies that promote sustainable development while fostering economic prosperity in both nations. The outline of this study is as follows: Section 2 is a literature

review, Section 3 includes the materials and methods, Section 4 is the results and discussion, and Section 5 is the conclusion.

1. Literature review

The nexus between energy consumption, carbon emissions, and economic growth is a topic of significant interest and importance in the field of environmental economics and sustainable development. Research in this area has focused on understanding the complex relationships among these variables and their implications for policy-making and economic prosperity. Moreover, the role of domestic investment in shaping these dynamics has emerged as a critical factor that warrants further investigation. The literature emphasizes the need for further research to better understand the relationships between energy consumption, carbon emissions, economic growth, and domestic investment. Addressing these gaps in knowledge can contribute to evidence-based policy-making and foster sustainable development pathways in the United States, Canada, and beyond.

1.1 *Energy Consumption, Carbon Emissions, and Economic Growth*

Energy consumption, carbon emissions, and economic growth are interconnected components of modern industrial societies, each exerting influence on the others. Research exploring their relationships spans various disciplines, from economics to environmental science. The nexus between these factors is complex, with multiple feedback loops and dynamics shaping their interactions. Numerous studies have delved into the connection between energy consumption and economic growth. Energy is a fundamental input in production processes, driving industrialization, infrastructure development, and technological innovation (Stern, 2000). Soytaş and Sari (2003) found empirical evidence suggesting that energy consumption Granger causes economic growth, particularly in developing countries. This implies that energy availability and utilization are crucial drivers of economic activity. However, economic growth often comes at the expense of increased carbon emissions. As economies expand, energy demand rises, leading to greater emissions of greenhouse gases. The Environmental Kuznets Curve (EKC) hypothesis offers a theoretical framework for understanding this relationship. Initially, economic growth is associated with rising emissions, but as societies become wealthier, they tend to adopt cleaner technologies and reduce emissions (Grossman & Krueger, 1995). Nonetheless, empirical studies provide mixed evidence regarding the validity of the EKC hypothesis, with some supporting its predictions (Cole, 2004; Haider and Amira, 2023) while others refuting it (Holtz-Eakin & Selden, 1995; Dogan & Seker, 2016). Energy efficiency emerges as a critical factor in decoupling economic growth from emissions growth. Improving energy efficiency can mitigate carbon emissions while sustaining economic development (Sharif et al., 2023). Investments in energy-efficient technologies, renewable energy sources, and cleaner production processes can reduce carbon intensity and enhance resource productivity, leading to more environmentally sustainable and economically resilient growth trajectories (Apergis & Payne, 2010; Ozturk & Acaravci, 2010). Policy interventions play a crucial role in shaping the relationship between energy consumption, carbon emissions, and economic growth. Governments worldwide are increasingly adopting measures to promote clean energy and mitigate climate change. Carbon pricing mechanisms, such as carbon taxes or cap-and-trade systems, aim to internalize the social and environmental costs of carbon emissions, incentivizing businesses and consumers to transition towards low-carbon alternatives (World Bank, 2018). Additionally, investments in clean energy infrastructure, research and development, and regulatory frameworks are essential for fostering

innovation and facilitating the transition to a low-carbon economy (European Commission, 2019; IEA, 2021).

1.2 Domestic Investment, Economic Growth, and CO2 Emissions

Domestic investment is widely recognized as a critical driver of economic growth and development. Scholars such as Romer (1986) argue that investments in physical and human capital lead to productivity gains and technological progress, fostering long-term economic prosperity. Barro (1991) emphasizes the importance of investment in infrastructure, education, and innovation in stimulating economic growth. However, the impact of domestic investment on environmental sustainability, particularly in terms of CO₂ emissions, is a subject of ongoing debate. Research on the relationship between domestic investment and CO₂ emissions yields mixed findings. While investment in energy-intensive industries and infrastructure may initially contribute to emissions growth, technological progress and efficiency improvements can mitigate these effects over time (Nadya & Daryn, 2022). However, empirical evidence regarding the direct impact of domestic investment on CO₂ emissions is inconclusive. Some studies suggest a positive relationship (Ang, 2007), while others find no significant correlation (Halicioglu, 2009). Furthermore, economic growth has long been associated with increased CO₂ emissions. The Environmental Kuznets Curve (EKC) hypothesis posits an inverted U-shaped relationship between income and environmental degradation, suggesting that as economies develop and reach higher income levels, they become more environmentally conscious and adopt cleaner technologies (Grossman & Krueger, 1995). However, empirical studies provide mixed evidence regarding the validity of the EKC hypothesis, with some supporting its predictions (David, 2004) while others refute it (Wang & He, 2019). The complexities of the relationship between domestic investment, economic growth, and CO₂ emissions extend beyond simple causal links. Factors such as the composition of investment, technological innovation, and policy interventions play crucial roles in shaping emission trajectories. For example, investments in renewable energy and energy efficiency can promote sustainable growth while reducing emissions intensity (Zhikang & Weisheng, 2023). Similarly, the adoption of stringent environmental regulations and carbon pricing mechanisms can incentivize businesses to invest in cleaner technologies and practices (Ugur, 2018). Moreover, the impact of domestic investment on CO₂ emissions may vary across different sectors and regions. Energy-intensive industries, such as manufacturing and transportation, are more likely to contribute to emissions growth, whereas investments in service-oriented sectors may have lower environmental footprints (Berna and Gülin, 2020). Additionally, regional disparities in economic development and energy infrastructure can influence emission patterns, highlighting the importance of context-specific analyses in understanding the relationship between investment, growth, and emissions (Kao & Wan, 2017). Understanding the relationship between domestic investment, economic growth, and CO₂ emissions is essential for designing effective policy interventions to promote sustainable development. Policymakers should prioritize investments in renewable energy, energy efficiency, and clean technologies to decouple economic growth from emissions growth (Sovacool & Dworkin, 2015). Additionally, implementing carbon pricing mechanisms, such as carbon taxes or cap-and-trade systems, can incentivize low-carbon investments and encourage businesses to internalize the social and environmental costs of CO₂ emissions (Ugur, 2018).

1.3 Energy-Growth-Emission Dynamics in the United States

The relationship between energy consumption, economic growth, and carbon emissions in the United States has been the subject of extensive research, reflecting the country's significant role in

global energy markets and its impact on climate change. This literature review aims to provide a comprehensive overview of existing studies that examine the relationship among energy consumption, economic growth, and carbon emissions in the US. Numerous studies have investigated the relationship between energy consumption and economic growth in the United States. Research by Kraft & Kraft (1978) found evidence of a long-run equilibrium relationship between energy consumption and GDP, suggesting that energy is a crucial input in driving economic activity. Similarly, Andrew (2019) employed a cointegration analysis to demonstrate a positive relationship between energy consumption and economic growth in the US over the long term. However, the environmental consequences of increased energy consumption, particularly in terms of carbon emissions, have raised concerns about the sustainability of economic growth. The United States is one of the largest emitters of carbon dioxide (CO₂) globally, primarily due to its heavy reliance on fossil fuels for energy generation and transportation. Research by Schmalensee et al. (1998) highlighted the role of energy-related CO₂ emissions in contributing to climate change and emphasized the need for policy interventions to mitigate emissions growth. While early studies provided mixed evidence regarding the existence of an inverted U-shaped relationship between per capita income and emissions (Selden & Song, 1994) more recent research suggests that income growth alone may not be sufficient to curb emissions without targeted policy interventions (Grossman & Krueger, 1995; Galeotti et al., 2006). Energy efficiency emerges as a critical factor in decoupling economic growth from emissions growth in the United States. Investments in energy-efficient technologies, renewable energy sources, and clean transportation infrastructure have the potential to reduce carbon intensity and enhance resource productivity (Sorrell et al., 2010). Policy initiatives, such as fuel economy standards for vehicles and energy efficiency regulations for buildings, have contributed to improvements in energy efficiency and emissions reductions across various sectors. The role of renewable energy in mitigating emissions while sustaining economic growth has garnered increasing attention in the United States. Studies have demonstrated the economic benefits of transitioning to renewable energy sources, including job creation, reduced air pollution, and enhanced energy security (Wei et al., 2010). Government incentives, such as tax credits and subsidies, have played a crucial role in promoting renewable energy deployment and driving down costs (Feldman et al., 2015).

1.4 Energy-Growth-Emission Dynamics in Canada

The linkage between energy consumption, economic growth, and carbon emissions in Canada has garnered significant attention from researchers, policymakers, and stakeholders due to its implications for both economic development and environmental sustainability. Several studies have explored the relationship between energy consumption and economic growth in Canada. Researchers such as Dickey & Fuller (1979) found evidence of a long-run equilibrium relationship between energy consumption and GDP in Canada, suggesting that energy plays a crucial role as a driver of economic activity. Similarly, Mahamat (2012) employed a panel cointegration approach to demonstrate a bidirectional causality between energy consumption and economic growth in Canada over the long term. However, the environmental consequences of increased energy consumption, particularly in terms of carbon emissions, pose significant challenges for Canada's sustainability objectives. Canada is one of the largest per capita emitters of greenhouse gases globally, primarily due to its reliance on fossil fuels for energy production and transportation. Research by Anthony and Wolfram (2016) highlighted the role of energy-related carbon emissions in contributing to climate change and indicated the urgency of transitioning to cleaner energy sources. The EKC hypothesis has been

frequently examined in the Canadian context to understand the relationship between economic growth and environmental degradation, including carbon emissions. While some studies suggest evidence of an inverted U-shaped relationship between income and emissions (Edward et al., 2018), others argue that the relationship may be more complex and contingent on various factors such as energy policies and technological advancements (Cleeren et al., 2016). Energy efficiency emerges as a critical factor in decoupling economic growth from emissions growth in Canada. Investments in energy-efficient technologies, renewable energy sources, and clean transportation infrastructure have the potential to reduce carbon intensity and enhance resource productivity. Policy initiatives, such as carbon pricing mechanisms and regulatory standards for energy efficiency, play a crucial role in promoting sustainable energy practices and emissions reductions across various sectors. The role of renewable energy in mitigating emissions while sustaining economic growth has gained traction in Canada. Studies have demonstrated the economic benefits of transitioning to renewable energy sources, including job creation, reduced air pollution, and enhanced energy security (Tansu et al., 2022).

2. Methodology

The estimation method employed in this study utilizes identical model equations for both countries, utilizing the same dataset and chosen variables. However, the Autoregressive Distributed Lag (ARDL) estimation technique incorporates distinct lag lengths tailored to each country, ensuring optimal model specification and accuracy. This approach allows for a complex examination of each country's economic performance, precluding the use of a panel method. The underlying assumption is that the economic dynamics and policy influences driving each economy are distinct and necessitate individualized analysis.

2.1 Data Source and Model specification

The study employed annual time series data extracted from the World Development Indicators (WDI) spanning from 1990 to 2021. The selected variables encompass CO₂ emissions, fossil fuel consumption, gross domestic product (GDP) per capita growth, gross fixed capital formation, foreign direct investment (FDI) inflows, and trade openness. CO₂ emissions are measured in metric tons per capita. GDP per capita growth is quantified as an annual percentage, while gross fixed capital formation is expressed as a percentage of GDP. Fossil fuel consumption and FDI are represented as proportions of GDP. Trade openness is determined by the ratio of GDP to the sum of exports and imports. However, domestic investment in the study is denoted by gross fixed capital formation. To assess the presence of a long-term relationship among the variables, the research utilized the autoregressive distributed lag (ARDL) bound test developed by (Pesaran et al., 2001). This method has been widely adopted by scholars such as Thobekile et al. (2022), Rathnayaka et al. (2021) and Hao (2023) within the framework of the single-equation total growth model. These studies have explored the relationship between CO₂ emissions, fossil fuel consumption, and various control factors on economic growth. The estimated model is in Equation 1.

$$CO2_t = \beta_0 + \beta_1 FFC_t + \beta_2 TOP_t + \beta_3 GFCF_t + \beta_4 GDPPC_t + \beta_5 FDI_t + \varepsilon_t \quad (1)$$

In Equation 1, CO₂ represents energy emissions, FFC denotes fossil fuel consumption, TOP signifies trade openness, GFCF stands for gross fixed capital formation, GDPPC represents gross

domestic per capita growth, FDI indicates foreign direct investment, and ε_t is the error term. The rationale for including each variable in Equation 1 is that CO₂ emissions represent a critical environmental concern influenced by various economic activities, making them pivotal for studying the relationship between economic growth and resource consumption. Non-renewable resource consumption, particularly fossil fuels, is intricately linked to CO₂ emissions. Trade openness impacts economic growth by facilitating the exchange of goods and services across borders, shaping production patterns, energy use, and emissions. Gross fixed capital formation, entailing investment in infrastructure and capital, is essential for economic growth and can influence resource consumption and environmental sustainability. GDP per capita reflects a country's economic development level and consumption patterns, which can in turn affect CO₂ emissions. FDI brings capital and technology, impacting economic growth and potentially influencing resource use and environmental sustainability. However, since this research aims to evaluate the significance of these variables separately within each country, it necessitated the identification of the appropriate model specifications for each nation. To achieve the correct model specification for the estimated model in the United States, the variables CO₂, fossil fuel consumption, and trade openness were transformed using natural logarithms. This transformation helps to stabilize the data and addresses potential issues related to non-linear relationships. On the other hand, for the accurate model specification in Canada, the variable CO₂ was converted into logarithmic form. This adjustment aims to ensure that the model appropriately captures the relationship between CO₂ emissions and other variables within the Canadian context. By adapting the model specifications to the specific characteristics of each country, the study aims to provide more robust and insightful analyses of the factors influencing energy emissions and economic dynamics in the United States and Canada.

2.2 Estimation Technique

To investigate the long-term and short-term relationships between the series, this study used the ARDL-bound testing approach introduced by Pesaran et al. (2001). In this analysis, the relationship between GDP per capita growth and gross fixed capital formation (representing domestic investment) with CO₂ emissions in Canada and the USA is deemed crucial, as these factors contribute significantly to the gross national product. The ARDL model has gained prominence in recent years owing to its advantages over other econometric models. One notable advantage is its ability to accommodate variables with different orders of integration, namely I (0) and I (1), and to handle limited sample sizes effectively (Tong et al., 2020; Mohammed & Ruslee, 2015). The specification of the ARDL model for this study is in Equation 2. However, the estimation method employed is consistent for both countries (Canada and the US), using the same set of variables. This approach ensures comparability and allows for a comprehensive examination of the relationship between economic factors and CO₂ emissions in both nations.

$$\Delta CO2_t = a + \sum_{i=1}^k \delta_i \Delta CO2_{t-i} + \sum_{i=1}^p \phi_i \Delta FFC_{t-i} + \sum_{i=1}^r \varrho_i \Delta TOP_{t-i} + \sum_{i=1}^s \varphi_i \Delta GFCF_{t-i} + \sum_{i=1}^{\sigma} \theta_i \Delta GDPPC_{t-i} + \sum_{i=1}^{\pi} \delta_i \Delta FDI_{t-i} + \varepsilon_t \quad (2)$$

In the assessment of ARDL bound testing cointegration, the methodology proposed by Pesaran & Shin (1999) is employed. This approach uses Wald statistics within the model to assess the significance of variable lag coefficients. The F-statistic, derived from the correlation coefficient in the F-test, is then compared to the critical value of the ARDL cointegration coefficient. This critical value is determined

based on the maximum asymptotic spread of the F-statistic, aiding in the decision to accept or reject the null hypothesis (Pesaran et al., 2001). However, due to the smaller sample size selected for analysis, it becomes imperative to compare the model's F-statistic value with the threshold value suggested by Narayan (2005) for the asymptotic distribution of the F-statistic. This adjustment ensures that the conclusions drawn from the analysis are robust and reliable even with the limitations posed by the sample size. The expression for ARDL bound testing cointegration is presented in Equation 3, encapsulating the statistical framework utilized to assess the presence of cointegration among the variables under consideration.

$$\Delta CO2_t = a + \sum_{i=1}^k \delta_i \Delta CO2_{t-i} + \sum_{i=1}^{\rho} \phi_i \Delta FFC_{t-i} + \sum_{i=1}^{\tau} \varrho_i \Delta TOP_{t-i} + \sum_{i=1}^{\varsigma} \varphi_i \Delta GFCC_{t-i} + \sum_{i=1}^{\sigma} \theta_i \Delta GDPPC_{t-i} + \sum_{i=1}^{\pi} \epsilon_i \Delta FDI_{t-i} + \lambda_1 CO2_{t-1} + \lambda_2 FFC_{t-1} + \lambda_3 TOP_{t-1} + \lambda_4 GFCC_{t-1} + \lambda_5 GDPPC_{t-1} + \lambda_6 FDI_{t-1} + \varepsilon_t \quad (3)$$

In this context, δ , ϕ , ϱ , φ , and ϵ stand for the short-term parameters to be calculated, while $\lambda_1, \lambda_2, \lambda_3, \lambda_4, \lambda_5$, and λ_6 denote the long-run relationship. The determination of cointegration hinges on rejecting the null hypothesis, which asserts that $(\lambda_1^{-1} \lambda_2^{-1} \lambda_3^{-1} \lambda_4^{-1} \lambda_5^{-1} \lambda_6 = 0)$ are not all equal to zero. During ARDL bound testing, the confirmation of a cointegration relationship among variables occurs when the F-statistic of the estimated model surpasses the highest critical value listed for I (1) in the model's critical values table. Conversely, if it falls below the lowest critical bound for I (0), it indicates the absence of a cointegration relationship. However, it's important to estimate the error correction model due to the presence of at least one causal relationship among the variables, as indicated by the F-statistic of the long-run estimation and the error correction model lag. The short-run economic activity parameters are deduced by estimating the error-correction model concerning the long-run estimation. The error correction estimated model is in Equation 4.

$$\Delta CO2_t = a + \sum_{i=1}^k \delta_i \Delta CO2_{t-i} + \sum_{i=1}^{\rho} \phi_i \Delta FFC_{t-i} + \sum_{i=1}^{\tau} \varrho_i \Delta TOP_{t-i} + \sum_{i=1}^{\varsigma} \varphi_i \Delta GFCC_{t-i} + \sum_{i=1}^{\sigma} \theta_i \Delta GDPPC_{t-i} + \sum_{i=1}^{\pi} \delta_i \Delta FDI_{t-i} + \Omega ECT_{t-1} + \varepsilon_t \quad (4)$$

where ΩECT_{t-1} represents the error correction term to be estimated. The symbol Ω signifies the pace of adjustment dynamics from the short run to the long run equilibrium.

However, as per the ARDL error correction model criteria, the error correction coefficient must be negative and statistically significant to establish a long-run relationship.

3. Research results

The descriptive statistics for all observations of both countries are displayed in Tables 1 and 2. Table 1 delineates the results for the US, while Table 2 corresponds to Canada. The data in Table 1 reveals that the mean gross fixed capital formation exhibits the highest value among the selected variables. However, the means of CO2 emissions, fossil fuel consumption, trade openness, GDP per capita growth, and FDI are relatively close, suggesting a low degree of variability among them. Specifically, the average CO2 emissions in the US amount to 2.88 metric tons per capita annually, while the gross fixed capital formation stands at 21 percent. These statistics provide the central tendencies and variability of the variables under examination, offering a foundational understanding of their distribution and characteristics within the respective countries. The correlation matrix presented in

Table 1 reveals relationships within the US economy. Firstly, the coefficient value of fossil fuel consumption (FFC) stands at 0.921, indicating a strong positive correlation with CO₂ emissions.

Table 1. Descriptive Statistics and Pairwise Correlation Matrix-USA.

Parameters	CO ₂	FFC	TOP	GFCF	GDPPC	FDI
Mean	2.875	4.428	3.213	21.00	3.595	1.602
Median	2.944	4.448	2.216	21.00	3.720	1.505
Maximum	3.018	4.459	3.428	23.00	10.530	3.410
Minimum	2.567	4.291	2.985	18.00	-2.830	0.460
Std.Dev	0.126	0.040	0.134	1.295	2.321	0.752
Skewness	-0.733	-1.811	-0.096	-0.090	-0.377	0.065
Kurtosis	2.280	5.811	1.983	2.461	6.274	2.811
Jarque-Bera	3.557	28.03	1.425	0.430	15.05	2.303
Probability	0.168	0.001	0.490	0.806	0.000	0.316
Sum	92.02	141.71	102.81	672.00	115.06	51.29
Sum Sq. Dev	0.498	0.050	0.564	52.00	167.09	17.56
Observation	32	32	32	32	32	32
Correlation matrix						
CO ₂	1.000					
FFC	0.921	1.000				
TOP	-0.505	-0.319	1.000			
GFCF	0.458	0.253	-0.189	1.000		
GDPPC	0.233	-0.204	-0.057	0.347	1.000	
FDI	0.022	-0.025	0.472	0.316	0.201	1.000

Source: created by authors.

This suggests that higher levels of fossil fuel consumption are associated with increased CO₂ emissions. Conversely, trade openness demonstrates a negative moderate association (coefficient of 0.505) with CO₂ emissions, implying that greater trade openness is correlated with lower CO₂ emissions.

Table 2. Descriptive Statistics and Pairwise Correlation Matrix-Canada.

Parameters	CO ₂	FFC	TOP	GFCF	GDPPC	FDI
Mean	2.758	74.484	66.176	21.625	3.238	2.805
Median	2.757	74.715	66.165	22.000	2.915	2.285
Maximum	2.855	76.550	82.770	24.000	20.780	9.170
Minimum	2.610	71.700	49.220	18.000	-14.440	0.140
Std.Dev	0.053	1.254	7.964	1.913	8.112	1.957
Skewness	-0.369	-0.391	-0.040	-0.236	0.080	1.615
Kurtosis	3.333	2.332	3.007	1.593	2.822	6.026
Jarque-Bera	0.876	1.412	0.009	2.935	0.076	26.122
Probability	0.645	0.493	0.995	0.230	0.962	0.000
Sum	88.28	2383	2117	692.1	103.2	89.77
Sum Sq. Dev	0.088	48.76	1966	113.5	2043	118.7
Observation	32	32	32	32	32	32
Correlation matrix						
CO ₂	1.000					
FFC	0.532	1.000				
TOP	0.586	0.574	1.000			
GFCF	-0.069	0.171	-0.239	1.000		
GDPPC	0.445	0.257	0.158	0.002	1.000	
FDI	0.465	0.317	0.509	0.223	0.099	1.000

Source: created by authors.

The coefficient for gross fixed capital formation (GFCF) is 0.458, indicating a minimal positive linkage with CO₂ emissions. This suggests that higher levels of domestic investment may lead to slightly increased CO₂ emissions. Additionally, the GDP per capita growth rate exhibits a weak positive relationship with CO₂ emissions, while foreign direct investment (FDI) displays the weakest correlation with the dependent variable. However, in Table 2, which depicts the descriptive statistics for Canada, indicate that CO₂ emissions, GDP per capita, and FDI display closely clustered mean values, indicating lower variability among these variables. The average CO₂ emissions per capita annually amount to 2.758 metric tons. Fossil fuel consumption boasts the highest mean value at 74.48%, followed by trade openness at 66.18%, and gross fixed capital formation at 21.63% yearly. In the context of Canada, the correlation coefficients between fossil fuel consumption and CO₂ emissions (0.532), as well as between trade openness and CO₂ emissions (0.586), indicate a moderate positive relationship. This suggests that higher levels of fossil fuel consumption and trade openness are associated with increased CO₂ emissions in Canada. Conversely, the coefficients for GDP per capita (0.445) and FDI (0.465) display a medium-weak association with energy emissions. This indicates that while there is a positive relationship between GDP per capita growth and FDI with CO₂ emissions, the strength of this relationship is relatively weaker compared to fossil fuel consumption and trade openness. Interestingly, the coefficient for gross fixed capital formation (-0.069) exhibits a negative and weakest relationship with CO₂ emissions in the Canadian economy. This suggests that higher levels of domestic investment in fixed capital may be associated with slightly lower CO₂ emissions. However, the strength of this relationship is shows weaker compared to other factors such as fossil fuel consumption and trade openness.

3.1. Stationarity test

Before applying the ARDL bound test for cointegration, the unit root tests proposed by Dickey & Fuller (1981) and Phillips & Perron (1988) were utilized to assess the characteristics of the selected variables. These tests are instrumental in determining the order of integration for the time series data, providing insights into their stationarity properties. According to the criteria outlined by Dickey & Fuller (1981) and Phillips & Perron (1988), a unit root is considered present when the asymptotic p-value exceeds the 5% critical value. The inclusion of an intercept term in these tests enables an examination of the underlying dynamics within the series. Upon conducting the unit root tests at a 5% significance level, it was observed that all variables were found to be non-stationary and integrated at the first difference. The results of the stationarity test are presented in Tables 3 and 4.

Table 3. Unit root test-USA.

Variable	Level	ADF	PP	Variable	Level	ADF	PP
CO ₂	0	1.595	0.314	GFCF	0	-2.362	-1.789
CO ₂	1	-7.061***	-6.212***	GFCF	1	-3.974***	-3.866***
FFC	0	2.487	-0.617	GDPPC	0	-4.952***	-4.959***
FFC	1	-13.450***	-7.230***	FDI	0	-3.662***	-2.439
TOP	0	-1.929	-1.851	FDI	1	-5.599***	-9.197***
TOP	1	-5.975***	-6.096***				

Note: ***1%.

Source: created by authors.

Specifically, Table 3 illustrates the outcomes of the unit root tests for the variables about the US. The tests indicated that CO₂ emissions, fossil fuel consumption, trade openness, and gross fixed

capital formation were non-stationary at the levels, necessitating the application of first differencing to achieve stationarity. However, for FDI, while the ADF test at the level suggested stationarity, the Phillips-Perron (PP) test yielded contrary results, indicating non-stationarity. Therefore, the first differencing was employed to ensure that FDI is fully integrated at order one. Additionally, the variable GDP per capita was found to be stationary at the level, suggesting it follows an I (0) process.

Table 4. Unit root test-Canada.

Variable	Level	ADF	PP	Variable	Level	ADF	PP
CO ₂	0	-1.753	-1.680	GFCF	0	-0.836	-0.962
CO ₂	1	-6.294***	-6.303***	GFCF	1	-5.236***	-6.276***
FFC	0	-2.082	-2.072	GDPPC	0	-3.953***	-3.952***
FFC	1	-6.053***	-6.034***	FDI	0	-4.142***	-2.807*
TOP	0	-2.091	-2.188	FDI	1	-5.154***	-10.300***
TOP	1	-3.678***	-3.702***				

Note: ***1%, *10%.

Source: created by authors.

Upon applying the same unit root tests to the variables for Canada, the findings mirrored those obtained for the US, as illustrated in Table 4. The results of the stationarity test revealed that the variables exhibit a mixture of order one integration I (1) and order zero integration I (0). This suggests that some variables require first differencing to achieve stationarity, while others are already stationary in their original form. This outcome implies that the ARDL model can indeed be applied to the dataset for Canada, similar to the situation observed for the US. The presence of both I (0) and I (1) variables indicates that the dataset possesses the necessary characteristics for the ARDL framework, enabling the investigation of long-term relationships among the variables while accounting for short-term dynamics.

3.2. ARDL-bound test of cointegration

In examining the presence of long-term cointegration among the variables, the ARDL bound test is employed. Before conducting the ARDL bound test, it is crucial to select an appropriate lag length to ensure the accuracy of the results. To accomplish this, difference estimation equations are formulated using various information criteria, and the most suitable one is chosen. In this study, the Akaike Information Criterion (AIC) is utilized due to its efficiency in optimizing expected outcomes. The AIC is renowned for its consistency and effectiveness in capturing changes in the relationships between variables. Tables 5 and 6 present the outcomes of the bound test for cointegration. Drawing upon theories from Pesaran et al. (2001) and Narayan (2005), a common approach is adopted in this study. However, given the limited number of observations utilized, the study leans towards Narayan's (2005) method to determine the existence of cointegration among the variables. In this framework, the null hypothesis posits no long-run cointegration, which is indicated by an F-statistic coefficient lower than the 5% upper critical value. As demonstrated in Tables 5 and 6, the F-statistic of CO₂ exceeds the upper critical value, suggesting a long-term relationship among the variables.

Table 5. ARDL Bound test cointegration results-USA.

Test Statistic	Value	Significance	I (0)	I (1)
F-statistic	8.630	10%	2.08	3.00
		5%	2.39	3.38
		1%	3.06	4.15

Note: AIC selection criterion (1,0,2,2,1,2) for optimum lag selection.

Source: created by authors.

This implies that CO₂ emissions, fossil fuel consumption, gross fixed capital formation, GDP per capita, FDI, and trade openness exhibit long-term interdependence.

Table 6. ARDL Bound test cointegration results-Canada.

Test Statistic	Value	Significance	I (0)	I (1)
F-statistic	19.263	10%	2.08	3.00
		5%	2.39	3.38
		1%	3.06	4.15

Note: AIC selection criterion (4,1,0,3,3,3) for optimum lag selection.

Source: created by authors.

3.3 ARDL results for the US

Table 7 indicates both the long and short-run coefficients of the variables, along with an adjusted R-squared value indicating that 98% of the variation in the dependent variable is explained by the explanatory variables.

Table 7. ARDL results-USA.

Long Run	Coefficient	Std. Error	t-statistic	Prob.
FFC	2.720***	0.216	12.540	0.000
TOP	-0.314***	0.059	-5.254	0.000
GFCF	0.021***	0.007	3.124	0.006
GDPPC	-0.014	0.105	-1.352	0.195
FDI	0.006	0.012	0.528	0.604
Constant	-8.586***	1.055	-8.131	0.000
Short Run				
Δ TOP	0.090*	0.051	1.764	0.096
Δ TOP (-1)	-0.118**	0.048	-2.439	0.026
Δ GFCF	0.011**	0.004	2.489	0.024
Δ GFCF (-1)	0.010***	0.003	2.950	0.009
Δ GDPPC	-0.002	0.001	-1.538	0.143
Δ FDI	0.001	0.004	0.261	0.796
Δ FDI (-1)	0.021***	0.004	4.950	0.000
ECT (-1)	-0.634***	0.069	-9.114	0.000
Diagnostic test				
χ^2 Reset			0.441	0.516
χ^2 Normality			0.114	0.944
χ^2 Serial correlation			1.014	0.388
χ^2 ARCH			2.025	0.153

Note: ***1%, **5%, *10%; AIC (1,0,2,2,1,2); Adjusted R² = 0.98; DW = 2.075. χ^2 Normality – normality test for residuals, χ^2 Serial, LM serial correlation test, χ^2 Arch, autoregressive conditional heteroscedasticity, χ^2 Reset, Ramsey reset test. The probability values are provided in parentheses.

Source: created by authors.

The analysis reveals intriguing details, particularly regarding the variable of trade openness and its relationship with CO₂ emissions in the US economy. In the short run, the coefficient of trade openness demonstrates a mixed positive and negative effect on CO₂ emissions. The short run coefficient (0.09) suggests a positive relationship, indicating that an increase in trade openness initially corresponds to a rise in CO₂ emissions. This could be attributed to heightened economic activity and increased production accompanying greater trade integration. However, the subsequent coefficient (0.12) of trade openness exhibits a negative effect on CO₂ emissions in the short run, suggesting a reversal in the relationship after a lag of one year. This reversal may stem from factors such as technological

advancements, efficiency gains, or adjustments in production processes, which could mitigate the environmental impact of trade over time. Remarkably, in the long run, the coefficient (0.31) of trade openness unveils a negative association with CO₂ emissions. This suggests that as economies become more open to trade over time, there emerges a mitigating effect on CO₂ emissions. This phenomenon could be linked to mechanisms such as the diffusion of cleaner technologies, the adoption of more stringent environmental regulations spurred by international trade agreements or shifts in consumption patterns towards less carbon-intensive goods. These findings emphasize the complex connection between globalization, economic development, and environmental sustainability. While trade openness may initially exacerbate environmental pressures, particularly in the short term, the observed long-term negative relationship suggests the potential for trade integration to act as a catalyst for environmental improvement. This aligns with the Environmental Kuznets Curve hypothesis, which posits that environmental degradation initially worsens with economic growth but eventually improves as societies reach higher income levels and prioritize environmental protection.

However, the insignificant short and long-run coefficient of GDP per capita growth shows a negative relationship with CO₂. In the short run, the first difference and one-period lag coefficients (0.01) and (0.01) of gross fixed capital formation have a positive relationship with CO₂. It implies that an increase in gross fixed capital formation leads to an expansion in CO₂. On the other hand, the coefficient (0.02) of gross fixed capital formation has a positive association with CO₂ in the long run. It shows that a rise in gross fixed capital formation leads to an increase in CO₂ in the long run. In the short run, the observed positive correlation between the one-period lag coefficients of gross fixed capital formation (0.01) and CO₂ emissions unveils a dynamic relationship between investment in physical assets and environmental outcomes. This suggests that in the immediate aftermath of an increase in gross fixed capital formation, there is a corresponding expansion in CO₂ emissions. This finding emphasizes the inherent carbon intensity often associated with the initial stages of economic development and investment-driven growth trajectories. The positive association between capital formation and CO₂ emissions in the short run may stem from factors such as increased industrial activity, infrastructure development, and energy consumption, all of which tend to exert upward pressure on carbon emissions. Conversely, the long-run coefficient (0.02) of gross fixed capital formation reveals a sustained positive association with CO₂ emissions over extended periods. This indicates that as economies undergo structural transformations and mature over time, higher levels of investment in fixed capital continue to drive up CO₂ emissions. This phenomenon can be attributed to the persistence of carbon-intensive production processes, the expansion of energy-intensive industries, and the lagged effects of infrastructure investments on emissions. Additionally, the long-term positive relationship between gross fixed capital formation and CO₂ emissions underlines the challenges associated with decoupling economic growth from environmental degradation, particularly in the context of capital-intensive development pathways. The coefficient of (0.02) of FDI shows a positive relationship with CO₂ in the short run. This implies that an expansion in FDI inflows increases CO₂ in the short run. This finding reflects the immediate impact of FDI on economic activities that are typically energy-intensive or carbon-emitting, such as manufacturing or heavy industries. In the short term, the influx of foreign investment may stimulate production and industrial activities, thereby driving up carbon emissions. On the contrary, the positive long-run coefficient of FDI is not statistically significant which shows that it does not influence CO₂. This implies that the influence of foreign direct investment on CO₂ emissions is not robust over extended periods. Several

factors could contribute to this outcome, including the potential for technological advancements, changes in production processes, or shifts in consumption patterns that mitigate the environmental impact of FDI over time. Furthermore, there is a possibility that other intervening variables or structural changes in the economy may dampen the long-term relationship between FDI and CO₂ emissions. The coefficient (2.72) of fossil fuel consumption indicates a positive connection with CO₂ in the long run. It shows that an increase in fossil fuel consumption expands CO₂ emission in the long term in the US economy. The coefficient of fossil fuel consumption signifies a robust positive relationship with CO₂ emissions in the long run. This finding shows the significant impact of fossil fuel consumption on carbon dioxide emissions within the US economy over extended periods. As fossil fuels remain the primary source of energy for various sectors such as transportation, industry, and electricity generation, an increase in their consumption invariably leads to higher CO₂ emissions. This positive association between fossil fuel consumption and CO₂ emissions reflects the carbon-intensive nature of the US economy's energy infrastructure and highlights the challenges associated with transitioning to cleaner and more sustainable energy sources. The ARDL error correction coefficient (-0.634) indicates that when a deviation occurs the target variable has to adjust by 63.4% annually. This coefficient reflects the speed at which the system returns to its equilibrium state following a shock or disturbance. In this case, a negative coefficient indicates that the adjustment process is towards restoring equilibrium, with a magnitude indicating the pace of adjustment.

3.4. ARDL outcome for Canada

Table 8 presents the estimated long- and short-run coefficients of the selected variables from the ARDL model, along with an adjusted R-squared value indicating that 97% of the variation in the dependent variable is explained by the regressors.

Table 8. ARDL results-Canada.

Long Run	Coefficient	Std.Error	t-statistic	Prob.
FFC	-0.134*	0.064	-2.154	0.063
TOP	0.030*	0.014	2.030	0.076
GFCF	0.042*	0.019	2.140	0.064
GDPPC	0.022**	0.001	2.596	0.032
FDI	0.055*	0.027	2.071	0.072
Constant	9.896**	3.434	2.881	0.021
Short Run				
$\Delta \text{CO}_2 (-1)$	-0.330***	0.073	-4.563	0.002
$\Delta \text{CO}_2 (-2)$	0.256***	0.075	3.416	0.009
$\Delta \text{CO}_2 (-3)$	-0.715***	0.081	-8.778	0.000
ΔFFC	-0.011***	0.002	-4.517	0.002
ΔGFCF	0.005**	0.002	2.404	0.043
$\Delta \text{GFCF} (-1)$	0.006**	0.002	3.201	0.012
$\Delta \text{GFCF} (-2)$	-0.004	0.002	-1.679	0.132
ΔGDPPC	0.003***	0.000	15.395	0.000
$\Delta \text{GDPPC} (-1)$	-0.002***	0.000	-6.123	0.000
$\Delta \text{GDPPC} (-2)$	-0.001***	0.000	-5.274	0.000
ΔFDI	0.002**	0.001	2.954	0.018
$\Delta \text{FDI} (-1)$	-0.013***	0.001	-10.419	0.000
$\Delta \text{FDI} (-2)$	-0.012***	0.002	-8.767	0.000
ECT (-1)	-0.247***	0.016	-15.361	0.000
Diagnostic test				
χ^2 Reset			0.362	0.728

Long Run	Coefficient	Std.Error	t-statistic	Prob.
χ^2 Normality			1.639	0.441
χ^2 Serial correlation			0.136	0.722
χ^2 ARCH			1.836	0.172

Note: ***1%, **5%, *10%; AIC (4,1,0,3,3,3); Adjusted R^2 =0.97; DW=2.145; χ^2 Normality – normality test for residuals, χ^2 Serial – LM serial correlation test; χ^2 Arch – autoregressive conditional heteroscedasticity; χ^2 Reset – Ramsey reset test. The probability values are provided in parentheses.

Source: created by authors.

The analysis shows the dynamics of CO₂ emissions in the Canadian economy. In the short run, the coefficients of the one-period lag and previous 3-years of CO₂ emissions exhibit a negative influence on the current CO₂ emissions, with coefficients of 0.33 and 0.72, respectively. This suggests a counterintuitive trend within the Canadian economy, where recent and relatively distant past levels of CO₂ emissions exert a dampening effect on present emissions. Conversely, the coefficient of the two-period lag of CO₂ emissions shows a positive relationship with present CO₂ emissions in the short term, with a coefficient of 0.26. This suggests a delayed rebound effect, wherein CO₂ emissions from two years ago positively influence current emissions. This could include delayed impacts of economic activities on emissions or the persistence of carbon-intensive practices despite efforts to mitigate emissions. Furthermore, the coefficient of fossil fuel consumption exhibits a negative short-run relationship with CO₂ emissions, indicating that an expansion in fossil fuel consumption decreases CO₂ emissions in the short term. This unexpected finding may be attributed to temporary shifts in energy consumption patterns or short-term fluctuations in economic activity affecting emissions levels. In contrast, the negative long-run coefficient of fossil fuel consumption suggests a more consistent and sustained relationship with CO₂ emissions over extended periods. This indicates that as fossil fuel consumption increases in the long term, there is a corresponding decline in CO₂ emissions within Canada's economy. This may include the adoption of cleaner technologies, improvements in energy efficiency, or shifts towards renewable energy sources, gradually reducing the carbon intensity of fossil fuel consumption over time.

However, as indicated in Table 8, the first different and previous 2-year coefficients (0.01) and (0.01) of gross fixed capital formation have positive short-run association with CO₂ in the short run. It implies that an increase in gross fixed capital formation expands the CO₂ in the short term. On the contrary, the gross fixed capital formation coefficient (0.04) has a positive association with CO₂ in the long term. This means that in the long run, an increase in fixed capital formation leads to a rise in CO₂ in Canada. The positive short-run association observed between the first difference and the previous 2-year coefficients of gross fixed capital formation and CO₂ emissions suggests that an increase in gross fixed capital formation contributes to an expansion of CO₂ emissions in the short term within Canada's economy. This indicates that immediate increases in investment in physical assets, such as infrastructure or machinery, tend to lead to higher levels of CO₂ emissions. This relationship likely arises due to the energy-intensive nature of construction activities or industrial production processes associated with capital formation. Conversely, the positive long-run coefficient of gross fixed capital formation reveals a sustained positive association with CO₂ emissions over extended periods. This implies that in the long term, as the accumulation of fixed capital continues, there is a corresponding increase in CO₂ emissions within Canada. This long-term trend may be attributed to factors such as the persistent use of carbon-intensive technologies, the expansion of energy-intensive industries, or the lagged effects of infrastructure investments on emissions.

However, the first difference in GDP per capita coefficient (0.003) has a positive relationship with CO₂ in the short run. On the other hand, the previous one-year and two-year GDP per capita coefficients (0.002) and (0.001) have a negative association with CO₂ emissions. In the long run, the GDP per capita coefficient (0.02) has a positive connection with CO₂. The positive short-run relationship observed between the first difference in GDP per capita coefficient and CO₂ emissions suggests that an increase in GDP per capita leads to higher CO₂ emissions in the short term within the economy. This finding indicates that immediate increases in economic activity and prosperity tend to be accompanied by higher levels of CO₂ emissions, likely due to increased consumption, industrial production, and energy usage. Conversely, the negative association between the previous one-year and two-year GDP per capita coefficients (0.002 and 0.001, respectively) and CO₂ emissions implies that in the short term, past levels of GDP per capita are associated with lower CO₂ emissions. This suggests a lagged effect wherein improvements in economic efficiency or shifts in consumption patterns may lead to reduced emissions over time. In the long run, the positive connection between the GDP per capita coefficient and CO₂ emissions indicates that as the economy grows and becomes more prosperous over extended periods, there is a corresponding increase in CO₂ emissions. This long-term trend may be attributed to factors such as increased energy consumption, industrialization, and transportation needs associated with economic development. Conversely, the first difference in the FDI coefficient (0.002) has a positive short-run relationship with carbon dioxide emission. The previous one-year and two-year coefficients (0.01) and (0.01) of FDI have a negative linkage with CO₂ in the short term. In the long run, the FDI coefficient (0.06) has a positive association with CO₂. The positive short-run relationship observed between the first difference in FDI coefficient (0.002) and carbon dioxide emissions indicates that an increase in foreign direct investment leads to higher CO₂ emissions in the short term. This finding suggests that immediate inflows of foreign investment may stimulate carbon-intensive economic activities, such as industrial production or infrastructure development, resulting in higher emissions. Conversely, the negative linkage between the previous one-year and two-year coefficients of FDI (0.01) and CO₂ emissions in the short term implies that past levels of foreign direct investment are associated with lower CO₂ emissions. This suggests a lagged effect wherein previous investments in cleaner technologies or shifts in production processes may lead to reduced emissions over time. In the long run, the positive association between the FDI coefficient (0.06) and CO₂ emissions suggests that as foreign direct investment accumulates over extended periods, there is a corresponding increase in CO₂ emissions. This long-term trend may be attributed to factors such as the adoption of carbon-intensive technologies, the expansion of energy-intensive industries, or the increasing demand for transportation and infrastructure associated with foreign investment-driven economic growth. Additionally, in the long run, the trade openness coefficient (0.03) has a positive relationship with carbon dioxide. The positive relationship between the trade openness coefficient (0.03) and carbon dioxide emissions in the long run indicates that as trade openness increases over extended periods, there is a corresponding rise in CO₂ emissions. This finding suggests that the integration of economies through trade may lead to increased economic activity and industrial production, resulting in higher emissions of carbon dioxide. Several factors may contribute to this long-term positive association between trade openness and CO₂ emissions. For instance, increased trade may lead to higher energy consumption for transportation and logistics, as well as increased production in carbon-intensive industries to meet growing demand from international markets. Additionally, trade liberalization may lead to the relocation of industries to

countries with less stringent environmental regulations, resulting in higher emissions. The error correction coefficient (-0.247) indicates that in terms of a disequilibrium, the target variable has to adjust 24.7% per annum. This coefficient quantifies the speed at which the system returns to its long-run equilibrium following a deviation. This means that the system adjusts relatively slowly to deviations from its long-run equilibrium, with only a fraction of the gap being closed each year.

3.5. Models stability Diagnostic

The results from the recursive tests indicate that the estimated models in this study demonstrate stability and consistency. This conclusion is drawn from the observation that the lines representing the cumulative sum and cumulative sum of squares of the recursive residuals remain within the 5% critical bounds. However, the deviations of the estimated model's parameters from their expected values do not exhibit significant departures over time, suggesting that the model remains reliable and consistent throughout the analysis period. This stability and consistency of the estimated model are crucial for ensuring the validity and robustness of the findings and conclusions drawn from the analysis. It provides confidence in the reliability of the estimated relationships between the variables and enhances the credibility of the study's results. Figures 1 (a,b) show the recursive CUSUM and recursive CUSMSQ tests for the ARDL estimated results for the US economy while Figures 1 (c,d) are for Canada.

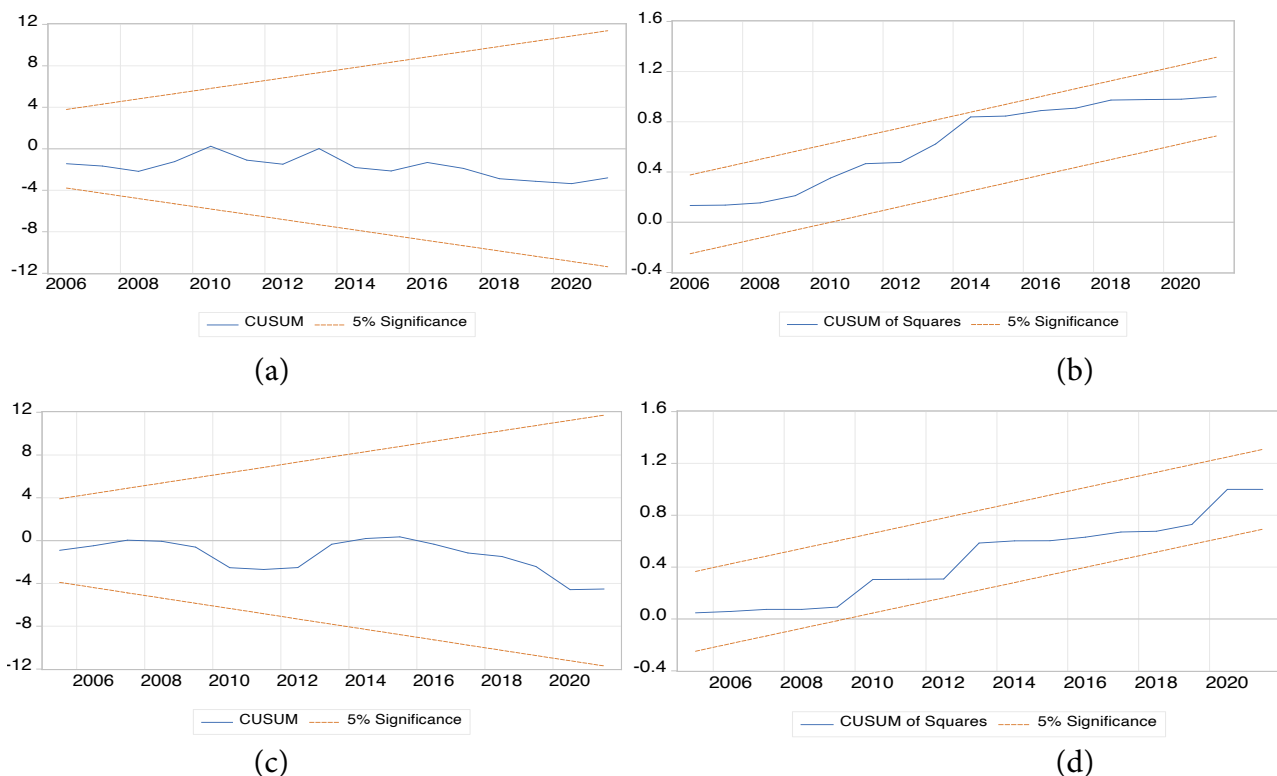


Figure 1. Cumulative sum of recursive residuals and squares of recursive residuals for USA (a and b) and Canada (c and d).

Source: created by authors.

3.6. Granger causality test

The outcomes of the Granger causality test in Tables 9 and 10 are for the US and Canada, respectively. In the context of the Granger (1969) causality test, the null hypothesis states that no

causality exists between the variables under consideration. This null hypothesis is rejected when the F-statistics p-value falls below a predetermined significance level, typically set at 0.1. If the p-value is below this threshold, it indicates that there is sufficient evidence to reject the null hypothesis, suggesting the presence of causal relationships between the variables. By employing the Granger causality test with a significance level of 0.1, helps to determine whether one variable can be considered a predictor of another, thereby informing decision-making processes and policy formulation. This helps in understanding the dynamics of the system under study and aids in making informed choices regarding future actions and interventions. However, the outcome of the Granger causality in Table 9 for the US, shows that there is a bidirectional causality relationship between fossil fuel consumption and CO2 emissions. This indicates that changes in fossil fuel consumption can lead to changes in CO2 emissions, and vice versa. This finding shows the intertwined nature of these variables, where the combustion of fossil fuels contributes significantly to carbon dioxide emissions, while the resulting emissions, in turn, reflect the level of fossil fuel consumption. The findings established a unidirectional causal relationship running from trade openness to CO2 emissions. This suggests that changes in trade openness can influence CO2 emissions. The unidirectional nature of this causality relationship implies that factors related to trade openness, such as increased economic activity or changes in production patterns due to trade integration, have a discernible impact on carbon dioxide emissions.

Table 9. Granger causality test results-US.

Null Hypothesis	F-Statistic	Prob.	Decision
FFC does not Granger Cause CO2	7.272	0.011	Rejected
CO2 does not Granger Cause FFC	12.937	0.000	Rejected
TOP does not Granger Cause CO2	7.498	0.010	Rejected
CO2 does not Granger Cause TOP	0.141	0.711	Not rejected
GFCF does not Granger Cause CO2	0.091	0.764	Not rejected
CO2 does not Granger Cause GFCF	0.158	0.693	Not rejected
GDPPC does not Granger Cause CO2	2.739	0.109	Not rejected
CO2 does not Granger Cause GDPPC	0.010	0.919	Not rejected
FDI does not Granger Cause CO2	2.148	0.153	Not rejected
CO2 does not Granger Cause FDI	0.031	0.861	Not rejected

Source: created by authors.

However, the outcome Granger causality test for Canada in Table 10, shows a unidirectional causality running from fossil consumption to carbon dioxide emission in the Canadian economy.

Table 10. Granger causality test results-Canada.

Null Hypothesis	F-Statistic	Prob.	Decision
FFC does not Granger Cause CO2	4.024	0.031	Rejected
CO2 does not Granger Cause FFC	1.838	0.179	Not rejected
TOP does not Granger Cause CO2	1.478	0.247	Not rejected
CO2 does not Granger Cause TOP	4.924	0.015	Rejected
GFCF does not Granger Cause CO2	2.049	0.149	Not rejected
CO2 does not Granger Cause GFCF	0.487	0.619	Not rejected
GDPPC does not Granger Cause CO2	0.501	0.611	Not rejected
CO2 does not Granger Cause GDPPC	1.704	0.202	Not rejected
FDI does not Granger Cause CO2	0.298	0.744	Not rejected
CO2 does not Granger Cause FDI	1.481	0.246	Not rejected

Source: created by authors.

This finding suggests that changes in fossil fuel consumption led to corresponding changes in carbon dioxide emissions, indicating the significant role of fossil fuels in driving greenhouse gas emissions within the Canadian economy. The results revealed a unidirectional causality from CO₂ emissions to trade openness. This indicates that changes in carbon dioxide emissions influence trade openness. This relationship emphasizes the potential impact of environmental factors, particularly carbon emissions, on trade dynamics within the Canadian economy.

4. Discussion

The empirical results from both short- and long-run estimations and the Granger causality tests reveal consistent implications. They suggest that the use of fossil fuels as an energy source significantly influences CO₂ emissions. Specifically, a 1% increase in fossil fuel energy usage is associated with a subsequent long-term increase in CO₂ emissions in the USA. However, in Canada, the findings indicate that both short-term and long-term fossil fuel energy use is associated with a reduction in CO₂ emissions. These findings align with previous studies by Chen et al. (2019), Zhang et al. (2019), Li & Haneklaus (2021), and Liu (2021), which examined the significant positive influence of non-renewable energy on China's CO₂ emissions. Similarly, Munir & Riaz (2020), Abokyi et al. (2021), and Lin & Agyeman (2019) have established a significant association between fossil fuels and carbon emissions generation in cross-country analyses involving the United States. Conversely, the negative impact of fossil fuel on CO₂ emissions in Canada validates the results of Ehigiamusoe (2020), who found a negative relationship with CO₂ in African countries. According to the ARDL output, economic growth has a significant impact on pollution levels primarily in the long run in Canada, where it materially increases pollution over time. In the short run, economic growth in Canada positively and negatively influences CO₂ emissions. However, in the United States, there is no significant effect of economic growth on CO₂ emissions observed in either the short run or the long run. The current study's findings regarding the impact of GDP on CO₂ emissions align with the results of a similar study by Adeleye et al. (2021), which also found a significant positive effect of GDP on CO₂ emissions in both the short run and long run. These findings support the Environmental Kuznets Curve (EKC) hypothesis, suggesting that as economies develop, environmental degradation initially worsens but eventually improves as income levels rise.

The Granger causality checks also indicate a bidirectional causality between CO₂ and fossil fuel emissions in the United States, while a unidirectional causality is observed between fossil fuel and CO₂ emissions in Canada. This finding is consistent with previous research by Minlah & Zhang (2021), which similarly identified a unidirectional causality between these variables. However, the estimated results show that while FDI does not have a significant influence on CO₂ emissions in the long run in the United States, it does have a positive short-run effect. Conversely, in Canada, FDI has a positive impact on CO₂ emissions in the long run, but its effects are mixed in the short run, with both positive and negative effects observed. The Granger causality test found no causal relationship between FDI and CO₂ emissions in both countries. These findings contradict the outcomes from studies by Salahuddin et al. (2018) and Sarkodie (2018), which found a unidirectional causality between FDI and CO₂. Trade openness has a negative impact on CO₂ emissions in the long run in the United States, while exhibiting a mixed positive and negative influence in the short run. Conversely, in Canada, there is a positive effect of trade openness on CO₂ emissions in the long run. The Granger causality test found a unidirectional relationship between CO₂ and trade openness in

both countries. These findings provide support for the EKC hypothesis, suggesting that as economies develop, environmental degradation initially worsens but eventually improves as income levels rise.

The findings suggest that gross fixed capital formation has significant impacts on pollution levels in both the short and long run in both economies. However, despite these observed impacts, the Granger causality test did not establish a causal relationship between gross fixed capital formation and pollution. Kobayakawa (2022) suggested that countries which prioritize investment in carbon-intensive capital formation tend to experience accelerated economic growth.

Conclusions

The study investigates the dynamic relationship among domestic investment, GDP per capita, and carbon dioxide (CO₂) emissions in the United States and Canada. Utilizing annual time series data spanning from 1990 to 2021 sourced from the World Bank, the analysis employs the Autoregressive Distributed Lag (ARDL) bound testing to cointegration approach. The findings from the bound test cointegration reveal a long-run relationship between the selected variables in both countries. In the United States, the ARDL short-run results indicate a positive relationship between FDI and gross fixed capital formation with carbon dioxide emissions, while GDP per capita shows no significant impact. However, in the long run, only gross fixed capital formation is found to positively influence CO₂ emissions, with FDI and GDP per capita growth showing no significant effects. Notably, other independent variables such as trade openness exhibit a positive short-run effect and a long-run negative relationship with CO₂ emissions, while fossil fuel consumption is found to positively impact carbon dioxide emissions. The Granger causality test established a bidirectional relationship between fossil fuel consumption and carbon dioxide while a unidirectional causality from trade openness to CO₂ emissions was found in the US. In the context of Canada, there is a positive short-run and long-term linkage observed between gross fixed capital formation and CO₂ emissions. The short-run findings also reveal a mixed positive and negative effect of FDI and GDP per capita on carbon dioxide emissions in the Canadian economy. However, in the long run, both FDI and GDP per capita are found to have a positive impact on CO₂ emissions. Conversely, fossil fuel consumption exhibits negative short- and long-term effects on carbon dioxide emissions in Canada, while a positive effect from trade openness is observed in the long run. The Granger causality test indicated a unidirectional relationship among CO₂ emissions, fossil fuel consumption, and trade openness in Canada's economy.

The study findings suggest policy interventions to address the complex dynamics between economic growth, foreign investment, and environmental sustainability in both the United States and Canada. Given the positive linkage observed between gross fixed capital formation and CO₂ emissions, policymakers should prioritize investments in renewable energy sources such as solar, wind, and hydroelectric power to mitigate carbon emissions and promote sustainable energy generation. Additionally, the mixed effects of FDI and GDP per capita on carbon dioxide emissions emphasize the importance of improving energy efficiency measures. Policies aimed at incentivizing energy-efficient technologies and practices in industries and households can help reduce carbon emissions while supporting economic growth. Furthermore, the positive effect of trade openness on carbon emissions observed in the long run in both countries calls for policies that promote sustainable trade practices. Implementing carbon pricing mechanisms, enforcing environmental regulations, and promoting eco-certifications in international trade agreements can help mitigate the environmental impact of trade activities. Moreover, given the positive relationship between fossil fuel consumption

and carbon dioxide emissions, policymakers should prioritize investments in clean technologies and alternative fuels. Research and development funding for technologies such as carbon capture and storage (CCS), hydrogen fuel cells, and sustainable biofuels can facilitate the transition to a low-carbon economy. Finally, public awareness and education campaigns are essential for fostering a culture of environmental sustainability. Governments and non-governmental organizations should collaborate to raise awareness about the environmental consequences of consumption patterns, encourage sustainable lifestyle choices, and promote community-based initiatives for environmental conservation.

While the study offers significant details, it has limitations. It relies on annual data from 1990 to 2021, which may have constraints in availability and accuracy. The methodology used may not fully capture the complexity of the relationship between variables. The findings are specific to the US and Canada, limiting generalizability. Other factors influencing CO₂ emissions, such as government policies and technological advancements, were not included. Alternative methodologies could offer different insights. These limitations suggest areas for future research.

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The Impact of Varying Styles of Leadership on Team Dynamics and Project Success

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Abstract

The present study examines the impact that distinct styles of leadership have on team dynamics and project success. By combining purposive, convenience, and networking sampling techniques to avoid overreliance on one single sampling technique, we used partial least squares structural equation modelling on a sample of 188 responses obtained from a semi-structured matrix-based questionnaire. Our findings revealed that autocratic leadership has no significant impact on team dynamics or project success. All other styles considered (i.e. servant leadership, agile leadership, ethical leadership, and laissez-faire leadership) have a statistically significant impact on team dynamics and project success. Furthermore, servant leadership and agile leadership have a strong positive correlation with team dynamics and project success, whereas ethical leadership exhibits a moderate positive linkage with team dynamics and project success. Laissez-faire leadership and autocratic leadership have weak positive correlations with team dynamics and project success. Lastly, team dynamics impact project outcomes in a statistically significant manner. Our analysis concludes that the most effective leadership style among all the above is servant leadership, which has a statistically significant positive impact on team dynamics and project success.

Key words

leadership style; teams dynamics; project success; project management.

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Introduction

Haque et al. (2015) argued that within distinct economic sectors, leadership is an essential component of operational success and the management of projects. Strong leadership skills are one of the requirements within project management for the successful implementation and execution of

strategic goals (Kumar, 2009). In the modern business environment, effective project management has been vital for the timely conclusion of operations (Duggal, 2023). The role of the leader turns out to be more important in project management because the completion of tasks relies heavily on collaboration, coordination, and teamwork. Thus, for successful completion, the art and science of guiding a team could be regarded as project leadership. In other words, a common goal is achieved by a group of people under the project's leadership since collective work enables the team to achieve more compared to individual efforts (Duggal, 2023). Nonetheless, project leaders demonstrate different styles of leadership; yet there is no conclusive evidence on which style of leadership is more efficient and effective in the completion of a successful project, especially in the field of project management. Interestingly, in project management, a project lead could also be part of a project team, working with teammates and being involved in maintaining relationships with clients while scheduling the timely completion of the project within the constraints imposed by the budget. For the successful completion of the project, there is a heavy reliance of project managers on tools and techniques, such as Gantt charts, dashboards, and so on (Leadership in Project Management, 2023).

In this study, project success is defined through the multidimensional approach. Turner & Zolin (2012) and Shenhar et al (2001) frameworks have been considered by evaluating three key dimensions (the triple baseline) to measure project success. The first dimension is the 'time' of completion of a successful project and whether this happened within the scheduled timeframe. 'Cost' is the second dimension, indicating that the project adheres to the defined budget, and 'quality/scope' is the third dimension, confirming that the project will be successful through the deliverables meeting the scope, objectives, and the agreed-upon quality standards. Interestingly, the fourth dimension by which to measure project success in this study is 'stakeholder satisfaction'. Müller & Jugdev (2012) stated that stakeholder satisfaction is a very important aspect in measuring the overall success of a project, especially from the perspectives of clients and team members. Hence, we considered these four dimensions to measure project success. Urbański et al. (2019) argued that "implementing risk management frameworks help in enhancing project success and ensure the effectiveness of project planning in a competitive business environment". Thus, risk management and planning are important factors that need to be taken into consideration regarding the role of leaders actively involved in project management processes. This research further expands the body of empirical knowledge regarding leadership styles, especially within the project management space. In addition to that, the analysis aims to offer a more detailed overview of these characteristics compared to more general approaches embraced by the most recent literature. Scholars and academics will benefit from this study since it will help them enhance the existing body of knowledge, while project management professionals will benefit by learning about the leadership techniques that are more effective. Conclusively, this research aims to investigate how distinct styles of leadership affect team dynamics and process success.

1. Literature review

1.1 Effectiveness

Effectiveness refers to how a process has been performed for us to achieve the desired result (Jense, 2005). It describes the level of convergence between the attained target and the goal that was set at the outset of a project. According to Jensen (2005), effectiveness enables the organisation to achieve the mission, vision, goals, and strategic objectives, which, in the business context, is a capacity and

capability being combined in the appropriate manner. Powerful leadership plays a pivotal role in a project's success. According to Urbański et al. (2019), customer satisfaction is enhanced when a project leader has good management skills and the ability to deliver a project in a timely manner within the allotted budget.

1.2 Project Management

According to Good (2024), a project leader, in a certain timeframe, should ensure that the desired results are attained by using the knowledge and skills of the diverse group members. Hence, there is a clear purpose and a strategy to accomplish the short-term unique task within the specified time limit. Project requirements are kept in mind while it is ensured that not only tools and techniques are employed, but also that the skills and knowledge of the invaluable team members are used effectively by the project leads (PMI, 2017). It is important to understand that project leadership and project management are two distinct terminologies (Kumar, 2009). Hence, it is also possible that a successful manager might not always be a successful leader. Nonetheless, with the changes in the operative dynamics, it is also likely that project managers might develop strong leadership abilities and eventually emerge as successful leaders. Thus, with the changes in environmental demands, strong leadership is recommended to project managers in order to remain competitive, if not always successful. One could argue that creative and innovative abilities could be used by successful managers to develop leadership capabilities, so they remain effective in managing team dynamics and completing projects in a timely manner.

1.3 Team Dynamics in Project Management

We define a team as a structured group of individuals that demonstrate intention towards achieving a common goal (Zlotan & Vancea, 2015). From project initiation to project closing, the group of individuals working collectively to accomplish the task is regarded as the project team. There is a chance that for certain projects, cross-functional teams are formed, which means that individuals from different departments are collaboratively working together to achieve a common objective. According to Vige (2022), project scope and timely completion of the project is also the responsibility of project teams. "Teamwork is defined as the procedure between individuals within a team collectively working to resolve an issue or provide a solution to a given task" (Schmutz et al., 2019). As per Project Central (2021), three main objectives of a project management collaboration is to ensure team effectiveness in the completion of a project, develop an environment that team members feel good about, and are confident about assigned tasks while being engaged in the timely delivery of the project in a stress free manner.

1.4 Leadership Styles and Project Management

Kruse (2013) argued that being in a top position in the organization or having a status of seniority does not reflect leadership. In fact, it has more to do with how others are inspired and guided towards achieving a common goal, so it is more about having a positive social influence on team members to get things done (Kruse, 2013). Although, different styles of leadership are exhibited by individuals in project management, below we have listed some of the most commonly appearing styles (Table 1).

Feder (2022) argued that the laissez-faire leadership style could be both constructive in inspiring creativity as well as destructive in developing a feeling of loss among employees. In other words, there is a possibility that the imagination of team members is enhanced under the laissez-faire style of leadership by providing members a platform to experiment on the grounds that experimentation could foster creativity; delegation of authority could reap good rewards.

Table 1. Leadership styles in project management.

No.	Leadership styles in project management	No.	Leadership styles in project management
1.	“Servant Leadership	4.	Agile Leadership
2.	Ethical (Transactional) Leadership	5.	Autocratic Leadership”
3.	Laissez-Faire Leadership		

Source: developed by the authors.

Conversely, Lindauer (2024) argued that instead of characterized as a leadership style, it is practically a “non-leadership” style because employees do not receive significant guidance. On the other hand, ethical managers help teammates understand that project success is possible only if group members are truthful as well as accessible to one another, express their goals and challenges, and ultimately work together to ensure how their tasks should be planned so that everyone can have access to help and support (Bhatti et al., 2021). Such an approach leads to transparency, higher engagement and commitment, and higher respectability among customers and clients. However, at times, this type of leadership could be costly because of heavy reliance on existing norms. According to Haque & Yamoah (2021), project success and team dynamics are positively affected by the ethical leadership style because of ethical behaviour, integrity, and fairness. These aspects are crucial for project success and the well-being of team dynamics. Interestingly, ethical leaders can be better described as role models that are effective in creating and fostering a culture of trust, transparency, and accountability within a team (Brown & Treviño, 2006). “This leadership style enhances team cohesion by encouraging open communication and mutual respect, which are essential for effective collaboration and conflict resolution” (Walumbwa et al., 2011). Furthermore, positive team performance is a result of ethical leadership, which leads to project success, since there is a supportive and collaborative environment where team members are motivated and feel valued, thus, exhibiting their finest efforts (Piccolo et al., 2010). In addition to that, it is highly likely that projects led by ethical leaders tend to be successfully completed because of the high levels of commitment, high morale, and engagement, among team members (Mayer et al., 2009). According to Kenton (2024), servant leadership is a leadership style and attitude that describes how somebody interacts with others—whether as a senior manager or as a coworker—to gain respect rather than authority. The system symbolizes a decentralized organization and with a servant leadership approach, leaders acquire respect from others by prioritizing the needs of those around them. This fosters a shared vision among employees, which means that when they participate in decision-making, the results are typically on target. On the other hand, few servant leaders are familiar with this kind of administration (Kenton, 2024). The implementation of this method may necessitate significant cultural adjustments and although it is not often a simple process, it can be extremely satisfying. This leadership style encourages leaders to listen actively, show empathy, and provide resources and support, which enhances team cohesion and morale (Liden et al., 2008). As team members feel valued and empowered, they are more likely to be engaged and committed to their work, leading to improved performance and higher quality project outcomes (van Dierendonck, 2011). Consequently, projects led by servant leaders are often more successful due to the high levels of trust, motivation, and collaboration within the team (Spears, 2010).

Based on Nadine (2023), an Agile leadership style is marked by the ability to remain calm under pressure, successfully adapt to uncommon events, be open to creativity, discover techniques to inspire, engage people, and keep teams on track. This style improves responsiveness at all stages, and the leader has a greater appetite for difficult and important tasks, which leads to offering teams more motivation.

Nonetheless, customers might take advantage of the leader's flexibility. Agile leadership, which focuses on adaptability, collaboration, and empowerment, significantly enhances team dynamics and project success. Agile leaders encourage flexibility and responsiveness to change, fostering an environment where team members are empowered to take initiative and make decisions (Rigby et al., 2016). This leadership style promotes a culture of continuous improvement and learning, enabling teams to quickly adapt to new challenges and evolving project requirements (Dugan, 2017). By facilitating open communication and collaboration, agile leadership helps to build strong, cohesive teams that can deliver high-quality results efficiently (Appelo, 2016). As a result, projects led by agile leaders tend to be more successful, as teams are more engaged, innovative, and capable of meeting complex and dynamic project goals (Boehm & Turner, 2005). Centralized decision-making, directive communication, and minimal input from team members are key characteristics of the autocratic leadership style. According to Bass & Bass (2008) this style is most effective in critical situations where quick decision-making and clear directions are required, especially in times of crisis, because team members need more guidance as they lack the necessary experience. However, its effectiveness largely depends on the context and the nature of the team and the project. In some cases, autocratic leadership can lead to high productivity and efficiency, especially when tasks are straightforward and require strong oversight (Harms et al., 2018). Interestingly, the correlation between autocratic leadership and project success is somewhat complex. Shafer (2010) argued that although autocratic leaders could be effective in the completion of a project in a swift manner, the impact on the creativity and morale of the team is largely negative. Gastil (1994) found that lower job satisfaction and lack of motivation are evident in teams operating under an autocratic leader because members might feel no recognition and lack of participation in the process; this then leads to high employee turnover or reduced overall team performance. Consequently, although short-term project success is likely under the autocratic leadership style because of tight control and quick decision-making, it might impact team dynamics in the long-run (Sims et al., 2009).

There are other styles that could have an impact on team dynamics and project outcomes. However, for the purpose of specificity, only selected ones are discussed in this study. Nonetheless, a brief overview of visionary leadership is also given. This is a leadership style that is characterized by forward-thinking, innovation, and imagination. Visionary leaders can see the bigger picture and find creative methods for depicting it. However, there is a significant amount of risk, and personnel may burn out if they are continuously wondering 'What if' and never finish a job (King, 2023). Another such style is participative leadership, which encourages open discussion and innovation among teammates (Zylfijaj et al., 2014). Group members are encouraged to offer their thoughts and opinions during the process of decision-making when a group-related choice must be taken (Simply Psychology, 2024). One advantage of participatory leadership is the way it fosters employee involvement and responsibility. One disadvantage of participation in leadership is that it may be time consuming. Since choices are reached through discussion and building consensus, it may take more to achieve a result than under more authoritarian approaches to leadership.

1.5 Theoretical Framework and Hypothesis

For the scope of this project, only specific styles of leadership are considered. Thus, our study underlines and compares depth of knowledge to breadth of knowledge. Figure 1 presents a summary of the theoretical framework of the paper.

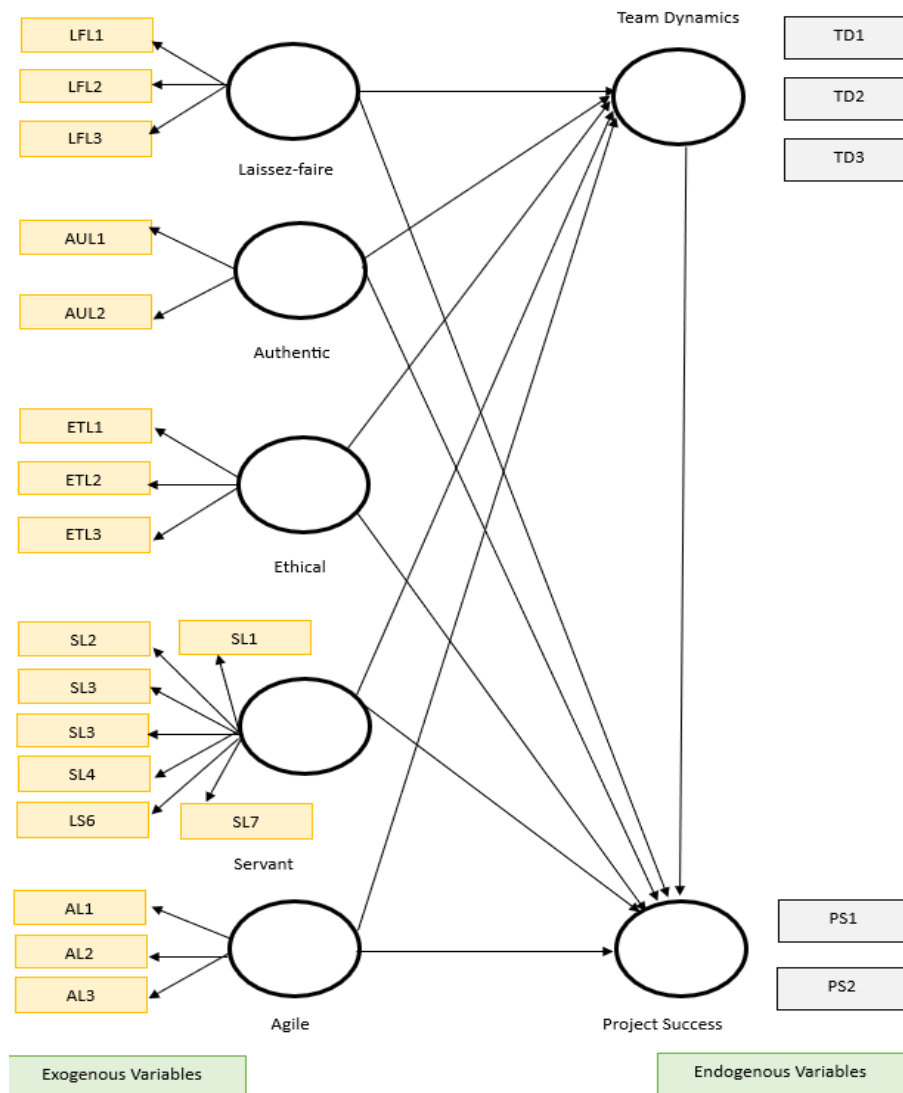


Figure 1. Theoretical framework of the paper.

Source: developed by the authors.

Based on the literature the following hypotheses are developed:

Ha: Distinct leadership styles do not significantly affect team dynamics of the project team.

Hb: Distinct leadership styles do not significantly affect project success.

Hc: There is no positive correlation between leadership style, team dynamics, and project success.

2. Methodology

Sekaran & Bougie (2013) state that the type of research determines the choice of research philosophy. The use of positivism was selected to examine the relationship between the variables employed, something that enabled us to gain mathematical objectivity. De Vaus' (2006) analytical approach is followed to ensure our research findings are supported by quantitative data. The use of cross-sectional data enables us to collect and analyze data with only one time lag (Sekaran & Bougie, 2013). Secondary data is used to gain a deeper understanding of our research goals. The cross-sectional design to compare the variables of interest used in this study, is based on the strategy employed by earlier researchers' work, namely, Haque et al. (2021), and Rahman et al. (2020). Out of the initial 350 respondents who were surveyed, 188 fully completed questionnaires were selected for

final analysis, yielding a response rate of 53.7%. We combined purposive, convenience, and networking sampling techniques to avoid overreliance on one single sampling technique. The basis for selecting respondents was based on the convenience and purposive sampling technique. Moreover, strong networking also played a pivotal role in the data collection process. The choice of the preferred industries (construction, education, Information Technology, healthcare, and manufacturing) is based on an axiological perspective, which means that the researchers focused primarily on the sectors where they had optimal chance to gather data to draw logical conclusions. The axiological stance is clearly stating that the selection of respondents from five sectors (healthcare, manufacturing, construction, IT, and education) was intentional. The prime motivation was to explore dynamics of leadership across a diverse range of industries to attain a broader understanding of how leadership style impacts businesses in varying contexts. We considered both service and production-oriented industries to ensure we had a comprehensive scope for understanding leadership impact. We hypothesized that these different sectors might show varying team dynamics and leadership effectiveness because of varying project types, leadership needs, and the overall operational environment (Northouse, 2018). The benchmark of a minimum of 35 respondents from each sector was considered, following Roscoe (1975) who suggests a minimum representation of greater or equal of 30 respondents (Table 2).

Table 2. Respondents from five different sectors in the present study.

Sectors	Number of respondents	Sectors	Number of respondents
Healthcare	37	Manufacturing	39
Education	40	Construction	36
Information Technology	36	Total	188

Source: developed by the authors based on the primary data using funnel approach.

The use of convenience sampling is based on the convenience of the respondents and in these sectors, researchers have excellent connectivity. Although this can introduce personal bias, Harman's single-factor test reduces the typical technique bias. The focus remains on dynamic sectors commonly found in all types of economies to enable more concentrated and in-depth studies. Perhaps this is due to the researcher's axiological position rather than their scientific technique.

Partial Least Squares Structural Equation Modeling (PLS-SEM) was used for the quantitative analysis. Good research emphasizes depth over breadth (Kaur & Haque, 2024; Haque, 2018); in the same spirit, we restricted our focus and only selected five sectors with at least 10 employees (study respondents were only those whose project-related job was that of the Project Manager, Team Leader, Team Member, and Project Coordinator). These individuals were specialized in projects and had experience of working in teams on different projects. The majority of participants are team members (86), team coordinators (38), team managers (35), and team leads (29) respectively (Table 3).

Table 3. Job categories of respondents.

Job Categories	Number of respondents	Job Categories	Number of respondents
Team members	86	Team managers	35
Team coordinators	38	Team Lead	29
Total			188

Source: developed by the authors using the funnel approach.

Hence, the views of team members are more evident in comparison to other job categories represented in this study. One limitation of the present study is that we have not assigned equal weights in terms of representation to all considered job categories. While managers (e.g., Project Managers and Team Leaders) may assess leadership styles from a strategic standpoint, team members might focus more on operational and interpersonal aspects (Dulewicz & Higgs, 2005). Nonetheless, the focus of this manuscript was on styles of effective leadership on the project success and thus team members' views work in favor to attain the objective of this study. In other words, team members are directly affected by the leadership style and their performance and project success might be affected more than other identified job categories. However, the lack of equal representation of all used job categories still remains a limitation of the study. There is just one time interval because the data was collected within five months reflecting the cross-sectional aspect of the study (Sekaran & Bougie, 2013).

Despite variances and growing discrepancies in the sample framework, we used Haque's (2018) approach of combining several sampling strategies to ensure fair representation; this is also an effective approach for minimizing dependency on a single technique. Furthermore, questions were asked at the appropriate time, while responders were given no time restriction. Moreover, the common technique bias was avoided using Harman's single-factor test (Hu & Bentler, 1999). As a technique, the items of all variables included in the study were confined to a single factor explaining 30% of the total variance, which was considerably below the 50% cut-off mark (Hu & Bentler, 1999). In addition to that, all respondents held an undergraduate or postgraduate degree; the questionnaire was written in English and pilot testing was conducted prior to data collection with three academics and five respondents selected at random. Finally, secondary data has also been considered with a total of 32 articles examined to understand the styles of leadership in relation to team effectiveness. Only papers published in Scopus databases were selected. Finally, the data was gathered through bibliometric analysis, which helps in confining data specificity.

3. Results

Ringle et al. (2015) stated that Structural Equation Modelling (SEM) analysis commonly uses Smart-PLS (statistical software). We used the same SEM in this study. Haque (2024) argued that it has emerged as a popular choice among researchers for its efficiency to attain accuracy in results. Leadership Styles (autocratic, laissez-faire, ethical, servant, and agile leadership) are exogenous variables (an independent reflective) while Team Dynamics and Project Success are endogenous variables is employee performance.

3.1 Measurement of Model Validity

Discriminant and convergent validity are indicators of measurement model validity attained by using PLS (SEM). Cronbach's alpha (α), composite reliability (CR), and average variance extracted (AVE) reflect construct validity. As Table 4 shows, the items are acceptable because the obtained values for α and CR are greater than the benchmark value of 0.7, while AVE is only 0.5 (Hair et al. 2014).

Table 4. Finding of the measurement model (first order, reflective).

Construct	α	CR	AVE	Construct	α	CR	AVE
Servant Leadership	0.90	0.92	0.72	Autocratic Leadership	0.75	0.78	0.36
Agile Leadership	0.88	0.90	0.64	Team Dynamics	0.92	0.94	0.81
Ethical Leadership	0.85	0.88	0.56	Project Success	0.91	0.93	0.72
Laissez-Faire Leadership	0.80	0.84	0.49				

Source: developed by the authors.

To ensure external consistency of the model via discriminant validity, Fornell-Larcker criterion and cross loading were used. “The latent variable’s AVE should be greater than the squared correlations between those considered latent variables” (Fornell and Larcker, 1981; Imran et al. 2018). The discriminant validity confirmed in this study is reflected in Table 5.

Table 5. Fornell-Larcker Criterion.

Construct	Servant Leadership	Agile Leadership	Ethical Leadership	Laissez-Faire Leadership	Autocratic Leadership	Team Dynamics	Project Success
Servant Leadership	0.85	0.75	0.65	0.45	0.20	0.85	0.80
Agile Leadership	0.75	0.80	0.70	0.50	0.30	0.75	0.70
Ethical Leadership	0.65	0.70	0.75	0.55	0.25	0.65	0.60
Laissez-Faire Leadership	0.45	0.50	0.55	0.70	0.35	0.45	0.40
Autocratic Leadership	0.20	0.30	0.25	0.35	0.60	0.20	0.10
Team Dynamics	0.85	0.75	0.65	0.45	0.20	0.90	0.90
Project Success	0.80	0.70	0.60	0.40	0.10	0.90	0.85

Source: developed by the authors.

According to Haque et al. (2021), heterotrait-monotrait ratio of correlations (HTMT) is a new criterion to measure discriminant validity. Since the values obtained is less than 1, we confirm that they are acceptable (Table 6).

Table 6. Results of HTMT.

Construct	Servant Leadership	Agile Leadership	Ethical Leadership	Laissez-Faire Leadership	Autocratic Leadership	Team Dynamics	Project Success
Servant Leadership	0.91						
Agile Leadership	0.88	0.87					
Ethical Leadership	0.77	0.83	0.77				
Laissez-Faire Leadership	0.61	0.64	0.68	0.54			
Autocratic Leadership	0.29	0.41	0.33	0.47	0.45		
Team Dynamics	0.94	0.88	0.77	0.61	0.29	0.31	
Project Success	0.94	0.88	0.77	0.61	0.29	0.94	0.20

Source: developed by the authors.

3.2 Structural Model Assessment

To draw logical conclusions, a structural model assessment is carried out and the path coefficient is used for evaluating the structural model assessment. In Table 7, the data analysis outcome is demonstrated through t-values ≥ 1.96 at the 0.05 significance level as a threshold value, and the t-value reflects a positive relationship.

In this study, R^2 suggests moderate variation in team dynamics (0.72) and (0.85) in project success by leadership styles, reflecting over 70% variation in the team dynamics due to leadership styles, while 85% variance in project success is explained through the model (Table 7). The size effect of leadership style on team dynamics is found to have a largely weak impact ($f^2 = 0.25, 0.20, 0.18, 0.15, 0.05$, and 0.30), project success: $f^2 = 0.2, 0.22, 0.19, 0.17$, and 0.03 (Table 7).

Table 7. Findings of Structural Model.

Hypotheses	B	t-value	Decision	f ²	R ²
Servant Leadership → Team Dynamics	0.85	15.67	0.000**	0.25	0.72
Agile Leadership → Team Dynamics	0.75	12.34	0.000**	0.20	
Ethical Leadership → Team Dynamics	0.65	10.01	0.000**	0.18	
Laissez-Faire Leadership → Team Dynamics	0.45	7.45	0.000**	0.15	
Autocratic Leadership → Team Dynamics	0.20	1.98	NS	0.05	
Team Dynamics → Project Success	0.09	18.92	0.000**	0.30	0.85
Servant Leadership → Project Success	0.80	16.45	0.000**	0.25	
Agile Leadership → Project Success	0.70	13.67	0.000**	0.22	
Ethical Leadership → Project Success	0.60	11.23	0.000**	0.19	
Laissez-Faire Leadership → Project Success	0.40	8.50	0.000**	0.17	
Autocratic Leadership → Project Success	0.10	1.56	NS	0.03	

Note: ***p<0.1, **p<0.05, ns= nonsignificant (p>.05) (Two Tail).

Source: developed by authors.

The results of this study show that servant leadership style, agile leadership style, ethical leadership style, and laissez-fair leadership have a statistically significant positive impact on team dynamics (SL: $\beta = 0.85$, $t = 15.76$; AGL: $\beta = 0.75$, $t = 12.34$; EL: $\beta = 0.65$, $t = 10.01$; LL: $\beta = 0.45$, $t = 7.45$; Table 5), while autocratic leadership has no significant impact on team dynamics (AL: $\beta = 0.09$, $t = 1.98$; Table 7). Interestingly, results also confirmed that team dynamics have significant impact on project success (TD: $\beta = 0.90$, $t = 18.92$; Table 7). Moreover, it is also found that servant leadership, agile leadership, ethical leadership and laissez-fair leadership have statistically significant impact on the project outcome (SL: $\beta = 0.80$, $t = 16.45$; AGL: $\beta = 0.70$, $t = 13.67$; EL: $\beta = 0.60$, $t = 11.23$; LL: $\beta = 0.40$, $t = 8.50$; Table 7). However, autocratic leadership has no significant impact on project success (AL: $\beta = 0.10$, $t = 1.56$; Table 7). Thus, we reject both hypotheses. In other words, different leadership styles affect team dynamics and project success differently. Funnel approach revealed that servant leadership is conducive to success in project work across all given considered sectors. Thus, it is confirmed from this study that the servant leadership style is significantly interlinked with project success. However, it is also noted that there is evidence regarding the variation of servant leadership in considered sectors. In terms of visibility, servant leadership is more prominent in the education sector, followed by healthcare, IT, manufacturing, and to a lesser extent in the construction sector.

Not all styles have a significant impact since the autocratic style was found to have no significant impact on team dynamics and project success. This study, to some extent, supports the work of Feder (2022) while opposes the work of Lindauer (2024) since we established the impact of laissez-faire leadership style on team dynamics and project success. In addition to that, the results of this investigation are aligned with the work of Piccolo et al. (2010) regarding positive impact of ethical leadership on team dynamics and project success. Since servant leadership has a statistically significant impact on project success as well as team dynamics, we support earlier studies who have found identical results (Liden et al., 2008; Spears, 2010; van Dierendonck, 2011; Kenton, 2024). Lastly, the findings of this study also support the work of Appelo (2016) and Boehm & Turner (2005) that project success and team dynamics are positively impacted in a statistically significant manner by the agile leadership style. It is interesting to note that employees perform better under all types of leadership apart from the autocratic leadership style. Our findings partially differ from the work of Haque et al. (2015) that the transactional (ethical leadership) style has a negative impact on the performance and team motivation and morale. The funnel approach showed that servant leadership works surprisingly

well in the education industry, while ethical leadership and agile leadership style are more effective for individuals working in the IT sector.

In addition to the first two hypotheses, the third hypothesis was to examine the strength (direction) and degree (magnitude) of the correlation between the variables of interest. The results showed that there is a statistically significant strong positive correlation between servant leadership and team dynamics as well as project success (SL→TD: = 0.000 < 0.05; $p < 0.05$; SL→PS: = 0.000 < 0.05; Table 8). Similarly, agile leadership also has a strong positive correlation with team dynamics and project success (AGL→TD: = 0.000 < 0.05; $p < 0.05$; AGL→PS: = 0.000 < 0.05; Table 8). Additionally, ethical leadership and laissez-faire leadership has a positive moderate correlation with team dynamics and project success (EL→TD: = 0.001 < 0.05; $p < 0.05$; EL→PS: = 0.001 < 0.05; LL→TD: = 0.001 < 0.05; $p < 0.05$; LL→PS: = 0.001 < 0.05; Table 8). Furthermore, there is no statistically significant correlation between autocratic leadership and team dynamics as well as project success (AL→TD: = 0.07 > 0.05; $p < 0.05$; AL→PS: = 0.01 > 0.05; Table 8).

Table 8. Correlation between variables of interest.

Correlation variable	Pearson Correlation	Sig Value	Results	Interpretation
Servant Leadership → Team Dynamics	0.91	0.000	$P < \alpha$	****
Agile Leadership → Team Dynamics	0.75	0.000	$P < \alpha$	***
Ethical Leadership → Team Dynamics	0.65	0.001	$P < \alpha$	**
Laissez-Faire Leadership → Team Dynamics	0.45	0.001	$P < \alpha$	**
Autocratic Leadership → Team Dynamics	0.20	0.07	$P > \alpha$	*
Team Dynamics → Project Success	0.90	0.000	$P < \alpha$	****
Servant Leadership → Project Success	0.80	0.000	$P < \alpha$	****
Agile Leadership → Project Success	0.87	0.000	$P < \alpha$	****
Ethical Leadership → Project Success	0.60	0.001	$P < \alpha$	**
Laissez-Faire Leadership → Project Success	0.40	0.001	$P < \alpha$	**
Autocratic Leadership → Project Success	0.10	0.10	$P > \alpha$	*

Note: NS = No Significance, ** = significant, *** = highly significant, and **** = highly statistically significant.

Source: developed by authors.

Thus, servant leadership style is the most effective, followed by the agile leadership style. Servant and agile leadership styles have the highest impact on the effectiveness of team and project success; therefore, this study supports the work of Akhaya et al. (2022) and Aftab et al. (2022). Since this study found that ethical leadership has moderate positive correlation with team dynamics and project success, the work of Gulzar and Rehman (2021) is contradicting. There is partial confirmation of the work of Nauman et al. (2022) and Wang et al. (2022) because the moderate correlation was established with the laissez-faire style. However, this study contradicts the work of Gayan (2023), Skogstad et al. (2007), and Zhang et al. (2023) by confirming moderate positive relationship between the laissez-faire style of leadership and team effectiveness. The study found a statistically significant positive correlation between the variables of interest, except from one style. To put it another way, the path coefficient base model (CI values ranging from 0.40 to 0.85, Table 9) shows that when leadership styles are combined, they have significant impact on the performance of team and project success. Thus, there is substantial evidence that we can reject hypothesis 3.

From secondary sources, it is concluded that distinct styles have both pros and cons. They impact team dynamics and success to a certain extent. Laissez-faire leadership style allows empowerment, but it could lead to unclear directions at times of crises (Skogstad et al., 2007; Gayan, 2023; Zhang et al.,

2023). On the other hand, transparency enhances among team members with the ethical style, however, it could create discrepancies among team members and stiff competition within the team because the reward-and-punishment approach can create an unbalanced team (Walumbwa et al., 2012; Gulzar & Rehman, 2021; Martin et al., 2021).

Table 9. Path Coefficient in the base line model.

Structural Path	Coefficient Path
Servant Leadership → Team Dynamics	0.85***
Agile Leadership → Team Dynamics	0.75***
Ethical Leadership → Team Dynamics	0.65***
Laissez-Faire Leadership → Team Dynamics	0.45**
Autocratic Leadership → Team Dynamics	0.20 (NS)
Team Dynamics → Project Success	0.90***
Servant Leadership → Project Success	0.80***
Agile Leadership → Project Success	0.70***
Ethical Leadership → Project Success	0.60***
Laissez-Faire Leadership → Project Success	0.40**
Autocratic Leadership → Project Success	0.10 (NS)

Note: * $p < .05$, ** $p < .01$, *** $p < .001$.

Source: developed by authors.

Visionary leadership helps in creating team dynamics to perform better, but it can lead to situations of alienation (der Voet & Steijn, 2021; Liu et al., 2022). Participative leadership could impact the crisis in a negative manner, but both the well-being and the self-esteem improve (Ali et al., 2022; Wang et al., 2022). Moreover, secondary sources revealed that servant leadership has a positive impact on team effectiveness (Ruiz-Palomino et al., 2021; Nauman et al., 2022). It is important to note that while servant leadership has broad applicability, it may be most effective in certain types of projects, depending on contextual factors like the project phase and industry requirements. In certain types of sectors, servant leadership is often the key driver behind project success, especially in healthcare and education (Eva et al., 2019). However, in fast-paced industries like IT where projects are time sensitive, and high stake or construction projects where triple baseline is frequent, servant leadership might not be very effective. Lastly, team performance is affected positively by agile leadership, as it is more connected to external parties and able to resolve conflicts, however, agile women leadership is frequently found positive while agile men leadership is not always fruitful (Hoobler et al., 2018; Akhaya et al., 2022; Aftab et al., 2022). From the empirical literature at hand, we identified that Van Dierendonck (2011) argued that team cohesion and communication increase due to an environment of trust with team dynamics leading towards project success, while servant leadership fosters an environment of trust, collaboration, and empowerment. However, if not always, but in most situations, team dynamics reap positive and successful results. Moreover, Greenleaf's (1977) work revealed that stakeholders' and teams' needs are met when projects are overall successful. In the present study, we found that team performance and project successes have been statistically significant and positively affected by servant leadership, thus, the positive correlation confirms servant leadership's role and indicates that it is mostly team dynamics that contribute towards project success.

It is important to note that the original study did not analyze specifically the sectoral impact because it was not the prime focus of this study. Additionally, the sample size constraints also restricted us in the sectoral analysis because the sample size is relatively smaller in each sector, thus, it limited

our ability to commence a meaningful cross-sector analysis without reducing the statistical power and numerical significance.

Conclusion

The overall conclusion is that the most effective leadership style among all is servant leadership. This style has a statistically significant positive impact on team dynamics and project success. Nonetheless, the agile leadership style also has a strong significant correlation with team dynamics and project success. However, we also conclude that different styles affect teams differently. Consideration of the nature of the project is critical, but to a larger extent project leaders and managers should ensure agility and adaptability. Based on the quantitative statistical analysis we conducted, we conclude that there is sufficient evidence to reject all three considered hypotheses of the study. In other words, distinct styles of leadership affect team dynamics and project success markedly.

In the present study, we investigated the current practices by project leaders rather than explored the ideal practices or hypothetical scenarios promoting ideal practices. Our conclusion is aligned with the work of Eva et al. (2019) since we identified that servant leadership is highly effective in environments that require higher stakeholder engagement and strong team collaboration, especially in healthcare and education. Nonetheless, we also acknowledge that servant leadership might not always be the most effective style in fast-paced industries, where quick decision-making and top-down directives are critical factors, such as in construction and high-stakes IT projects.

One of the limitations the present research has is that it is using quantitative data and not qualitative data. Hence, mathematical objectivity is attained, and results are numerically expressed, but in-depth analysis is missing. The hidden embedded truth (useful truth) is missing while factual truth has been attained. Moreover, this research is conducted in a limited timeframe therefore a longitudinal design is not used. In other words, by using cross-section analysis we focus on a specific point in time rather than different time intervals.

One of the limitations of this study is that project managers and project leaders might assess the leadership style from a strategic dimension (standpoint) while team members and team coordinators might focus higher on the interpersonal and operational perspective. Another limitation of the study is the omission of a sectoral analysis because we did not mainly focus on sectors in this study. Since, the sample size was small for each sector there was a sample constraint that limited us in conducting a meaningful cross-sector analysis. Perhaps, the cross-section analysis would have reduced the statistical power and numerical significance to a certain extent, though, we did not want to lose mathematical objectivity.

While present study provides invaluable insight by exploring the impact of various leadership styles on team dynamics and project success, yet the study offers a broader and general view. In other words, the project related specific factors such as nature, required timeframe, implementation phase, and the project implementation context are not considered that could impact the leadership styles' effectiveness. This is the limitation of the study that we focused on generalizability component to be in confined scope independent of project-specific characteristics, however, it serves foundation for the future studies.

Future researchers could consider the use of qualitative analysis to gain a more in-depth understanding of these matters. They could also consider in-depth interviews and panel discussions to ensure there is more concrete evidence regarding the variations in the variables of interest. Another

suggestion is to use advanced research instruments such as interviews and focus groups with experts from the field to gain more comprehensive information. In other words, they could consider the use of expert panels to gain more field related (i.e., project management) practical information. Future studies shall consider this limitation and use it as a foundation for their studies to have a comparison between strategic dimension (managers and leaders) and interpersonal and operational dimension (coordinators and members). Moreover, we suggest that future studies shall consider cross-section analysis to gain more in-depth insights about the specific topic. In other words, future research shall address the differential impacts of leadership styles across various sectors through larger sector-specific samples. In addition to that, the future studies shall consider the inclusion of determinants of leadership styles such as project's nature, implementation phase, required timeframe, and context of project implementation. These project related factors shall be considered because this could impact the effectiveness of the leadership styles. Future studies shall take into consideration project-specific characteristics to understand the impact of varying leadership styles on the team dynamics and project success in more depth. By incorporating this suggestion, future studies would be adding additional practical applicability layer to present research on leadership styles.

In the light of present findings, one of the most important recommendations for organizations dealing with distinct styles of projects is that they should consider hiring a professional mentor or a professional coach, who could work along with teams to guide them so that their effectiveness and motivation leads to desired project results. This would also lead to having closer interactions and face-to-face sessions, thus, helping the team share their concerns and groom their leadership skills to take on future projects. An effective listening mechanism should also be developed to ensure that all members feel that they are being heard, which in turn, will improve their sense of belongingness. Project success heavily relies on the collaborative approach. Once employees feel that they are valued, and their concerns are addressed they are willing to collaborate further. Moreover, organizations should ensure that goals and targets are continuously reminded because every project is different, and a new approach might be necessary. A clear role definition is also pivotal for project success, since employees should be regularly reminded about their responsibilities, and there should be a fair system in place in terms of accountability. Perhaps, a periodic assessment of the progress could help teams in measuring their performance and reflect on ways to improve the future course of actions. There should be a proper strategic approach to develop role models within the team, who exhibit excellence in their approach and behavior. This will further make team members honest, responsible, and ensure good work ethic that would lead to project success.

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Factors affecting Information and Communication Technology (ICT) Development on a National Scale

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Abstract

This research aims to investigate factors influencing in-country ICT development projects, considering decision-making roles within a social and political context to foster consensus, focusing on Small Island Developing States (SIDS) including Samoa. This study argues that such factors can be classified into processes (h1), governance (h2), and sociocultural indicators (h3). The conceptual framework is built on multiple decision-making models including social choice and rational decision-making procedures, as well as the inclusion of the International Telecommunications Union (ITU) ICT Development Index Framework. This research employed semi-structured interviews and Analytical Hierarchy Process (AHP) analysis to uncover key obstacles, including complex processes, financial sustainability, and cultural norms. The study identified barriers such as leadership styles, geography, and policies, emphasising the importance of decision-making roles within a social and political context. Solutions proposed include the integration of ICT policies, cultural values, and local capacity development. The findings underscore the need for stakeholder collaboration and consideration of socio-cultural factors in decision making. Despite limitations in sample size and bias, the study contributes to understanding the intersection of technology, governance, and culture in ICT development. Implications from the study support the existing literature and provide practicality to the information obtained. It provides practical advice for foreign investors to take into account the social and cultural norms of the local community when establishing businesses in foreign countries, particularly in societies where culture significantly influences decision-making processes. The political implications seem to suggest monitoring the progress and impact of local policies on the development of local businesses. Future research should gather diverse perspectives and employ mixed-methods approaches to deepen insights and address similar challenges in other countries.

Key words

ICT, decision making, AHP, process, governance, socio-cultural.

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Introduction

Information and Communication Technology (ICT) has become an essential part of our daily lives, integrated in the activities we carry out, processes being implemented, and decisions and opportunities presented for individuals, communities, sectors or nations as a whole. For example, the International Telecommunications Union (ITU) (2021) report on digital development recorded the continuous increase of worldwide Internet access from 16% in 2005 to 66% in 2021. The remaining percentage amounts to a total of 2.7 billion people offline, with the majority residing in Small Island

Developing States (SIDS), Landlocked Developing Countries (LLDCs) and Least Developed Countries (LDCs). In the Pacific Islands, ICT has been recognised as a driver of economic development (ADB, 2003; Chan Mow, 2014). The regional recognition of Internet services and applications for the online exchange of information in academia, business, and for entertainment purposes consequently increased the number of smart phones and personal computers owned by individuals.

Even though ICT has been globally recognised as boosting economies in one way or another, some countries struggle to adapt to such technological changes. Several studies have indicated a multitude of factors as barriers to ICT project execution in the form of leadership styles, business strategies, the implementation of e-governance, geography, policies, regulations, and so forth (Gichoya, 2005; Thabit & Jasim, 2019; Briglauer, 2014; Okoro, 2021). Therefore, it is important to conduct research on how countries can leverage national infrastructure and other technical resources for developing economies. Hence, this research aimed to investigate factors affecting in-country ICT development projects with the influence of decision-making roles in a social and political context to foster consensus. Theoretically, embracing change and adaptation plays a crucial role in technological development, evident across all societal levels and practiced within both private and public sectors. This study argued that these changes are abundant and can be classified into processes (h1), governance (h2), and sociocultural factors (h3). This was achieved by addressing the following issues in our research questions: establishing what influences decision making in local ICT development projects; how cooperation between the private and public sectors contributes towards local ICT project developments; and whether culture plays any role in the promotion and development of local ICT services and setting up new businesses.

The majority of academic literature investigates technological environments on the level of individual firms, an amalgamation of private companies, governments as a whole or a collection of country analyses. Information is either collected from the individual firm employees or extracted from the databases of local and/or international organisations. At the micro level, the investigation of bureaucratic insights in the execution of national ICT development projects with regards to decision making is uncommon. There is very little academic literature in this area from bureaucrats, specifically in the Pacific region. Hence, this research intends to provide contributions to academic literature by providing insights from the perspective of government employees in the Pacific region, focusing on the decision-making process in national ICT development projects.

1. Literature review

The presence of ICT development in the Pacific region has grown significantly since the 1990s, with the establishment of internet connectivity and telecommunications services. Organisations such as the Asian Development Bank (ADB) (2003) and the Lowy Institute for International Policy (Cave, 2012) have documented this progression, noting increased mobile phone access and internet penetration. Studies highlight the impact of ICT on social and political systems, driving calls for transparency and accountability in governance (UN, 2023; Cave, 2012; Caelis International, 2018). However, challenges such as affordability, reliability, and digital skills gaps persist, hindering progress (ADB, 2003; Chan Mow, 2014; OOTR, 2020). Research on ICT development in the Pacific, particularly from government agencies, remains limited. Strategies to address challenges include stakeholder collaboration, policy frameworks, skill development, and infrastructure enhancement. Despite progress in infrastructure

and policy implementation, further improvements are needed in areas such as decision-making processes and cultural interferences to fully leverage the benefits of ICT in the region.

1.1. ICT as an enabler

The impact of technology on decision-making processes is evident worldwide, spanning from developed nations like Japan to developing countries like Indonesia and beyond. Studies on various industries and sectors reveal the critical role of learning, innovation, and public policy in driving economic growth, as seen in Japan's post-World War II industrial development (Odagiri & Goto, 1996). Similarly, developing countries experience challenges and opportunities in leveraging technology for business and government operations. For instance, research on SMEs in developing countries highlights the influence of external technological environments on business sustainability, emphasizing the importance of institutional parameters (Das et al., 2020). Studies also explore the adoption of IT tools like ERP systems for business agility, with attention to organizational factors that affect successful implementation (Zubaedah et al., 2017). In developed nations like Hong Kong, adaptive responses to changes in business environments involve strategic technological investments by firms to enhance performance (Kim & Pae, 2007). Additionally, ICT and e-government initiatives contribute to reducing corruption and improving public services, as evidenced by studies examining the correlation between ICT development, e-government, and corruption levels across different countries (Lee et al., 2018). Moreover, technological advancements such as broadband penetration and mobile telecommunication services have shown positive impacts on academic achievement, social development, and overall economic growth globally (Caldarulo et al., 2023; Loo & Ngan, 2012; Rezki, 2023; Lam & Shiu, 2010). These findings underscore the transformative potential of technology across diverse contexts, highlighting the need for effective policy frameworks and organizational strategies to harness its benefits fully.

1.2. Challenges of adopting ICT in the workforce

Studies on various industries and sectors reveal the critical role of learning, innovation, and public policy in driving economic growth, as seen in Japan's post-World War II industrial development (Odagiri & Goto, 1996). Similarly, developing countries experience challenges and opportunities in leveraging technology for business and government operations (Thabit & Jasim, 2019; Mbarika et al., 2002). For instance, research on SMEs in developing countries highlights the influence of external technological environments on business sustainability, emphasizing the importance of institutional parameters (Okoro, 2021). Studies also explore the adoption of IT tools like ERP systems for business agility, with attention to organizational factors that affect successful implementation (Gichoya, 2005; Zubaedah et al., 2017; Ahuja et al., 2009). In developed nations like Hong Kong, adaptive responses to changes in business environments involve strategic technological investments by firms to enhance performance (Choudrie et al., 2003; Choudrie & Lee, 2004).

A crucial component every so often overlooked in decision making is the social and cultural influence of the nation. The socio-cultural aspect affects all corners of a country whether it is a developed or developing nation. For instance, Yul Kwon's study (2011) examines how Korean Confucian culture affects the country's economy by analyzing transaction costs and innovation. He finds that cultural shifts like declining trust and work ethic worsen transaction costs and reshape the socio-economic landscape, harming Korea's economy. The study emphasizes the need for collaborative efforts from government, business, and society to counteract these challenges and promote sustainable economic growth. Masovic's research (2018) stresses the importance for

multinational corporations to consider socio-cultural factors when assessing the performance of their overseas subsidiaries. Key considerations include understanding cultural nuances, respecting local customs and religions, language proficiency, and developing indigenous capabilities. Language proficiency and religious observances are highlighted as crucial factors, alongside the correlation between regional education levels and local purchasing power. Furthermore, Okoro's (Okoro, 2021) from a developing nation's perspective demonstrates that technological factors, particularly workers' technical skills and their preference for manual versus automated services, significantly influence the adoption of modern technology by 5G telecommunication firms in Kenya.

The predominant focus of academic literature lies in examining technological landscapes at the level of individual firms, encompassing a range from private enterprises to governmental entities or broader country-level analyses. Data sources typically include information gathered directly from employees of these firms or extracted from databases maintained by local and/or international organizations. However, research into bureaucratic perspectives regarding decision-making in the implementation of national ICT development projects at the micro level is relatively scarce. Particularly within the Pacific region, there exists a notable dearth of academic literature addressing this aspect from the viewpoint of bureaucrats.

2. Methodology

This research aims to investigate what influences decision making for the country's development in the ICT sector. The nature of the study leans towards generation of social and political inferences. The interview technique – specifically semi-structured interview- was selected for primary data gathering. The interview was conducted with 10 individuals from government and private businesses in Samoa via online (from 12th to 24th September 2022) and face-to-face (from 10th January to 15th February 2023). The results were analyzed using the Analytical Hierarchy Process (AHP) method. The empirical aspect was drawn on the AHP method which is one of the various methods developed for multi-criteria decision making. The purpose of AHP method was to analyze the hypothesis and results obtained from the interview process. Since this methodology involved assigning weights to the different variables, it would assist in recognizing the criteria and sub-criteria that have more influence or risk. In conjunction with formal interviews, a plethora of informal discussions and dialogues were amassed in casual settings including collaborative work at the office in Samoa, as well as the academic laboratory life in Japan. Engaging in ongoing conversations about my research with fellow colleagues and academic supervisors helped scrutinize and refine concepts and ideas surrounding the study.

2.1. *The semi-structured interview process*

The interview design was constructed with open-ended questions to allow for collecting additional information through follow-up questions based on the interviewee's responses. In stating that, the interviewees were also encouraged to express their views in their own terms inducing additional queries and enabled deep exploration of the participants experiences. Based on keywords of 'decision making' and 'ICT development projects' selecting the research participants leaned heavily towards those within positions that initiate and/or finalize the adoption and implementation of ICT projects. That is, those with managerial level and above from the private and/or public sector. As this research was instigated with the purpose of supporting countries struggling to keep up with the rapid changes in technological trends including Small Island Developing States, the interview was conducted for the country of Samoa. The one-on-one formal discussion was held with a total of ten (10) people, where

eight (8) participants were employed with the Government agencies in the ICT sector; and two (2) were employed with the private telecommunication and broadcasting companies. The eight Government interviewees included two (2) chief executive officers, 2 assistant chief executive officers and 4 principals (also classified as junior managers). Similarly, the representatives from the private telecommunication and broadcasting companies were employed at the managerial levels (Table 1). All participants used bilingual language -both Samoan and English- with a time duration ranging from 30 to 60 minutes.

Table 1. Interviewee's profiles.

Participant number	Management level	Relevant Experience	Sector
Participant 1	Upper level	Over 30 years of work experience in telecommunications and ICT sector at the national, regional, and international levels. Accumulated more than 10 years of top management posts at international organisations including the ITU and Commonwealth Telecommunications Organisation.	Public
Participant 2	Upper level	Over 20 years of work experience as an engineer in the broadcasting, ICT, telecommunications sector and breweries private company. Involved heavily in the implementation of previous ICT projects as the project chief. More than 7 years of work experience in top ICT management posts at the national and regional level.	Public
Participant 3	Middle level	Over 15 years of work experience as a satellite technician and electronic engineer in the private and public sector. Involved heavily in the implementation of national ICT projects including the national transition of analog television to digital television.	Public
Participant 4	Middle level	Over 20 years of work experience in ICT and finance sector, as a computer analyst, project coordinator and cybersecurity expert. Coordinated multiple national development projects in finance and cybersecurity.	Public
Participant 5	Lower level	Over 30 years of work experience in the telecommunication, broadcasting, and postal sector. Involved immensely in the local spectrum planning and management both in the policy and technical aspects. Has extensive knowledge of the history of the country's development in this sector.	Public
Participant 6	Lower level	Over 7 years of work experience in ICT. Mainly involved in project implementation as an assisting officer.	Public
Participant 7	Lower level	Over 9 years of work experience in ICT and financial audit. Main role in current projects as an assisting officer.	Public
Participant 8	Lower level	Over 7 years of work experience as an information scientist and radio spectrum technician. Involvement in ICT project implementation as an assisting officer	Public
Participant 9	Middle level	Over 20 years of work experience in telecommunications and broadcasting private sector, at the top management level. Heavily involved in the growth of the telecommunications sector in the areas of broadband network and infrastructure development.	Private
Participant 10	Middle level	Over 9 years of work experience in IT and broadcasting in the private sector. Currently involved in the implementation of the digital television project.	Private

Source: developed by the authors.

2.2. The Analytical Hierarchy Process (AHP)

The conceptual framework emphasizes decision making as playing a vital role in the successful implementation of ICT projects. Thus, the empirical aspect was drawn on the Analytical Hierarchy Process (AHP) method which is one of the various methods developed for multi-criteria decision making. In this study, the purpose of AHP method was to analyze the hypothesis and results obtained from the interview process. Since this methodology involved assigning weights to the different

variables, it would assist in recognizing the criteria and sub-criteria that have more influence or risk. The AHP was applied in the following manner: define the project goal; identify project criteria and establish hierarchy; pairwise comparison and synthesis of priorities; and evaluation. Focusing on the goal of improving local Internet access a list of relevant criteria and sub-criteria was created after considering the interview outcomes, relevant literature (Table 2), as well as the ITU core list of ICT indicators defined by the Partnership on measuring ICT for development (ITU, 2022).

Table 2. Supporting studies on ICT related investigated factors.

Year	Author	Country	Investigated Factors
2000 to 2005	V. W. Ambrika, T. Byrd & J. Raymond (2002), J. Choudrie, A. Papazafeiropoulou & H. Lee (2003)	LDCs, South Korea	Economic, financial, organizational, managerial, technological, political, and geographical indicators; and government roles.
2005 to 2010	V. Ahuja, J. Yang & R. Shankar (2008)	India	Internal-external collaboration and coordination. managerial issues, technical issues, employees IT capacity, and data security.
2010 to 2015	D. Yates, J. Gulati (2011), J.M. Bauer & W. Shim (2012), W. Briglauer (2014), R.L. Katz, S. Vaterlaus, P. Zenhausern & S. Suter (2010)	Global, EU countries, Germany	Financial investment, regulatory/administrative practices, infrastructure, and financial investment.
2015 to 2023	A.S. Yesuf (2017), S. Howick & J. Whalley (2017), N. Erkhembaatar & O. Bataa (2019), T.H. Thabit & Y.A. Jasim (2019), S.C. Okoro (2021)	Global, UK & Scotland, Mongolia, Iraq, Kenya	Security risks, business performance risks, telecommunication regulations risks, national policies, infrastructure and ICT access, political, economic, technological, and social indicators, technical knowledge, individuals' IT knowledge.

Source: developed by the authors.

Narrowing the individual factors further, the fishbone analysis was applied as shown in Figure 1 reproduced the criteria and sub-criteria chart in Figure 2.

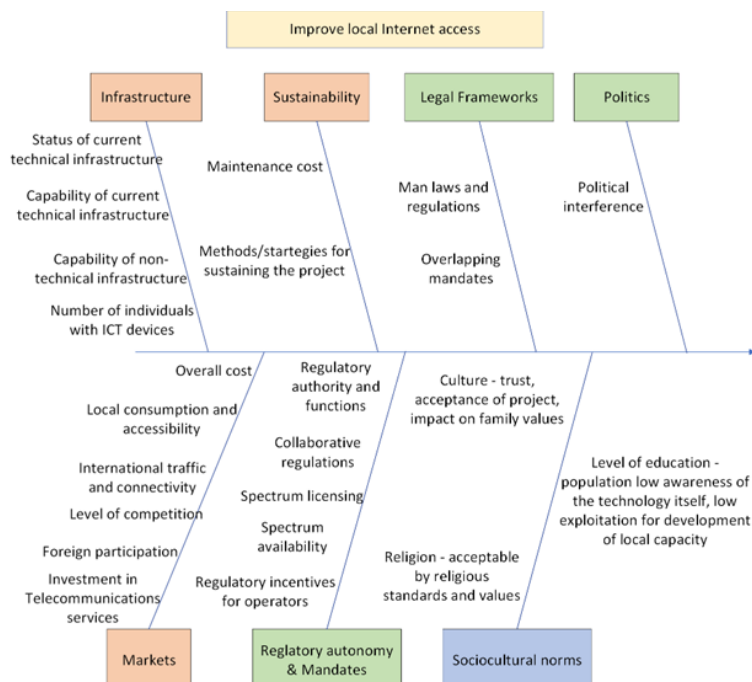


Figure 1. Fishbone analysis for Improving Internet access project.

Source: developed by the authors.

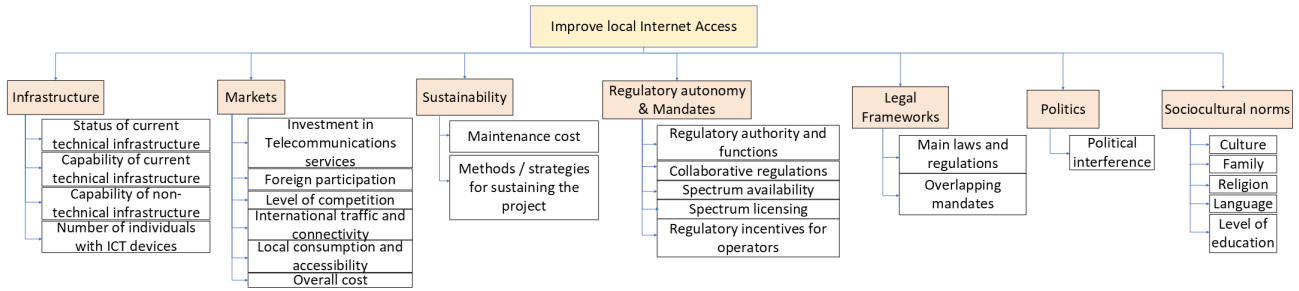


Figure 2. Improve local Internet access AHP chart.

Source: developed by the authors.

The pairwise comparison and synthesis of priorities were achieved using the pairwise comparison matrix and the fundamental scale of AHP which is reproduced in Table 3. After computing the comparison matrix, the priority vector or normalized eigen vector is found by calculating the average of each row.

$$A = (a_{ij})_{n \times n} \quad (1)$$

$$a_{ij} \approx w_i/w_j ; \text{ and } a_{ij} > 0 \quad (2)$$

Using (1) and (2), A matrix is structured as:

$$A = (w_i/w_j)_{n \times n} = \begin{bmatrix} \frac{w_1}{w_1} & \frac{w_1}{w_2} & \frac{w_1}{w_n} \\ \frac{w_2}{w_1} & \frac{w_2}{w_2} & \frac{w_2}{w_n} \\ \frac{w_n}{w_1} & \frac{w_n}{w_2} & \frac{w_n}{w_n} \end{bmatrix} \quad (3)$$

where A – pairwise comparison matrix; a – intensity between criteria/sub-criteria i and j; n – number of criteria/sub-criteria; w – weight.

Table 3. The fundamental scale.

Intensity of importance	Definition	Explanation
1	Equal importance	Two activities contribute equally to the objective
3	Moderate importance of one over another	Experience and judgement slightly favor one activity over another
5	Essential or strong importance	Experience and judgement strongly favor one activity over another
7	Very strong importance	An activity is strongly favored, and its dominance demonstrated in practice
9	Extreme importance	The evidence favoring one activity over another is of the highest possible order of affirmation
2,4,6,8	Intermediate values between the two adjacent judgements	When compromise is needed
Reciprocals	If activity <i>i</i> has one of the above numbers assigned to it when compared with activity <i>j</i> , then <i>j</i> has the reciprocal value when compared with <i>i</i> .	
Rational	Ratios arising from the scale	If consistency were to be forced by obtaining <i>n</i> numerical values to span the matrix

Source: Saaty (1987).

To check for consistency of the priority weights the Consistency Ratio (CR) is calculated from comparison between the Consistency Index (CI) and the Random Consistency Index (RI) reproduce in Table 4, where the priority is acceptable if CR is equal to or less than 10%. This process is repeated for the sub-criteria level.

Table 4. The fundamental scale for Random Consistency Index.

n	1	2	3	4	5	6	7	8	9	10
RI	0	0	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49

Source: Saaty (1987).

$$CI(A) = \frac{(\lambda_{\max} - n)}{(n-1)} \quad (4)$$

$$CR(A) = \frac{CI(A)}{RI_n} \quad (5)$$

where $\lambda_{\max}$ is the maximum eigenvalue of matrix A.

The application of AHP in this study focuses on the example of improving Internet access. Thus, the generation of weights for this example were measured against the information gathered from the semi-structured interview. Initially, this seemed like a good direction on a national comparison level for a developing country given the case of Samoa. However, it is important to note that all countries differ in terms of national processes, governance, and sociocultural situations. Therefore, determination of prioritization weights is crucial and likely different amongst nations. For instance, some nations may have strong ICT policies in place but lack pertinent infrastructure. Others may have the technical capability and relevant policies implemented but influence of political or religious leaders might present obstacles. Some countries may have the right resource at hand, support from the private sector moving towards digitization, but government regulations may not be up to date. As a result, the evaluation stage of the AHP method considered those areas.

Evaluation was applied in two ways. Firstly, the criteria and sub-criteria weights were measured according to the semi-structured interview outcomes. The second application involved priority granted per criteria whilst the remaining two have the same weight amount. Specifically, the distribution follows a ratio of 4:3:3 for process, governance, and sociocultural factors, respectively. Therefore, the interview outcomes showed regulatory autonomy and mandates, as well as legal frameworks as the highest priorities at 0.29 with a consistency ration value of 8.8% (Table 5).

Table 5. Interview outcomes priority vector and consistency results.

Criteria	Weights	$\lambda_{\max}$	7.70
Infrastructure	0.13		
Markets	0.08	RI	1.32
Sustainability	0.04		
Regulatory autonomy and mandates	0.29	CI	0.12
Legal frameworks	0.29		
Politics	0.04	CR	0.088
Socio-cultural norms	0.14		

Source: developed by the authors.

The second evaluation was based on the notion that all countries are different in terms of decision making. Therefore, the prioritised factors would most likely be different amongst national decision makers. Consequently, firstly, infrastructure, markets and sustainability criteria having the highest priorities while regulatory autonomy mandates, legal frameworks, politics and sociocultural norms have the same weights. Secondly, regulatory autonomy mandates, legal frameworks, and politics criteria having the highest priority while infrastructure, markets, sustainability and sociocultural norms have the same weights. Lastly, sociocultural norms criteria having the highest priority while infrastructure, markets, sustainability, regulatory autonomy mandates, legal frameworks, and politics have the same weights.

3. Research results

3.1. Interview key results

Qualitative results obtained are detailed as followed: what influence development of ICT in the country, impact of culture on ICT development, impact of ICT on the Samoan culture, the need for change, and enabling local ICT development. Firstly, multiple reasons were stated by the interviewees as factors influencing ICT projects from their profession's experiences. These factors span from local infrastructure to the affordability of ICT services for end-users, the exchange of information between stakeholders, instances of political interference, to cultural values and norms. The summarized key findings are presented in table 6.

Table 6. Barriers to the development of ICT in the country.

Barriers	Details	Interviewee
Complex processes and miscommunication	The process for disbursing funds from the government to other government entities or private companies lacks transparency for the recipients or applicants. Illustratively, a proposal from a ministry underwent five revisions over a two-year period to align with the requirements of the authorizing ministry. Another conspicuous problem in this discourse was the divergence of opinions between the involved parties regarding the utilization of the funds if approved. Likewise, private companies voiced similar apprehensions, particularly regarding the allocation of local projects to overseas firms and consultants, seemingly neglecting the existing local capacity. Establishing a new business poses considerable challenges, with international investors facing even greater obstacles compared to their local counterparts. The process for obtaining a business license is notably more prolonged for overseas companies	[Participants 4&8]
Financial sustainability	Local devices accessing online services have continuously grown, resulting in an increasing demand of broadband coverage and infrastructure. Infrastructure wise, costs are extremely high to develop or even upgrade a site. Currently such costs are on the private companies alone to bear. With the rise in demand for broadband coverage, government subsidies would provide support in the expansion of the network.	[Participants 9&5]
Political interference	Alternatively, with the broadcasting infrastructure, implementing agreements for settling broadcasting fees at the early stages of the project would have been ideal in sustaining the asset itself. Unfortunately, due to political matters, neither issue has been resolved.	[Participants 2,5,8&9]

Source: developed by the authors.

Secondly, according to the interview participants, culture is an important factor that influences ICT projects implementation in the country of Samoa. These vary from traditional resources to customary

practices to indigenous governance framework. Cultural resources can be a hinder throughout the progress of the projects experienced not just in the local ICT sector but in the transport and energy sectors as well. These resources include customary lands which are normally sought after for installation of new towers in the villages to improve mobile or television coverage. The majority of land in the country (more than 80%) are not free-hold land, but customary owned by family's members. Permission to use these lands has been a difficult encounter over the years due to family disputes.

- One thing to look at is providing the services [broadcasting or telecommunication] to rural areas is not an easy task. [...] For example, the leasing of lands for ICT developments. These lands are mostly customary owned, and the discussions to use a piece of the land usually for new site installation takes quite an amount of time to be resolved [Participant 5].
- It [culture] has both a positive and negative impact, and the negative impact is a hinder to the development of ICT. For example, at the community level, if there are new sites required to be installed for extension of coverage [broadcasting or telecommunication], they [family members] always come and fight over the land, and they always ask to give them some time for the families to discuss [...] and by the time they agree to it, or maybe after a few years, there is still no agreement, there will be no installation [as the due date for the project has passed] [Participant 2].

On the non-physical side, the absence of the Samoan language in local ICT devices such as smart phones, and personal laptops (to name a few) contributed to some difficulty in terms of the public usability of such devices. Similarly, the complexity of the formal language to be used in the workplace to address those at a higher position sometimes hinders communications and flow of information in the workforce.

- At the moment, our mobile phones and computers' settings is configured in English, there is no Samoan language [...] for the language, people should understand how to use the language on these devices [Participant 5].
- Another value would be the approach of the process so that the words you speak are in the context of the Samoan culture. Framing your speech, figuring out how to talk so that it is within the workplace speech is sometimes a problem. [Participant 3].
- In Samoa, seniority is very much a part of the culture, and you address that first before you provide your input into the decision making. [...] You have to consider your relationship with your superior and remember that you have people under your guidance that also collaborate with other teams so you don't want to affect [negatively] the other parts of the organization [Participant 3].

Thirdly, impact of ICT on the Samoan culture was recorded as having both positive and negative effects. The negative aspect included the use of derogatory language or online behaviour and mainly stems from the rise in accessibility of social media contents. On the contrary, such technological tools have also provided an efficient mobilization of resources, easy access and exchange of information, and ease of communication. The COVID-19 pandemic contributed to the rate of public's acceptance of the use of the Internet for online meetings and events.

- The norm of physically leaving the house to attend work, has changed to the 'working from home concept', and has created a flexible working environment which majority finds in favor of [...] [Participant 6].

- People are seamlessly informed, and people are quick grasping the concept of technology [...] For example, [during the pandemic period] funeral proceedings were held online, and people accepted it [...] overall we have modernized the culture so that it suits the time we are in [Participant 3].

The fourth key interview result focused on the term 'change'. In this study, the theory stated that change is important in technological development as observed in all levels of society. Hence, the term 'change' was consistently monitored in the participants' responses throughout the interview process. Consequently, the term 'change' surfaced a total of 11 times across all participants, with a notable recurrence among those holding managerial positions within government agencies. Some examples of statements obtained are as followed:

- People need to be aware of what is happening [technological shift] but some people are scared of new things or changes [...] but we need to get used to technology of a whole different kind [...] ICT has changed the way we live [Participant 1].
- Growing up with ICT [using a computer at home], it never changed my values, respect, structure, beliefs, and role in the family. It was just an additional component in part of the household, but it gave the confidence for people [in the family] to use [technology] [...] Our people are prone and very resilient to adapt to changes [Participant 3].
- Even though we have ICT policies in place, we need to look at the changes in technological trends, and make sure that these can be reflected in the regulations. We need to see if there are any alternatives we can include and implement to achieve new technological developments [Participant 5].

The last key result obtained focused on practical solutions to enable technological development in the country. That is how the public and private sector improve existing ICT services, or how to nudge people's way of thinking to accept technological changes. The findings encompass a spectrum of outcomes, spanning modifications in the education curriculum, enhancements to policies and regulations, evaluations of internal processes and procedures, and investments in capacity building.

3.2. The Analytical Hierarchy Process key results

As outlined in the methodology section, the AHP method was employed in two distinct phases. Initially, the weights for criteria and sub-criteria were determined based on the outcomes of semi-structured interviews. The second phase involved assigning priorities to each criterion, with the remaining two holding equal weight. This sub-section focuses on the key results obtained from the two cases.

3.3. Improve local Internet access – Interview outcome synthesis

From the interview information, the AHP analysis has been visualized in the following graphs. The analysis provides insights on criteria or factors that take precedence in decision making for the case of Samoa (Figures 3 & 4). The legal frameworks and regulatory autonomy & mandates criteria carry the highest weights, surpassing other factors. Socio-cultural norms hold roughly half of these weights, while infrastructure exceeds the 0.1 margin. Following these are markets, politics, and sustainability, situated at the lower end of the scale as in Figure 3.

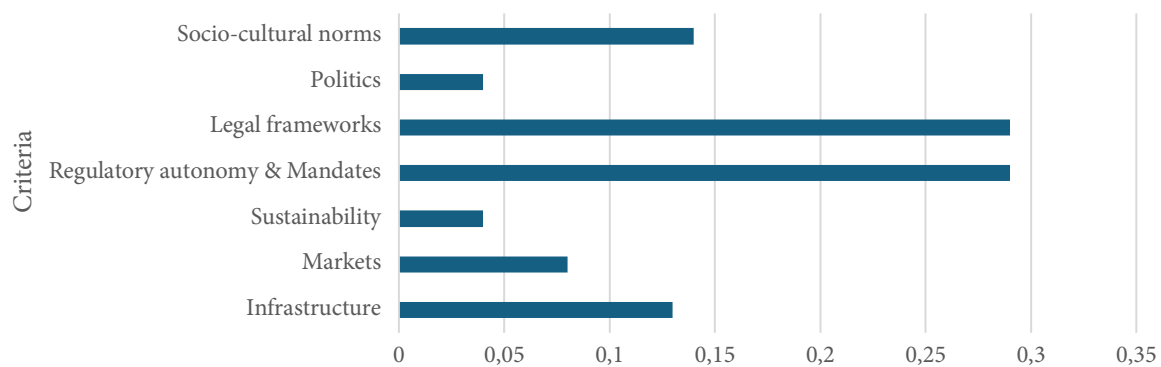


Figure 3. Priority vector results.

Source: developed by the authors.

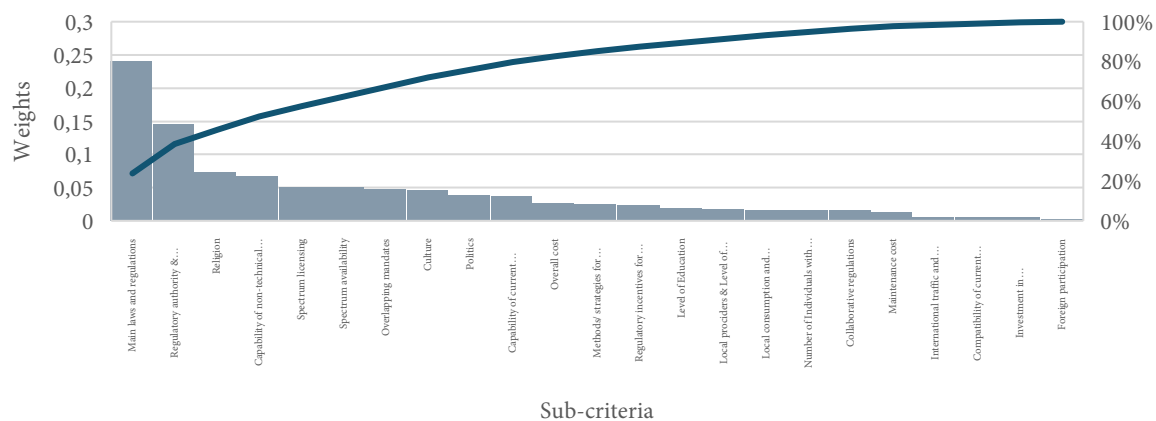


Figure 4. Global priority vector distribution graph.

Source: developed by the authors.

The global priority distribution which articulates the weights comparison between each criterion was computed and plotted as shown in the Figure 4. According to the graphs, the order of priority is: main laws and regulations; regulatory authority and functions; religion; capability of non-technical infrastructure workers; spectrum availability; spectrum licencing; politics; overlapping mandates; culture; capability of current infrastructure; overall cost; methods/strategies for sustaining the project; regulatory incentives for operators; level of education; local providers and level of competition; local consumption and accessibility; number of individuals with ICT devices; collaborative regulations; maintenance cost; international traffic and connectivity; compatibility of current technical infrastructure; investment in telecommunication services; and foreign participation.

3.4. Improve local Internet access – 4:3:3 case ratio

According to prior research, most countries have different situations (or less similar) regarding development in their technological environment. Table 2 summarized studies consulted and include indicators of what impact the growth and improvement of Internet access in certain countries. It showed that nations vary in their decision-making given the diverse ICT factors identified and categorized into process, governance and sociocultural indicators. Another contribution to this can be based on the specific conditions and relationships that exist within the country. Therefore, the scenario of 4:3:3 case ratio was developed where prioritization is assigned to a singular indicator, while

the remaining weights were divided equally amongst the other two criteria. The purpose of dividing the indicators in such a way was to highlight which indicator should be prioritized by decision makers given their level of impact or risk on the outcomes of ICT projects. In addition to the previous studies, relevant economic indicators were sought, compared and analysed between selected economies from the World Bank database. The economies selected for cross country analysis are Australia, Fiji, New Zealand and Samoa (from Oceania), India, Japan and Korea (from Asia), United Kingdom & United States of America. These countries were selected based on the availability of public information and academic studies found during the data gathering stage. Analysis drawn from the World Bank (WB, 2019) development indicators of selected economies showed that:

- Oceania countries exhibited higher percentile (above 80%) of political stability from 2012-2022, including Japan.
- However, government effectiveness showed higher performance (above 80%) from developed nations compared to the developing selected countries.
- All countries displayed increase in GDP growth between 2012 to 2022, except for the year 2020. In terms of ICT good export, Korea showed significant export percentile at above 15% and continuous growth from 2012, which in comparison to its ICT goods import was still greater. Contrast to the rest of the studied nations with ICT goods import percentage higher or like the number of exports.
- Ease of doing business, developed nations showed higher levels of performance (between 75% to 85%) compared to developing nations (between 50% to 60%) (WB, 2019)

This research did not investigate each country in detail to determine the actual reasons for this performance. However, the inclusion of these indicators in this section is to emphasize the fact that countries have different circumstances and may also have unique characteristics. Therefore process, governance and sociocultural factors may have different weights in decision making. As previously stated, the results were generated on the notion of diversity among countries concerning national processes, governance, and sociocultural contexts. Consequently, the decision-making process would vary among decision-makers in each country, contingent upon the specific circumstances and conditions prevalent in that nation. In the graphs, Figure 5 highlights sustainability, market, and infrastructure, emphasizing their elevated weights among the process sub-criteria. Within Figure 6, regulatory mandates, legal frameworks, and politics take precedence, underscoring their prioritization in governance factors. Lastly, in Figure 7, sociocultural norms emerge as the top priority, with process and governance factors sharing equal weight.

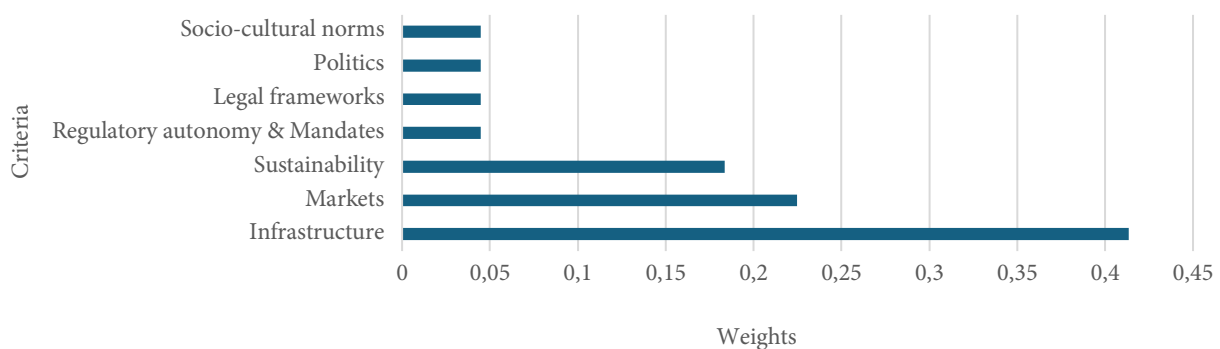


Figure 5. Process prioritization graph for Scenario 1.

Source: developed by the authors.

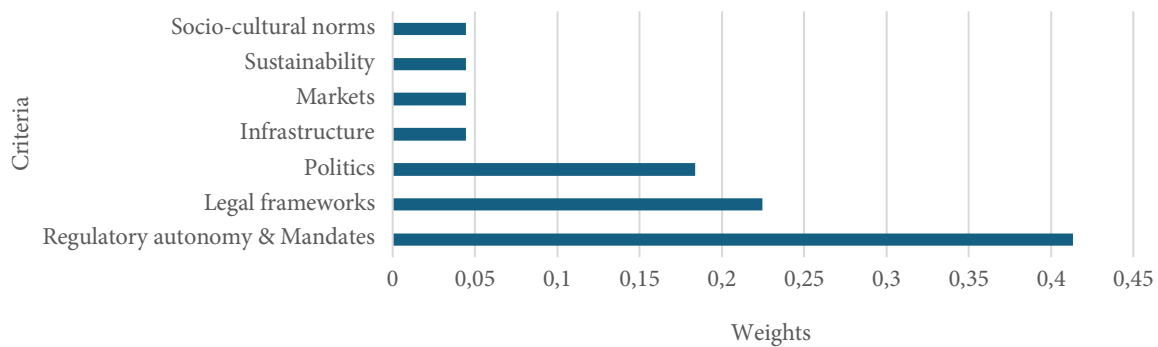


Figure 6. Governance prioritization graph for Scenario 2.

Source: developed by the authors.

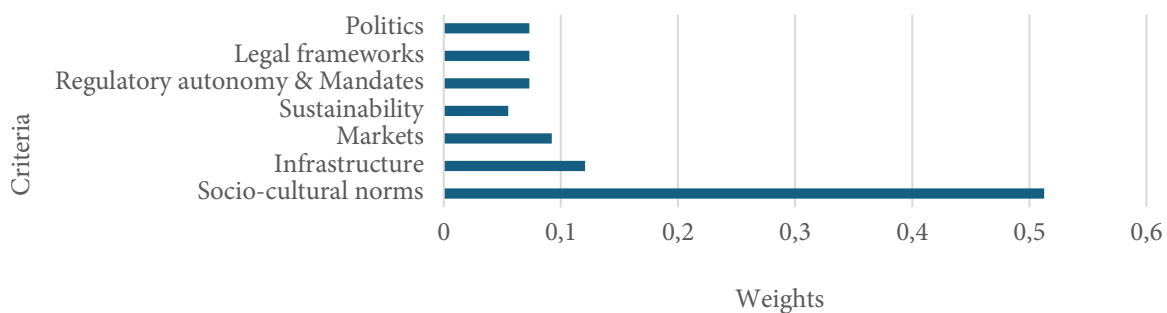


Figure 7. Socio-cultural prioritization graph for Scenario 3.

Source: developed by the authors.

4. Discussion

4.1 Factors that influence decision making in local ICT development projects

To summarize, this research supports the argument that various factors impact ICT development and can be categorized as processes (h1), governance (h2) and sociocultural factors (h3). For instance: complex processes (Choudrie et al., 2003) ; collaboration between stakeholders (Ahuja et al., 2009); financial sustainability (Katz et al., 2010; Gulati & Yates, 2011); political interference; language, family, cultural resources and sociocultural practices (Thabit & Jasim, 2019; Choudrie & Lee, 2004); geographical factors; national policies and regulatory practices (Choudrie et al., 2003; Howick & Whalley, 2007; Yesuf, 2017; Gruber & Koutroumpis, 2013; Gulati & Yates, 2011; Bauer & Shim, 2012); infrastructure security, availability and access (Erkhembaatar & Bataa, 2019; Yesuf, 2017; Bauer & Shim, 2012); household characteristics (Whitacre, 2008); and organizational issues which encompass leadership skills, management skills, IT capacity (Okoro, 2021; Yesuf, 2017; Ahuja et al., 2009). These can be categorized into three factors as shown in the Figure 8.

The interview results indicated the problem of complex criteria and time-consuming processes in securing financial aid for procuring specialized equipment's to monitor the status of the broadband connectivity in the country. The interview noted that numerous discussions were held, and multiple proposal modifications were done over prolonged year however the grant was not successfully released. Similarly, from personal observation, members from the private sector expressed concerns towards the government agencies' complex criteria's regarding projects grants. The members stated that complexity of the procedures result in miscommunication which delays the receipt of either an approval or disapproval of project proposals.



Figure 8. Categorizing ICT factors into process, governance and socio-cultural indices.

Source: developed by the authors.

Other studies have highlighted on the combination of factors which include strong government industry collaboration (Odagiri & Goto, 1996); changes in technological environments contributes to strengthen ties between stakeholders (Das et al., 2020); as well as changes in management frameworks enable firms or organizations to adapt to the changing business environments, which all contribute towards national development (Zubaedah et al., 2017; Kim & Pae, 2007).

Another example is the impact of infrastructure. Interview results noted that a surge in Internet accessible devices require an expansion in infrastructure and coverage which unfortunately is quite costly for the private businesses. This can also be seen in other countries where studies showed that lack of physical technical infrastructure also hinders ICT development (Gichoya, 2005; Thabit & Jasim, 2019), as evident that areas where higher diffusion of mobile phones and elevated signal levels showed higher social development (Rezki, 2023). On the broadcasting side, financial issues were also at play with regards to the local digital television project, caused by non-payment of the monthly tariff, resulting in difficulty of maintaining the digital television platform (Feagaimaali, 2022).

The results from this research support evidence from previous studies elaborated in the prior sections of this document. Majority of the studies focused on investigating individual ICT factors whereas this study represented a combination of several factors which are then re-categorized into three indicators as in Figure 8. The purpose of this is to streamline the process for decision makers in pinpointing the key indicators that exert the most substantial influence on the outcomes of ICT projects. Consequently, when employing decision-making methodologies like AHP, decision makers can allocate weights accordingly and establish a prioritized sequence for indicators, facilitating the development of a neutral position.

4.2. How cooperation between private and public sector contributes towards local ICT project developments

Cooperation in the form of transparency in exchange of information between stakeholders (both public and private) enable better understanding of policy requirements and private resources status for successful ICT project execution. Constant exchange of information take place from seeking non-technical advice in terms of rules and regulations, to technical expertise such as spectrum availability for additional broadband access. Channels of communication occur both in a formal and non-formal setting namely scheduled meetings, email correspondences, or phone call conversations. The interviewees emphasized maintaining these continuous correspondences, enabling the private

companies and ministries to be aware of ongoing projects and plans from both sides with respect to existing regulations, subsequently exerting coordination between sectors.

In terms of policies, the participants from the private sector agreed on full awareness of the local regulations executed regarding ICT services and applications. As a consequence of the rapid technological trends, the government representatives expressed ongoing plans of policy review to reflect international practices. The review would include frequency spectrum planning to cater trends in mobile technology, which is another problem identified by all the interviewees, as the local policies are not up-to-date with the rapid and increasing technological changes.

4.3. The role of culture in the promotion and development of local ICT services

Unfortunately, the majority of how culture impacts local ICT development is provided from the ministry perspectives. Evidence collected from the private sector were not enough to provide a thorough analysis on this question. Therefore, the influence of culture on decision making to enable development from the ministry side is elaborated below.

Firstly, in terms of attitude and beliefs, when addressing superiors, subordinates tend to withhold opinions in meetings and discussions as a form of respect. To add on, the local culture requires the use of formal speech when addressing superiors, which sometimes hinders communication. Also, with respect to attitudes to change, people fear change due to unfamiliarity with the concept. Moreover, with the concept of trust, it is noted that more trust is put in traditional constitutions compared to modernized constitutions (Masovic, 2018; Yul Kwon, 2011; Leach et al., 2022).

Secondly, the installation of additional infrastructure (e.g., cell towers) in rural areas require the use of customary lands. Time taken to acquire permission for these traditional resources range from months to years, depending on the family's decision. The participants raised this as one of the major issues encountered in most project rollouts. Thirdly, people are more comfortable and are able to absorb more information easily when communication is done via native languages. Therefore, some people struggle to use mobile devices and computers devices when the device's language settings are set in a second linguistic. Fourth, with religious beliefs affect decision making given their significance in identity values (Leach et al., 2022). Lastly, the availability of local academic and professional capacity contributes to the growth of the nation (Masovic, 2018).

4.4. The AHP application

The inclusion of the AHP method analyzes the hypothesis from a multi-criteria decision-making perspective providing additional clarity and rationale on the factors identified as impacting ICT development decisions. That is, the AHP can be a very useful tool to determine consensus in a discussion involving decision makers with various opinions (Gupta et al., 2017; Tam & Tummala, 2001). Accordingly, the AHP analysis reflected that Samoan bureaucrats consider governance indicators as the highest impact in decision making, in the form of main laws and regulations, regulatory authority and functions. The presence of religion in the higher end of priority indicated a strong influence, which is the case given the country's status a religious nation with Christianity as the main religion. The analysis also indicated the influence of politics which as one participant stated '...at the end of the day, politics is politics....we as leaders [bureaucrats] provide advice according to the law that we wrote and practice...' [Participant 2]. This indicates that decision making follow policies and regulations whilst acknowledging that political interference is inevitable. Lastly, the influence of culture is evident as significant in the several aspects of development, in the forms of customary approaches and ways of speech in the workplace, prolonged discussions between family members

regarding the lease of traditional lands for installment of new mobile tower sites, as well as the need for integrating the local language in digital devices.

On a global comparison, using the AHP to determine which of process, governance and sociocultural indicators is more likely to influence ICT projects outcomes, would be a very useful tool for decision makers. Analysis drawn from the World Bank development indicators showed that countries are different in their economical characteristics as seen in the different levels of political stability, governance effectiveness, ease of doing business and so forth. For instance, Oceania countries and Japan (Fiji, Samoa, New Zealand) exhibited higher percentile of political stability compared to developed nations (South Korea, UK and USA). However, government effectiveness showed higher performance from developed nations compared to the developing selected countries. Consequently, developed nations showed higher scores of eases of doing business performance compared to the selected developing countries (WB, 2019). Reasons for this can range from the type of political systems in place, to the presence of military, to the effectiveness of current regulations, the rate at which sectors are adapting to technological changes, and so forth. Nevertheless, the main idea is that diversity exist among countries concerning national processes, governance, and sociocultural contexts. Hence, determining prioritization weights becomes essential, and these weights are likely to vary across nations. For example, certain countries may boast robust ICT policies but lack essential infrastructure. In contrast, others may possess technical capabilities and well-implemented policies, yet face obstacles due to the influence of political or religious leaders. Some nations might have the necessary resources, support from the private sector for digitization, but struggle with outdated government regulations.

4.5. Solutions

Despite the numerous challenges outlined, this study also explored possible resolutions. To enable local ICT development, findings encompass a spectrum of outcomes from the modification of education curriculum to the evaluation of internal processes and procedures as well as investment in capacity building. To elaborate, interview results indicated that integrating ICT programs in the curriculum from the lowest level of education up to the tertiary level will aid in building the students' capacity from a young age. Capacity building programs for the older youth and generation, such as how to use ICT for development of local businesses. Awareness is very important for developments as direct communications with the people give both sides the opportunity to voice and address concerns about the project. Investment in infrastructure such as 3G and 4G technologies both from the private and government side, would ensure that services are widely available in the country. Based on previous research, possible solutions include the adoption and execution of relevant ministry processes and business strategies including the use of integrated software (Zubaedah et al., 2017; Kim & Pae, 2007); adoption and implementation of relevant policies and regulations; formation of ICT clusters (Porter, 1998; Maguire, 2003); public awareness and engagement; cultural values consideration or integration in decision making and developments (Kim & Pae, 2007; Masovic, 2018); and capacity development (Gichoya, 2005).

Conclusions

The previous studies majorly investigated technological environments on the level of individual firms or private companies, governments as a whole or collection of country analysis where data is extracted from the individual firm employees or from online databases. There was very little academic literature that concentrated on bureaucratic perspectives in the execution of national ICT

development projects, specifically in the Pacific region. Hence this research intended to provide contributions to academic literature by providing insights from the perspective of government employees in the Pacific region, by focusing on the decision-making process in national ICT development projects. The conceptual framework developed on multiple decision-making models including social choice (Sen, 1977), and rational decision-making procedures (Bazerman & Moore, 2009), as well as the inclusion of the ITU (2009) ICT Development Index Framework. According to the interview results, Samoa decision makers consider legal frameworks and regulatory autonomy & mandates as priorities, followed by socio-cultural norms. The corresponding priority weights obtained are shown in table 5 in the results chapter. A random index of 1.32 produced a consistency ratio of approximately 9% which is below the 10% acceptable threshold.

However, every nation differs in the decision-making process depending upon the specific conditions and relationships that exist within the country. Therefore, the 4:3:3 distribution results were computed and visualized. Decision making in local ICT development projects is affected by process, governance, and socio-cultural factors. Continuous exchange of information between stakeholders enables better understanding of government policies and private company needs. Furthermore, this study has shown that cultural values and traditional customs will one way or another influence the progress of ICT projects therefore decision makers must include social impact in their decision making. Unfortunately, this study also has its limitations in terms of data sample size, diversity of data, availability of people and unintentional bias. Firstly, majority of the interviewees, were only selected from government bodies in the ICT sector of Samoa. Inclusion of participants from non-ICT sector such as the academia, financial support organization, private companies, and other ministries would have provided diversity in data and a larger sample size. Unintentional bias was encountered in the data collection stage, as the interview participants were influenced by the outcomes of the Samoa 2021 general elections. Some of the responses received during the interview may have been swayed by personal emotions. Therefore, it was important to remain in a neutral position throughout the entire research process. An additional limitation recognizes the AHP outcome for the interview results was not re-evaluated with the participants for feedback due to time constraints. Furthermore, the 4:3:3 case ratio is limited in the sense of a single factor (whether, process, governance or socio-cultural) as being prioritized, whereas in some circumstances more than one factor may have the same priority impact. Implications from the study support existing literature and provide practicality to the information obtained. These can be observed as enabling better business environments and ministry operations through the periodic review of internal and external processes through the integration of technological tools, and encouraging foreign investors to consider the social cultural norms when establishing businesses in other countries (Kim & Pae, 2007; Masovic, 2018; Zubaedah et al., 2017). Political implications suggest adoption, and monitoring of relevant policies reflecting changes in the technological environment. Lastly, social implications recommend inclusion of IT subjects in the early stages of student learning, and involvement of public views in decision making through awareness and formal consultations to be integrated in the ICT project implementation phases (Interview results). Implications from this research emphasize the importance of decision-making roles in a social and policy context towards ICT development. It is crucial for both the private and public sector to implement appropriate strategies, technology and laws to enable growth in this industry and keep up with the rapid trends of technology. This study holds significance by providing contributions to both existing research and decision-makers, especially in developing economies. It offers practical solutions

for implementing and deciding on the adoption and execution of ICT projects within their respective countries. To improve knowledge in this area of study, further research is recommended to investigate the ICT development situation in other countries facing similar problems, adopting a methodology that will acquire both quantitative and qualitative data taking into account opinions from all relevant stakeholders, i.e., both the public and private sectors viewpoints.

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Exploring Cross-National Differences in Consumer Engagement: A Comprehensive Study of Business Processes, Interaction Methods, Incentives, and ICT Utilisation in the HoReCa Sector in Poland and the UK

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Abstract

This research aims to develop a framework for analysing companies' activities related to sourcing consumers' knowledge and apply this framework to the hotel, restaurants, and catering (HoReCa) sector in Poland and the UK. Data collection involves case studies within the HoReCa industry, and the research methodology considers the four key perspectives of companies' activities: (1) the business process, (2) methods of interaction, (3) incentives for knowledge sharing, and (4) ICT support. The research demonstrates that HoReCa companies actively engage consumers through diverse projects, emphasising feedback-related activities. While UK-based companies exhibit more extensive consumer involvement across various business processes, including product development, marketing, and customer service, Poland-based projects focus primarily on consumers' opinions. The study identifies significant differences in interaction methods, incentives, and ICT offerings between the two countries analysed. For academics, the study contributes to the understanding of cross-cultural variations in consumer engagement strategies within the HoReCa sector. From a practical standpoint, HoReCa businesses can tailor their consumer engagement strategies based on regional disparities highlighted in the study.

Key words

consumer engagement, HoReCa, cross-national differences, business processes, interaction methods, incentives, ICT utilisation.

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Introduction

As society becomes more interconnected, consumers have seamless access to engagement with both fellow consumers and businesses through information and communication technologies (ICT). Serving as integral stakeholders, they actively contribute to diverse activities, nurturing innovations and exchanging valuable knowledge (Eisenhardt, 2021; Pandey et al., 2014). Empirical studies indicate that consumer engagement is currently a widespread and frequent phenomenon, a mass activity that companies and managers should not overlook (Franke et al., 2016; Potra & Pugna, 2015). Consumers engage in numerous activities such as scoring and reviewing products, services, and companies, as well as developing, modifying, and designing products and services to better meet their needs (Ziemba et al., 2019; von Hippel, 2017). Recognising the scale and importance of consumer engagement, an increasing number of companies are placing consumers at the core of their business efforts, involving them in business processes and thereby tapping into consumer knowledge (Deloitte, 2018). This underscores the necessity for companies to be acutely aware of consumers as a source of knowledge and generators of innovative ideas.

Consumer engagement is closely linked to the theories of prosumers, consumer knowledge, and free innovation explored in the literature. Existing studies highlight the active engagement of 'prosumers', consumers who act as producers to some extent, impacting businesses by sharing knowledge for co-designing, co-producing, co-promoting, and co-creating products and services (Prahalad & Ramaswamy, 2004; Robert et al., 2019; Seran & Izvercian, 2014). The relationship between businesses and consumers is a significant issue, prompting authors to examine factors influencing the implementation of consumer knowledge in companies, online consumer communities, differences between national cultures affecting the willingness to share knowledge, and participation in knowledge-related activities offered by companies (Fernandes & Remelhe, 2016; von Hippel, 2017; de Jong et al., 2018; Ma et al., 2019; Strychalska-Rudzewicz, 2016; Tian et al., 2018). Other studies focus on behavioural issues, exploring the effects of national cultures on consumer behaviour (Kacprzak & Dziwanowska, 2015; Wojciechowska, 2017), and consumers' attitudes towards prosumption (Baruk, 2019; Ziemba & Eisenhardt, 2016).

However, there are significant issues that warrant further investigation in order to substantiate the theory regarding companies' efforts in acquiring consumer knowledge. From this standpoint, the actions undertaken by companies can influence consumers' interest in their products and services, thereby potentially enhancing consumers' inclination to share knowledge. Therefore, in acquiring consumer knowledge it is imperative to elucidate companies' strategies, which align with their business objectives and growth. Our study aims to address this gap by developing a framework for analysing companies' endeavours in acquiring consumer knowledge and applying this framework to HoReCa companies operating in both Poland and the UK. Through a comprehensive analysis, we thoroughly examined and delineated the similarities and disparities between these two countries.

In the literature, two elaborations of the HoReCa abbreviation can be found. The first explains it as hotels/restaurants/cafés (cafeterias), and the second as hotels/restaurants/catering. Despite this slight difference, both focus on companies and sectors that provide food and food-related services (Ceynova et al., 2023; Casolani & Del Signore, 2016; García-Madurga et al., 2021). HoReCa companies were chosen primarily because they continually cooperate with consumers, offering many channels and possibilities for collaboration, making it relatively easy to source consumers' knowledge. It can be postulated that HoReCa enterprises possess a well-established track record and substantial expertise in procuring and harnessing consumer insights for the purposes of business innovation and advancement.

Poland and the UK were selected due to the perceived differences in methods of acquiring consumer knowledge and opinions in these countries. This selection is based on previous joint research

results in these countries, which highlight associations between national culture, innovation, and consumer behaviour in the Polish and British contexts. According to Andrijauskienė and Dumciuvienė (2018), using Hofstede's (2019) cultural dimensions, the UK is perceived as more innovative compared to Poland. Moreover, researchers such as Fandrejewska (2017) and Wojciechowska (2017) have also used Hofstede's dimensions to analyse consumer behaviour in both countries. Their research revealed significant correlations between national cultural characteristics and consumer purchasing preferences, as well as the way consumers perceive branded products. The research findings indicate cultural and developmental differences between Poland and the UK. However, these findings are general and often analyse the issue in relation to enterprises or consumers broadly. There is a lack of studies focusing on cross-country analysis specific to the HoReCa sector. Therefore, we decided to conduct a study on selected HoReCa companies, examining variables such as business processes, methods of interaction with consumers, incentives, and ICT offerings. This sector-specific analysis aims to address the identified research gap.

The paper is organised into several sections. First, it presents a thorough review of the existing literature, followed by the formulation of research questions and hypotheses. Next, the research methodology and data collection process are detailed, leading to a comprehensive analysis of the gathered data and subsequent discussion. Finally, the paper concludes by highlighting the contributions to research and practical implications of the study, along with acknowledging its limitations and suggesting areas for further research.

1. Literature review

1.1. Literature review on HoReCa sector

The term HoReCa refers to a collection of commercial catering food establishments whose primary activity involves the production and sale of food for direct out-of-home consumption. HoReCa companies provide food and food-related services (Casolani & Del Signore, 2016; García-Madurga et al., 2021). According to the industry report for the Polish market in 2022 (Gastronomy News, 2023), 67% of people used to eat outside their homes, 55% used to take food away, and 53% are ordering food to their homes. Furthermore, the financial performance of Polish HoReCa companies in 2022 increased by 8.3% compared to the results for 2021 (Gastronomy News, 2023). The newest reports indicate that 84% of UK-based and 73% of Poland-based consumers agree that price rises would reduce their spending on everyday lunches from food outlets or restaurants (Gastronomy News, 2023; Mintel, 2022). Many studies focusing on HoReCa address environmental and sustainability issues, emphasizing that this sector's operations contribute to food waste (Buczacki et al., 2021; Vizzoto et al., 2020). Other studies concentrate on the role of traditional national foods in the HoReCa sector as a factor influencing tourists' destination choices (Stankov et al., 2016). HoReCa companies consistently collaborate with consumers, and such collaboration can be crucial for the long-term success of businesses and relationship-building. Successful collaboration strengthens participants' willingness to contribute to the joint production of collective goods (Ceynowa et al., 2023; Planko et al., 2019; Yamamoto & Suzuki, 2018). However, Bolisani et al. (2020) pointed out that the HoReCa sector faces difficulties in the knowledge management process, resulting in the fact that they have a large number of consumers, but know little about them, even the regular ones. Consequently, any effort to improve service is often based on the intuitions of the owner. Thus, the main purpose of this paper is to examine HoReCa companies' activities towards sourcing consumers' knowledge from the perspectives of two countries: Poland and the UK.

1.2. Companies' activities towards consumers' knowledge

A central theme in business research involves the difficulties encountered by companies regarding consumer knowledge and its impact on them (Chen et al., 2018). Consumer knowledge is a crucial resource for inspiring enhancements in products, services, operational procedures, and strategies. It

is noteworthy to enumerate the activities consumers may autonomously undertake without any explicit support or intent from companies. Practical cases demonstrate that consumers can critically assess and review companies, their offerings, and activities through well-established and widely used tools and web portals, enabling them to share their opinions effortlessly and swiftly. Moreover, consumers possess the capability to offer assessments and endorsements for particular products, services, and brands to fellow consumers, thereby influencing their purchasing decisions. (Khac et al., 2020; Rather et al., 2023). Simultaneously, consumers exert an influence on businesses and their operational and strategic processes.

Further studies and cases reveal that many companies proactively engage in specific activities, creating opportunities for consumers to share knowledge (Zollo et al., 2020), commonly known as firm-generated content (FGC) (Santiago et al., 2022). The benefits derived from such activities are primarily associated with the acquisition and utilization of consumers' knowledge for business purposes. Moreover, companies exercise complete supervision over the knowledge created and shared. Often, a company's activity can be regarded and analyzed from four main perspectives: (1) business processes that the company can develop and enhance by sourcing consumers' knowledge; (2) methods of interacting with consumers; (3) incentives offered to consumers to gather their knowledge; and (4) ICT provided for consumers, which can support both consumers in their knowledge-sharing endeavors and companies in sourcing consumers' knowledge.

1.3. Business Processes and consumers engagement

In our study, we utilized the APQC Process Classification Framework (PCF) (APQC, 2020). This framework encompasses operational processes and outlines different forms of consumer interaction within these processes. We chose the PCF because it functions as a classification system for cross-functional business processes (BP), intended to enable unbiased evaluations of organizational performance both internally and externally. Furthermore, the PCF sets a universal standard aimed at promoting enhancement through process management and benchmarking, irrespective of industry, scale, or geographical location (APQC, 2020). Therefore, by employing the PCF, it was possible to apply the same standards and rules for both countries – Poland and the UK, as well as for all HoReCa companies under consideration, irrespective of their size, industry, work stream, or location.

This study focused on four key operational business processes (BP), delineating the diverse avenues through which consumers could actively contribute to driving innovation. Leveraging the APQC PCF framework, companies' initiatives pertaining to consumer knowledge are integrated within the following processes: (BP2) product development and management; (BP3) marketing and sales strategies; (BP4) product delivery logistics; and (BP5) customer service management. Within each of these processes, specific consumer-related activities have been identified, tailored to the unique requirements of each process. For instance, consumers may participate in product development and management by conceptualizing novel product designs and functionalities, refining product compositions, augmenting product reliability and longevity, or streamlining product usability and intuitiveness. Further elaboration on these activities is provided in Figure 1.

Drawing upon the PCF and taking into account insights from existing literature, the following research question was asked: Q1: Which business processes do HoReCa companies engage consumers in for sourcing their knowledge in Poland and the UK?

1.4. The methods of the interaction with consumers

Companies' activities toward consumers' knowledge can be analyzed through the methods of interaction with consumers (Prentice et al., 2018). In the literature, three primary modes of consumer engagement are commonly identified: word-of-mouth recommendations, consumers aiding fellow consumers, and consumers assisting companies directly (Roy et al., 2018). The crucial factor is that

the way consumers interact with companies depends on the activities of both consumers and companies. From this perspective, both consumers and companies can initiate and develop the ways they interact with each other.

Liu et al. (2019) confirmed the proactive approach of companies in seeking feedback on their existing products, new product ideas, and prototypes, actively involving customers in the process. This finding is supported by numerous other scholars in the field. For instance, scholarly research has demonstrated that consumer engagement through reviews, evaluations, complaints, and opinions serves as a significant means of collecting customer feedback and discerning new requirements for product development or design (Jin et al., 2016; Qiao et al., 2018). Additionally, consumer engagement encompasses several avenues for proposing and refining products and processes (Liu et al., 2019). Therefore, consumers play a pivotal role in assisting companies in innovating by providing reviews and ratings for products and processes, sharing their opinions, insights, and experiences about products and processes, as well as actively participating in the design of products and processes.

Aligned with existing literature, our research incorporated three distinct modes of interaction with consumers offered by companies. These include: (1) scoring, allowing consumers to promptly provide evaluations on products, services, brands, and companies, ranging from 1 - indicating dissatisfaction to 5 - indicating high satisfaction; (2) reviewing, encompassing consumer actions such as providing feedback and opinions on brands, services, and products; and (3) designing, involving consumer engagement in product or service design activities. Subsequently, this study sought to address the research question: Q2: What are the methods of interaction between consumers and HoReCa companies in Poland and the UK?

1.5. Consumers' motivations and incentives

Understanding consumer engagement across various activities provided by companies necessitates delving into consumers' motivations for participating in this process and sharing their knowledge and ideas. The differentiation between intrinsic and extrinsic motivation holds significant importance (Vivek et al., 2012). Intrinsic motivation entails consumers engaging with companies for their own sake, devoid of apparent external inducements. Conversely, extrinsic motivation involves external incentives such as monetary rewards or acknowledgment from others. Some consumers are driven by hobbies and passion, others are primarily motivated by financial incentives. Similar findings were reported by West and Bogers (2014), who highlighted both monetary rewards (extrinsic benefits) and non-monetary rewards (intrinsic motivation) as driving forces behind consumers' engagement in open innovation projects. As outlined by Füller (2010), the motivation of most consumers stems from a combination of intrinsic factors such as enjoyment and altruism, internalized extrinsic motives including learning and reputation, and entirely extrinsic factors like payment, giveaways, and career opportunities. Consequently, for companies relying on consumer engagement, effectively identifying and understanding the diverse incentives at play poses a significant challenge.

In our study, we chose to focus exclusively on extrinsic incentives. Exploring personal incentives presents additional complexities and would require a different research approach, possibly involving a longitudinal analysis of consumer behavior to fully grasp individual motivations. The extrinsic incentives we examined encompassed material rewards, monetary compensation, complimentary product testing, free product samples, and bonus points. Hence, our subsequent research question aimed to address: Q3: What incentives do HoReCa companies offer to consumers in Poland and the UK?

1.6. ICT offered to consumers

Research on consumer engagement has identified ICT as an essential factor that allows consumers to interact outside the boundaries of companies, with well-chosen incentives being another crucial element (West & Bogers, 2014). Thus, ICT can support consumers' knowledge sharing and companies' activities aimed at that knowledge, serving as a form of incentive as well. Tools and apps are necessary

to provide a platform for consumers to produce and share knowledge and ideas (Gawer, 2010; Wang et al., 2024).

Indeed, numerous studies have indicated that interactive information and communication technology-based channels, coupled with a variety of internet-based tools, enable consumers to engage as co-designers, co-producers, and co-creators for businesses (Eisenhardt, 2021; Hernández-Serrano et al., 2017). Consumers are empowered to actively leverage ICT to apply their experiences, knowledge, and skills in contributing to the design, creation, and delivery processes of products and services (Oliveira et al., 2020). For instance, Starbucks revolutionized its consumers' roles through the utilization of social media and other platforms, shifting them from passive recipients of beverages to active contributors to innovation (Retaildive, 2023). Additionally, Chen et al. (2018) affirmed that ICT tools constitute a vital element supported by companies for engaging consumers in business innovation. However, Ceynowa et al. (2023) pointed out that to date, only a few studies have investigated the adoption of ICT within the HoReCa sector.

Aligned with prior studies on information and communication technology (ICT) facilitating consumer knowledge sharing (Ziemba et al., 2017), our investigation incorporated a range of ICT tools, including e-mails, online discussion forums, corporate websites, industry-specific websites, widely-used information platforms, sector-focused online portals, mobile applications, social media platforms like Facebook, and web-based surveys. Consequently, we aim to explore the following research question: Q4: What ICT do HoReCa companies offer to consumers in Poland and the UK?

2. Methodology

2.1 *The Conceptual Framework, Research Problem and Hypotheses Development*

The results of previous studies informed the selection of variables and categories for examining HoReCa companies. These studies suggest that in-depth research into the company-customer relationship requires consideration of business processes (Ziemba et al., 2019), methods of consumer interaction (Ziemba & Eisenhardt, 2018), incentives (Eisenhardt, 2020; Eisenhardt, 2019), and ICT (Eisenhardt, 2021; Ziemba et al., 2017) offered by the companies. The literature review supported our decision to identify four distinct research areas, which were aligned with our research questions. These areas are related to HoReCa companies' activities in acquiring consumer knowledge, as depicted in the conceptual model in Figure 1. The research areas and their associated variables provide the conceptual foundation for our research and its subsequent findings.

The research problem of this study is to investigate HoReCa companies' activities towards sourcing consumers' knowledge in Poland and the UK. Thus, the main research question is: What are the HoReCa activities towards sourcing consumers' knowledge? To answer this question, the empirical study focuses on addressing the following four specific questions:

RQ1: Which business processes do HoReCa companies engage consumers in for sourcing their knowledge in Poland and the UK?

To answer RQ1, we followed the PCF (APQC, 2020), and four operational business processes were taken into consideration. The following hypothesis was developed:

H1: There are statistically significant differences in business processes that HoReCa companies engage consumers in, in Poland and the UK.

RQ2: What are the methods of the interaction between consumers and HoReCa companies in Poland and the UK?

To answer RQ2 we used such variables as designing, reviewing, and scoring. The following hypothesis was developed: H2: There are statistically significant differences in the methods of the interaction between consumers and HoReCa companies in Poland and the UK.

RQ3: What incentives do HoReCa companies offer to consumers in Poland and the UK?

To answer RQ3 we used such variables as material reward, monetary compensation, free product testing, complimentary product testing, and bonus points. The following hypothesis was developed: H3: There are statistically significant differences in incentives the HoReCa companies offer to consumers in Poland and the UK.

RQ4: What ICT do HoReCa companies offer to consumer in Poland and the UK?

To answer RQ4 we used such variables as e-mails, online discussion forums, corporate websites, industry-specific websites, widely-used information platforms, sector-focused online portals, mobile applications, Facebook, and web-based surveys. The following hypothesis was developed: H4: There are statistically significant differences in ICT the HoReCa companies offer to consumers in Poland and the UK (Fig. 1).

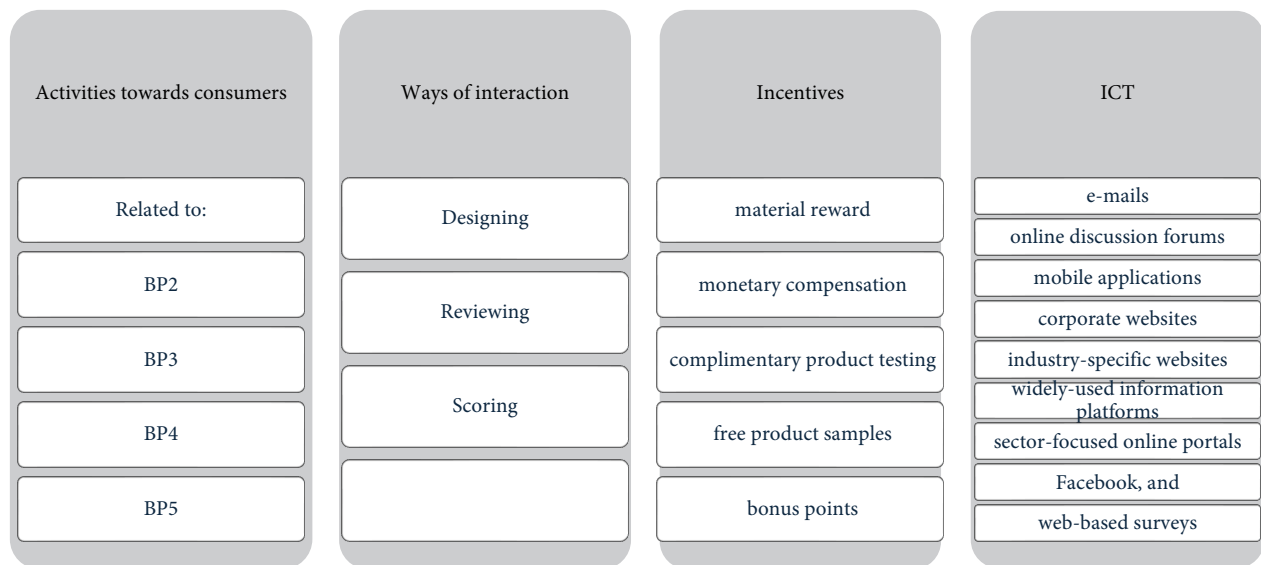


Figure 1. The conceptual framework of HoReCa companies' activities towards sourcing consumers' knowledge.

Source: created by authors.

2.2 Research procedure

This research employs a case study approach, centering on Poland and the UK, to investigate the potential for HoReCa companies to gather consumer knowledge. The study incorporates data from 1053 case studies, capturing diverse companies in terms of size, industry, and consumer engagement initiatives. To construct our methodology, we adhered to Eisenhardt's (1989) framework for building theories from case study research, emphasizing a structured research process:

Research Design: A comprehensive literature review framed research questions, exploring consumer innovation, engagement, and incentives. Multiple bibliographic databases and web resources were scrutinized.

Case Selection: Targeting companies in Poland and the UK actively engaging consumers in the projects aimed at their knowledge.

Instrument Development: A Microsoft Excel spreadsheet with six sheets facilitated empirical data documentation, defining terms, objectives, and categorizing observed companies based on PCF business processes, methods of interactions, incentives, and supporting ICT.

Main Research Process took place in 2018 and 2019, and simultaneous observations were conducted in Poland and the UK, with students reporting case studies for ongoing verification. Over 1500 case studies were documented and refined, resulting in a final sample of 1053 cases, categorized by industry using the British industrial classification. The focus narrowed to 66 HoReCa companies (29 in Poland, 37 in the UK).

Statistical Analysis: Microsoft Excel and Statistica packages were employed for a comprehensive analysis, incorporating Chi-Square tests for hypotheses and descriptive statistics for visualizing differences and similarities in consumer engagement between Poland and the UK.

The meticulous methodology ensures robust insights into HoReCa activities related to sourcing consumers' knowledge, contributing to the understanding of cross-cultural dynamics in consumer engagement practices.

3. Research results

3.1. HoReCa companies' activities aimed at consumers

The case studies compiled in Table 1 illustrate the diverse array of initiatives undertaken by HoReCa companies to involve consumers, thus serving as a conduit for acquiring consumer knowledge. Many of these companies involve consumers in feedback-related activities, expecting them to share their opinions on products and services they have used or experienced. Some enterprises offer more engaging projects, allowing consumers to design something, receive rewards, and promote the products they already know. It is noticeable that projects of Poland-based companies are more centered around consumers' opinions and their new ideas, while UK-based projects are slightly more differentiated, also focusing on competition, rewards, and promotional activities.

Table 1. Poland and the UK chosen HoReCa companies and their projects for consumers

Poland HoReCa businesses		UK-based HoReCa businesses	
Name	Description of the project	Name	Description of the project
KFC	GFP - Guests feedback programme for sharing opinions on the service quality	KFC	Get in touch - Guests feedback programme for sharing opinions on the service quality
McDonald's	Surveys on the service and food quality	Mariott Hotel	Guests' feedback for sharing opinions on the hotel's services quality
'Micha' soup restaurant	Consumers can impact on restaurant's menu by sharing opinions on tastes they would like to try in the future	Too Good To Go	A social impact company with a mission to fight food waste and ensure it is available for consumption before it ever needs to reach a landfill waste ground. Consumers download the app and benefit from getting access to reduced priced food.
My muesli flakes [MojeMusli.pl]	Consumers can create their own muesli combinations using 120 ingredients	Real Junk Food Project -cafes in the UK	Pay As You Feel Café. Consumers can donate or volunteer and share ideas and suggestions related to the projects services. Volunteers join WhatsApp groups to help and serve the customers in the café.
Burger bistro 'Pasi-bus'	Consumers can share ideas on the name of the "burger of the month"	Kenco. The coffee company	If consumers have any questions about Kenco's products, can fill in the contact form and suggestions form available on the website or call the customer care line
'Pod Sikorką' restaurant	Consumers can share opinions on the service and food quality	Tea Pigs	For many years, each month, they ran a competition with their stockists to find the stockist of the month who, in the funniest and most engaging way, shares opinions on Tea Pigs' offer.
Delicious tea [Smaczna herbata]	Consumers can create tea following their own preferences	Greggs	Using the mobile app consumers can enjoy tasty rewards on everything such as birthdays and they get a free hot drink for downloading the app.
My Starbucks Idea	Consumers share ideas for improving the café and its products Consumers can:	My Starbucks Idea	Consumers share ideas for improving the café and its products
Wedel – the Poland producer of sweets and chocolates	1. Design graphical elements and labels of the packages 2. In the 'Chocolate lovers club' they receive some discounts and bonus points as well as they can design and personalize some gadgets	Pizza Express	Refer-a-friend programme. The friend registers and the referrer and friend are offered free starters on next visit. The programme is for each friend who orders for the first time.

Source: Own elaboration.

The projects listed in Table 1 are selected examples of initiatives undertaken by HoReCa companies and are analysed in further detail. It is important to note that these projects primarily targeted ordinary consumers, with no requirement for expert knowledge or specific skills. Depending on the scope and objectives of each project, HoReCa companies engaged in activities such as listening to customers, seeking their input, and collaborating with them. Additionally, while some projects had a limited duration, many initiatives are ongoing, allowing consumers to continuously contribute their insights and innovative ideas.

3.2. Business processes the HoReCa companies involve consumers in Poland and the UK

Figure 2 presents the data analysis related to hypothesis H1 and research question RQ1. It shows that HoReCa companies in the UK engage consumers more extensively in their business operations and associated activities compared to those in Poland. Based on the PCF framework, four business processes were considered, i.e., BP 2.0 (Develop and manage products), BP 3.0 (Market and sell products), BP 4.0 (Deliver products), and BP 5.0 (Manage customer service).

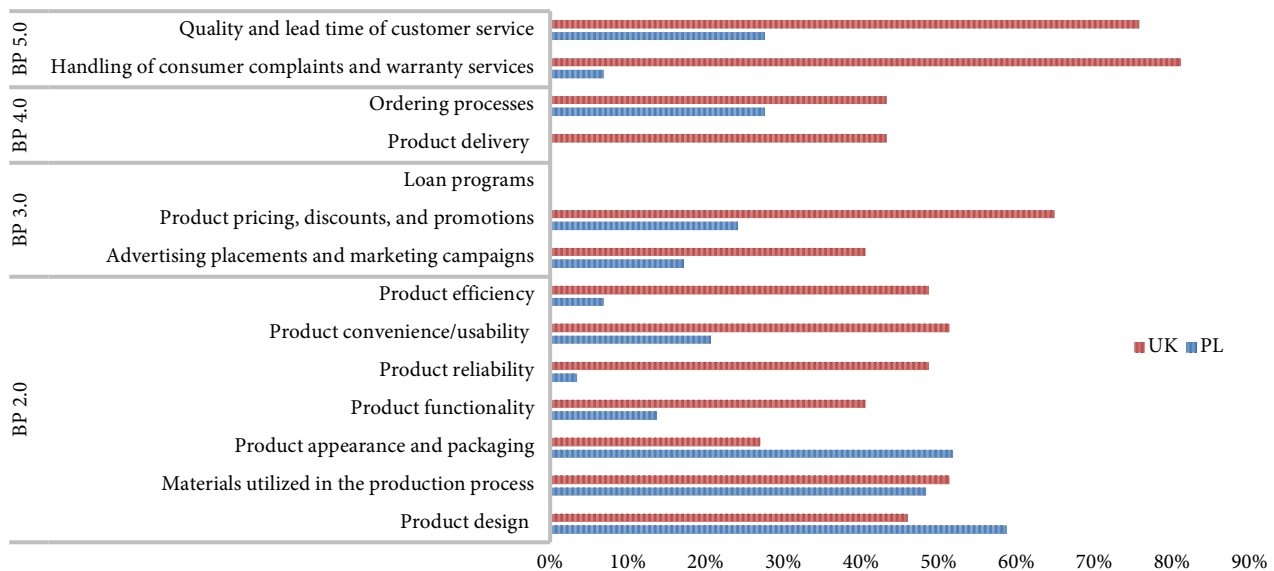


Figure 2. Business processes the HoReCa companies involve consumers - Poland and UK perspective. Source: Own elaboration.

Figure 2 shows that the differences are specifically related to the following consumers activities:

- Product functionality (BP 2.0): 40.05% of HoReCa companies in the UK and 13.8% in Poland involve consumers in activities related to product functionalities (a difference of 26.25%). Conversely, 51.7% of Polish and 27% of UK-based HoReCa companies engage consumers in projects focused on product appearance and packaging (a difference of 24.7%).
- Product pricing, discounts, and promotions (BP 3.0): 64.9% of HoReCa companies in the UK and 24.1% in Poland (a difference of 40.8%) involve consumers in a such activities.
- Products delivery (BP 4.0): 43.2% of HoReCa companies in the UK involve consumers in activities related to product delivery, whereas such activities were not observed in Poland, resulting in a difference of 43.2%.
- Handling of consumer complaints and warranty services (BP 5.0): 81.1% of HoReCa companies in the UK provide consumers with the opportunity to engage, while only 6.9% of HoReCa companies in Poland offer this possibility. The disparity is substantial, amounting to 74.2%. Likewise, Quality and lead time of customer service (BP 5.0) is provided by 75.7% of HoReCa companies in the UK, compared to just 27.6% in Poland, representing a difference of 48.1%.

Generally, the results of frequency procedures presented in Figure 2 show major differences between Poland and UK-based HoReCa companies. Thus, the Chi-Square test was applied to examine these differences. The results for testing hypothesis H1 are presented in Table 2.

Table 2. Differences in business processes the HoReCa companies engage consumers in Poland and the UK.

Parameters	BP 2.0	BP 3.0	BP 4.0	BP 5.0
Chi2	11.957	11.617	13.352	48.658
p-value	0.00055	0.0007	0.0003	< 0.00001

Source: Own elaboration.

As shown in Table 2, the p-value is lower than 0.05 for all four business processes, i.e., BP 2.0 (Develop and manage products), BP 3.0 (Market and sell products), BP 4.0 (Deliver products), and BP 5.0 (Manage customer service). This confirms that there are statistically significant differences in business processes the HoReCa engage consumers in Poland and the UK. Thus, hypothesis H1 is supported in our study.

3.3. The methods of interaction between consumers and HoReCa companies

To test hypothesis H2 and address research question RQ2, the data analysis presented in this section indicates that HoReCa companies in the UK more frequently offer scoring and reviewing as means of interaction compared to their counterparts in Poland (Figure 3).

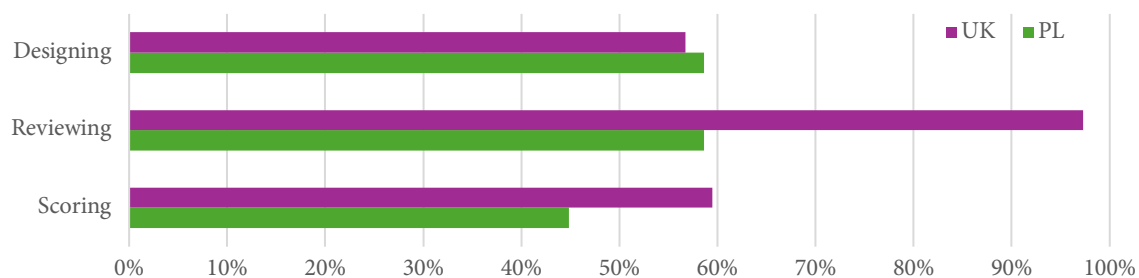


Figure 3. Methods of interaction between consumers and HoReCa in Poland and the UK.

Source: Own elaboration.

Figure 3 shows that 97.3% of UK-based HoReCa companies provide reviewing, compared to 58.6% in Poland, representing a difference of 38.7%. Additionally, 59.5% of UK-based HoReCa companies offer scoring, while 44.8% of Poland-based companies do the same. The availability of designing services is comparable between HoReCa companies in both countries.

For testing hypothesis H2 the Chi-Square test was used. The results are presented in Table 3.

Table 3. Chi-Square test results on differences in the methods of the interaction between consumers and HoReCa companies in Poland and the UK.

Parameters	Scoring	Reviewing	Designing
Chi2	1.397	15.375	0.023
p-value	0.237	<0.05	0.879

Source: Own elaboration.

As indicated in Table 3, the p-value is below 0.05 only for Reviewing. This indicates statistically significant differences in this method of interaction between HoReCa companies based in Poland and the UK. The test does not reveal any significant differences in the case of the remaining two methods of interaction, namely Scoring and Designing. In summary, hypothesis H2 is partially supported in our study.

3.4. Comparative analysis of incentives offered by HoReCa companies in Poland and the UK

To assess the third hypothesis H3 and investigate the third research question RQ3 frequency procedures were developed. Figure 4 unveils that HoReCa companies in the UK offer incentives to a greater extent than their counterparts in Poland. The most notable disparities are evident in:

- Free product samples: employed by 59.5% of HoReCa companies in the UK compared to only 20.7% in Poland (a difference of 38.8%).
- Bonus points: utilized by 32.5% of HoReCa companies in the UK versus only 13.8% in Poland (a difference of 18.6%).
- Monetary compensation: employed by 27% of HoReCa companies in the UK compared to just 10.3% in Poland (a difference of 16.7%).

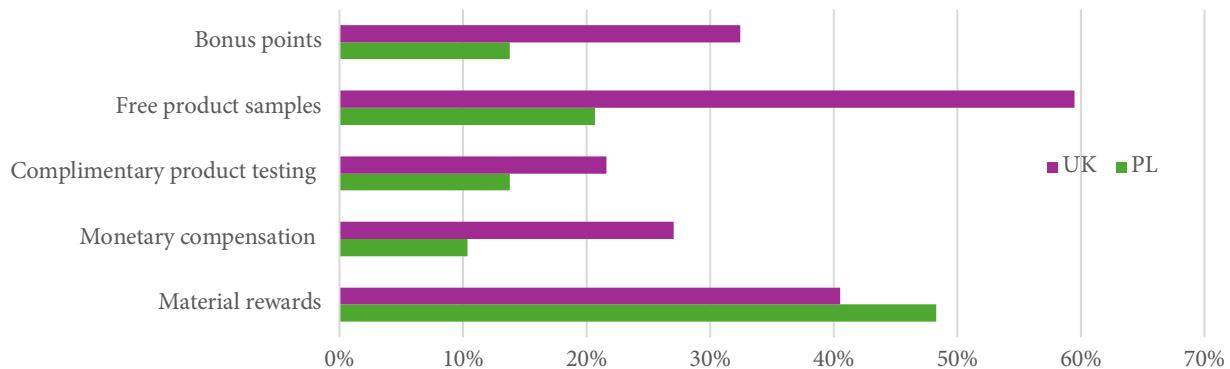


Figure 4. The incentives the HoReCa companies offer to consumers.

Source: created by authors.

The results of the Chi-Square test for testing hypothesis H3, as presented in Table 4, indicate minor differences in the incentives offered by HoReCa companies to consumers in Poland and the UK.

Table 4. Chi-Square test results on differences in the incentives offered in Poland and the UK.

Parameters	Material reward	Monetary compensation	Complimentary product testing	Free product samples	Bonus points
Chi2	0.3949	2.8604	0.6698	10.0044	3.0755
p-value	0.530	0.091	0.413	0.002	0.079

Source: Own elaboration.

As shown, the p-value is below 0.05 for only one incentive, namely free product samples, indicating statistically significant differences for this variable. The test does not reveal any significant differences in the case of the four remaining incentives, including bonus points, complimentary product testing, monetary compensation, and material rewards. Therefore, hypothesis H3 is rejected.

3.5. ICT the HoReCa offer to consumers in Poland and the UK

To test hypothesis H4 and to answer the RQ4, the data analysis using frequency procedures is presented in Figure 5.

As shown in Figure 5, HoReCa companies in the UK offer ICT to a greater extent than those in Poland. The only exception is the corporate website, which is more frequently offered by HoReCa companies in Poland. The most significant differences are observed for:

- Widely-used information platforms: offered by 48.6% of HoReCa companies in the UK and by 10.3% in Poland (a difference of 38.3%).
- Online discussion forums: provided by 54.1% of HoReCa companies in the UK and by 17.2% in Poland (a difference of 36.9%).

- E-mails: available from 83.8% of HoReCa companies in the UK and from 48.3% in Poland (a difference of 35.5%).
- Mobile applications: offered by 62.2% of HoReCa companies in the UK and by 31% in Poland (a difference of 31.2%).

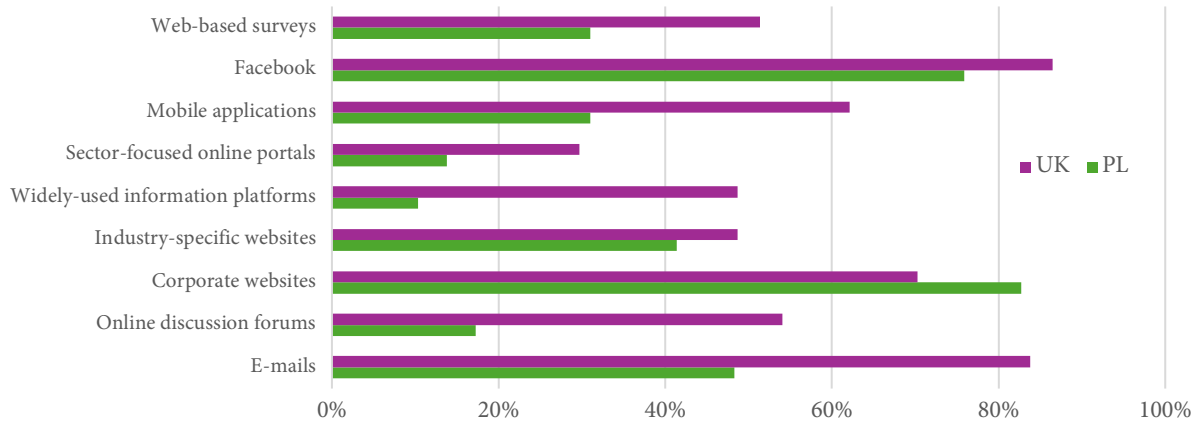


Figure 5. ICT the HoReCa offer to consumers in Poland and the UK.

Source: created by authors.

The results of the Chi-Square test for testing hypothesis H4 are presented in Table 5.

Table 5. Chi-Square test results on differences in ICT offered in Poland and the UK.

Parameters	E-mail	Online discussion forum	Corporate website	Industry-specific website	Widely-used information platforms	Sector-focused online portals	Mobile applications	Facebook	Web-based surveys
Chi2	9.449	9.363	1.381	0.347	10.995	2.351	6.307	1.234	2.747
p-value	0.002	0.002	0.240	0.556	0.001	0.125	0.012	0.267	0.097

Source: Own elaboration.

As show in Table 5, the p-value is lower than 0.05 for four ICT, i.e., e-mails, online discussion forums, widely used information platforms, and mobile applications, suggesting that statistically significant differences are observed. The test does not reveal significant differences for the remaining five ICT. In summary, hypothesis H4 is partially supported by the findings of this study.

4. Discussion

The results obtained show the cross-national differences in consumer engagement in the HoReCa sector in Poland and the UK. The results are spited into four categories, i.e. business processes, methods of interaction with consumers, incentives, and ICT offered by the companies.

Referencing to our results on business processes, HoReCa companies can engage consumers in different business processes and prioritize them. It is evident that certain processes, such as "Quality and lead time of customer service" (75.7% in the UK vs. 27.6% in Poland) and "Handling of consumer complaints and warranty services" (81.1% in Poland vs. 6.9% in the UK), are approached differently in these two countries, suggesting distinct national preferences or market demands. Similarly, noticeable differences are seen in other categories like "Product pricing, discounts, and promotions" and "Product efficiency", "Product convenience/reliability", "Product functionality", and "Product reliability" where UK companies show higher engagement rates compared to their Polish counterparts. This data highlights the cultural and operational differences between the two markets, providing valuable insights into how consumer engagement strategies are tailored differently in Poland and the UK. One notable observation is the complete absence of engagement in certain areas, such as "Product delivery"

(showing 0% for Poland). In contrast, UK companies show 43.2% engagement. For "Loan programs" (both) indicate that this is not area of focus or relevance for HoReCa companies in their consumer knowledge acquisition strategies regardless the country, suggesting this is not a strategic area for either market, potentially due to different business models or consumer expectations within the HoReCa sector.

Another interesting point is the relative emphasis on "Product design" and "Materials utilized in the production process". Polish companies place a greater emphasis on "Product design" (58.6% for Poland vs. 45.9% for the UK) suggesting a stronger focus on product development and quality at the production level. This could reflect a cultural preference in Poland for more bespoke, customized offerings or a competitive strategy focusing on product differentiation in the HoReCa sector. These differences underline how companies in different markets may adopt unique approaches and prioritize different aspects of their operations to engage consumers effectively and adapt to local market conditions.

Referencing to the results on consumer engagement through three modes: designing, reviewing, and scoring one can find "Reviewing" as a dominant mode in the UK, with 97.3% of consumers participating, compared to 58.6% in Poland. This suggests that UK consumers are highly active in providing feedback, opinions, and evaluations of products and services. HoReCa companies in the UK should prioritize channels and platforms that facilitate consumer reviews, such as online feedback forms, review websites, and social media pages.

What is more, in Poland, the levels of engagement across the three modes (designing at 58.6%, reviewing at 58.6%, and scoring at 44.8%) are more balanced. This suggests that Polish consumers are moderately engaged in all types of consumer-company interactions.

Referencing to the results on incentives UK consumers are more responsive to free product samples (59.5%) and bonus points (32.4%), while Polish consumers show a stronger preference for material rewards (48.3%). This suggests that UK consumers may be more engaged by incentives that allow them to experience or try new products (which aligns with a desire for knowledge and experience), while Polish consumers are motivated by tangible goods or direct rewards, potentially indicating a stronger preference for certainty and tangible value in their transactions. To practically engage consumers in these two markets, companies need to align their incentives with these preferences. In the UK, marketing efforts should emphasize opportunities for consumers to receive free samples and earn points through loyalty programs, catering to consumers who find value in exploration and experiential engagement (as a form of extrinsic motivation). In contrast, in Poland, companies should promote material rewards more prominently, ensuring that these rewards are visible and appealing to drive consumer engagement.

For ICT, the results show a strong preference among UK consumers for Facebook (86.5%) and emails (83.8%) as primary channels for engagement, while Polish consumers favor Corporate websites (82.8%) and also Facebook (75.9%). These insights suggest that companies should prioritize these platforms for their communication and engagement strategies, ensuring they are utilized effectively to connect with and motivate consumers. What is more, the high usage of corporate websites in Poland (82.8%) compared to the UK (70.3%) suggests that Polish consumers may trust or rely more on official channels for information. Therefore, companies should maintain updated, engaging, and transparent websites in Poland. In the UK, where web-based surveys are more popular (51.4% vs. 31.0% in Poland), companies could employ surveys to gather consumer feedback, opinions, and ideas to foster engagement and co-creation.

Conclusions

Following the previously presented results, the main findings are summarised in Table 6. The results from the Chi-Square test confirm statistically significant differences between Poland and UK HoReCa companies in terms of the consumers engagement.

Table 6. Summary of Research Hypotheses.

Hypotheses	Result
H1: There are statistically significant differences in business processes that HoReCa companies engage consumers in, in Poland and the UK	Supported
H2: There are statistically significant differences in the methods of the interaction between consumers and HoReCa companies in Poland and the UK	Partially supported
H3: There are statistically significant differences in incentives the HoReCa companies offer to consumers in Poland and the UK	Rejected
H4: There are statistically significant differences in ICT the HoReCa companies offer to consumers in Poland and the UK	Supported

Source: Own elaboration.

Referencing Table 6, the findings reveal important insights into how HoReCa companies engage with consumers in Poland and the UK, reflecting differences in business processes, interaction methods, and the use of ICT tools, while challenging assumptions about incentive structures. The most important are:

- Differences in Business Processes. The study supports Hypothesis 1, confirming that there are statistically significant differences in the business processes through which HoReCa companies engage consumers in the UK and Poland. In the UK, consumer engagement is primarily driven by reviewing, suggesting a focus on feedback and opinion-sharing. In contrast, Polish consumers exhibit a more balanced approach across various engagement modes, such as designing, reviewing, and scoring, highlighting diverse engagement processes.

- Differences in Interaction Methods. Hypothesis 2 is partially supported, indicating some significant differences in the ways consumers interact with HoReCa companies between the two countries. While the UK shows a strong preference for feedback through reviews, Polish consumers engage more evenly across multiple interaction modes. This suggests that UK companies may benefit from enhancing review platforms, whereas Polish companies should offer a broader range of engagement opportunities.

- Incentives Offered to Consumers. Hypothesis 3 is rejected, indicating that there are no statistically significant differences in the incentives offered by HoReCa companies in Poland and the UK. This finding suggests that both markets employ similar extrinsic incentive strategies, such as material rewards, monetary compensation, free product samples, and bonus points, without major differentiation. Companies in both countries may need to rethink their incentive strategies to better align with local consumer motivations.

- Differences in ICT Tools Offered. Hypothesis 4 is supported, confirming significant differences in the use of ICT tools offered by HoReCa companies in the UK and Poland. The UK shows higher engagement with social media platforms, corporate websites, and web-based surveys, reflecting a more digital-focused strategy. Meanwhile, Poland demonstrates a more varied use of ICT tools, with significant engagement through corporate websites and e-mails. This suggests that HoReCa companies in the UK should continue to invest in digital platforms, while those in Poland should maintain a diverse range of ICT tools to support consumer engagement.

The results obtained show the cross-national differences in consumer engagement in the HoReCa sector in Poland and the UK. The results led us to provide the following implications.

Companies should provide diverse opportunities for engagement, such as platforms for designing products, scoring mechanisms like star ratings, and forums for reviews and discussions. The findings align with the literature on consumer engagement modes, where companies seek active consumer participation to innovate and improve their offerings (Liu et al., 2019; Jin et al., 2016; Qiao et al., 2018). The emphasis on reviewing, scoring, and designing supports the proactive approach identified by Liu et al. (2019), in which companies actively solicit feedback and ideas from consumers.

The modes of interaction reflect the social dynamics of consumer participation in the innovation and feedback processes which led to two main social implications. Firstly, the high engagement in reviewing in the UK indicates a robust culture of feedback and opinion-sharing. This could suggest that UK consumers feel more empowered or are more accustomed to voicing their opinions about products and services. It also points to a potential social norm where consumer feedback is expected and valued, contributing to a more transparent and interactive relationship between companies and consumers. Our results support the report of consumers growing power and indicate that the consumer empowerment is still a crucial issue (Deloitte, 2014). Secondly, the balanced engagement across all modes in Poland suggests a more collaborative approach, where consumers are equally willing to participate in various stages of the product or service lifecycle—from design to scoring. This could reflect a consumer culture that values diverse forms of contribution, which companies can leverage to foster a sense of community and involvement. We noticed that the differences between Poland and the UK align with Fendrejewska's (2017) deliberations. She presented several indexes which showed that Poland is seen as a hierarchical society much more than the UK. Moreover, the UK is a more individualistic nation and a consumer is seen as “an autonomous entity with a distinctive set of attributes, qualities or processes”. All those characteristics align with our results as individuals from Poland and the UK differ significantly in terms of their willingness to share knowledge and take part in business-consumer relationships, to be a source of knowledge for companies and their expectations of the incentives.

The results on incentives suggest that different types of extrinsic incentives might impact social engagement behaviours differently in each country, reflecting cultural and social norms. The UK's preference for free samples and bonus points may indicate a consumer culture that values experimentation and sharing experiences. Consumers who receive samples might share their feedback and experiences more freely, promoting social engagement and word-of-mouth marketing. Our results are in line with Bhandari's and Rodgers's (2019) who suggest that brand feedback had a simultaneous positive and negative effect on purchase intentions, whereby brand trust mediated the positive effect and conclude that by describing mechanisms through which brand feedback occurs to influence brand outcomes. In Poland, a higher preference for material rewards might reflect a consumer culture that values certainty and tangible benefits over experimentation. This could imply that social dynamics around product engagement are less driven by shared experiences or peer influence and more by personal gain or visible status markers.

The use of ICT tools reflects social dynamics and behaviours in how consumers interact with brands and companies. The strong preference for social media, particularly Facebook, suggests that both Polish and UK consumers value platforms that allow for community interaction and social sharing. This implies that consumers in both countries are open to engaging with brands in a social and public context, where their interactions can be visible to others, potentially driving peer influence and community building. This approach was confirmed by Wang et al. (2021), who provided insights into how social media brand communities can be leveraged as a strategic tool for achieving business value. The preference for emails and corporate websites, especially in Poland, might indicate a desire for more controlled, direct, and potentially private communication channels, reflecting a more cautious approach to engagement. Our results are consistent with Sołek-Borowska (2018), whose research involving 153 Polish SMEs revealed that email is the most popular tool, used by 88% of the surveyed

entities. Conversely, the UK's openness to web-based surveys and online discussion forums suggests a greater willingness to share opinions and engage in public dialogue. The results we received confirm Andrijauskiene and Dumciuvienė's (2018) observations that the UK is seen to be more innovative than Poland.

Our research comprehensively analyses companies' activities towards sourcing consumers' knowledge in the HoReCa sector. The findings contribute to managerial aspects as well, guiding businesses in optimizing their consumer engagement and knowledge utilization strategies.

For managers in the HoReCa sector, understanding the distinct consumer motivations and preferences is crucial for developing effective engagement strategies. Managers need to carefully design incentive programs that align with the cultural and motivational differences of consumers in these markets. In the UK, for instance, offering a range of experiential incentives (like free samples or product testing) may appeal to consumers who value novelty and exploration, which could also lead to higher consumer advocacy and retention. Meanwhile, in Poland, more traditional incentives like material rewards should be the focal point, as they align with the prevalent consumer desire for concrete benefits. What is more, our results suggest that while both markets respond to extrinsic motivators, the type of motivator that resonates most can differ significantly. Managers must align their communication strategies with these insights. In the UK, campaigns should stress the fun and discovery aspects of receiving samples or accumulating points, framing these incentives in terms of enjoyment and learning. In Poland, however, the focus should be on the immediate and tangible benefits of participating in loyalty programs or promotional activities, possibly highlighting material rewards as a means to secure consumer loyalty.

Referencing to ICT and communication channels, understanding these preferences is crucial for managers aiming to enhance consumer engagement through digital platforms. Thus, managers need to recognize that different digital tools resonate differently across markets. In the UK, focusing on social media strategies (primarily Facebook) and integrating web-based surveys can help foster engagement by leveraging the public nature of these platforms and the willingness of consumers to provide input. In Poland, companies should emphasize their presence on corporate websites and email marketing campaigns to build trust and ensure a direct line of communication. To fully utilize ICT for consumer engagement, managers should foster an environment where consumers feel empowered to participate in the innovation process. This could involve using Facebook and other social media channels to solicit ideas, feedback, and participation in product development or using corporate websites and emails for more formal feedback and customer relationship management.

For managers in the HoReCa sector, insights based on modes of interaction are crucial for shaping effective engagement strategies. In the UK, their focus can be on enhancing review mechanisms, as our results emphasize high engagement in reviewing. Thus, managers in the UK should improve platforms for consumer feedback, making it easier for consumers to share their opinions. Encouraging reviews can help companies gather valuable insights for improving products and services while building a transparent, consumer-focused brand image.

In contrast, the need for diversified engagement methods in Poland was confirmed. Therefore, managers in Poland should offer a range of engagement options to cater to the balanced interest in different modes of interaction. For example, creating opportunities for co-design initiatives (like product design contests), implementing scoring systems for feedback, and facilitating review platforms can help maximize consumer involvement and satisfaction.

In summary, for HoReCa sector managers, understanding consumer engagement preferences is key. Particularly, UK focus shall emphasize review mechanisms to leverage high consumer engagement in providing feedback. Enhance platforms for reviews to gather insights, improve offerings, and build a transparent, consumer-focused brand image whereas Poland focus can be towards implementation of diverse engagement methods to cater to a balanced interest in different interaction modes.

Provide opportunities for co-design (e.g., product design contests), scoring systems, and review platforms to maximize consumer participation and satisfaction.

By aligning strategies with these preferences, managers can foster deeper consumer involvement and drive innovation.

The cultural differences are crucial for that study. We are aware that we have only mentioned them. The main point was to focus on knowledge-related analyses. Thus, additional in-depth studies are needed on cultural differences and how these differences impact the main research problem which sourcing consumers' knowledge.

Furthermore, the research embraced two sets, i.e., Poland and UK-based HoReCa companies which were selected on the basis of the case studies observation. We are aware that this selection may impact the results. It is advisable to extend further research to other sectors and a bigger number of companies. By doing so the validity and reliability of the further research and results can be strengthened.

The analyses we performed are aimed at the pre-pandemic time. During the COVID-19 pandemic, some projects aimed at consumer knowledge were opened or closed for various reasons. That opens new possibilities for our research and encourages us to perform the next step of the research to be able to compare the results for two periods of time, i.e. pre- and after-pandemic.

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Business Investment Opportunities for Community Welfare: Evidence from Indonesia

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Abstract

This research uses panel data covering 34 provinces for 13 periods from 2009 to 2021. Foreign direct investment has an important role not only in improving Indonesia's economic position compared to other countries but also as a driver for the sustainability of Indonesia's business and economy. The researchers analyse the extent to which gross domestic regional product (GDRP), domestic investment, the Gini coefficient, and literacy influence foreign direct investment (FDI) inflow into Indonesia. The authors choose the best model among various alternatives, namely, pool, fixed effects, and random effects regression with the Chow and Hausman test methods. Through the best model, namely, refined random effects, the authors prove that GDRP, regional domestic investment, regional Gini coefficient, and regional literacy influence the increase in Indonesia's FDI. This research contributes to the theoretical gap, practical knowledge gap, and empirical gap. The results of this research have a new insight that knowledge and skills, innovation, and a supportive economic situation are the keys to successful business investment movements.

Key words

foreign direct investment, gross domestic regional product, domestic investment, Gini coefficient, literacy.

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Introduction

In conducting international business, multinational companies refer to three objectives, namely, gaining market share, obtaining economic resources abroad, and gaining efficiency with relatively low production factor costs abroad (Moon, 2015). Indonesia has made changes to investment regulations and human resource reforms. This cannot be separated from the country of Indonesia, which has three potential multinational corporation goals (Jensen, 2008; Lekovic, 2018).

Investors' interest is due to a country's purchasing power, which is reflected in the gross domestic product. The GDP is an economic quantity that is reflected in economic activities among households, businesses, the government, and the rest of the world. Therefore, GDP not only measures a country's performance but also acts as a benchmark for purchasing power in the local market (Egerer et al., 2016; OECD, 2015). As such, Indonesia's GDP as purchasing power for MNCs has implications for

increasing market share and reducing risk because the market is divided into two parts, namely, domestic and overseas. Indonesia's role in ASEAN countries is highly regarded in the international market because of its ever-increasing GDP, vast territory, population diversity, and natural resources. Table 1 compares Indonesia's GDP in 2022 with that of several ASEAN countries (Analytica, 2015; Magazzino et al., 2021; Ng & Kee, 2017).

Table 1. Gross Domestic Products of 10 ASEAN Countries.

No	Country	Population in millions	GDP Nominal millions USD	GDP Nominal per capita USD
1	Indonesia	274.859	1,318,807	4,798
2	Thailand	70.078	536,160	7,650
3	Singapore	5.637	466,789	82,807
4	Malaysia	32.993	407,923	12,364
5	Vietnam	99.462	406,452	4,086
6	Philippines	111.57	404,261	3,623
7	Myanmar	53.886	56,757	1,053
8	Cambodia	16.767	29,912	1,784
9	Brunei	0.442	16,639	37,667
10	Laos	7.477	15,304	2,046
	ASEAN	672.397	3,657,636	5,439

Source: World Bank, 2023.

In terms of the population in the ASEAN region, Indonesia is in first place, with 40% of the entire population of ASEAN countries being Indonesian residents. Furthermore, in terms of per capita income, Indonesia ranks fifth after Singapore, Brunei, Malaysia, and Thailand (World Bank, 2023). Thus, Indonesia has the potential for large and evenly distributed purchasing power for each of its residents (Ishikawa, 2021; Shimizu, 2021). The trend towards Indonesia's purchasing power is a basic need for its population, so this is what makes the Indonesian region potentially the most lucrative market in Southeast Asia (Cole et al., 2017; Lipsey & Sjöholm, 2011; Smeeding, 2005).

The GDRP, which is spread across 34 provinces throughout Indonesia, presenting conundrum with various resources and economic activities. Several provinces with incomes of more than 1 trillion rupiah are concentrated on the island of Java, which is dominated by four provinces, namely, the Special Regions of Jakarta, East Java, West Java, and Central Java, accounting for 54% of Indonesia's GDP (Badan et al., 2023). Regional market behaviour is very interesting regardless of the visible and invisible differences in the GDRP structure (Garnier & Madlener, 2016; Mawutor et al., 2023).

If we look at the GDP structure, gross domestic physical capital formation will contribute 30% of Indonesia's GDP in 2022 after the COVID-19 pandemic (Badan Pusat Statistik, 2023). The share of gross domestic physical capital formation from total GDP is quite large from the economy in producing goods and services; approximately 30% of GDP is physical capital, while human capital has not been considered. Therefore, economic investment activities could be more significant than expected if human investment could be calculated with certainty. Therefore, lower investment risks encourage business groups to increase investment in the hope that people's purchasing power situation will continuously improve (Hoag & Hoag, 2002; Wanger & Ar, 2022; Wei, 2013). The discovery of new natural resources will also encourage domestic and foreign investment in areas with abundant economic resources.

The reason is that purchasing power, abundant economic resources, and business efficiency due to the cost of local production factors that will be used are the main international business objectives of every multinational corporation (MNC) entering Indonesia. Moreover, the goal of gaining market share is a derivative goal because every product produced is considered to have a comparative advantage. The following is the development of FDI flowing into Indonesia in the last decade, as shown in Figure 1.

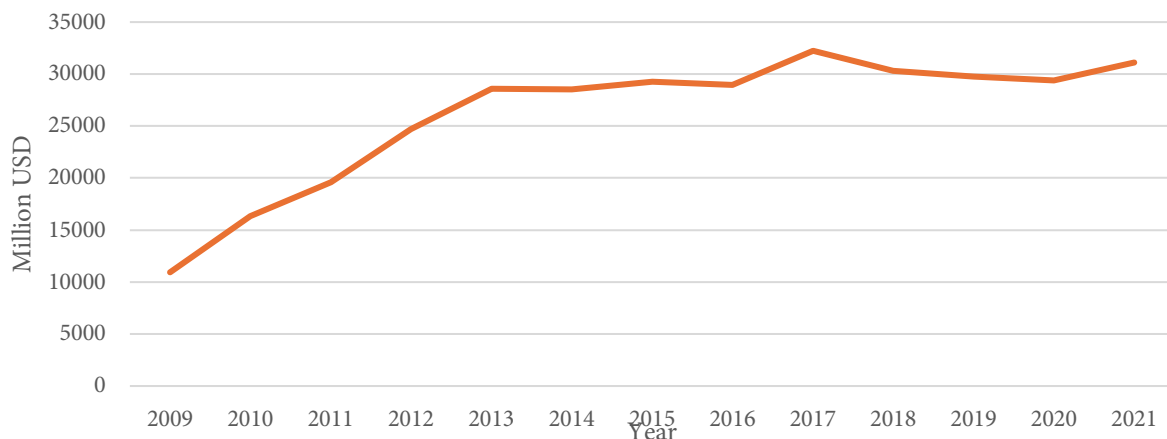


Figure 1. Foreign Direct Investment Inflow to Indonesia.

Source: BPS Indonesia, 2023.

FDI in each province is always increasing and is accompanied by an increase in people's income, which reflects increasing purchasing power. As a result, the overall income of citizens may improve, contributing to increased purchasing power. The end of 2021 was the time when the COVID-19 pandemic began, and Indonesia's economic enthusiasm began to rebound. Likewise, economic resources that were previously unmanaged can then be managed wisely (Trushkina, 2019).

There are five provinces in Indonesia that are the leading destinations for FDI. In 2022, foreign investment reached IDR 1,207.2 trillion or exceeded the target set by the Indonesian Government, namely, IDR 1,200 trillion. Moreover, West Java is one level below Central Sulawesi, with realized foreign investment or foreign direct investment of US\$ 6.5 billion. This achievement was followed by North Maluku, which reached an investment value of US\$ 4.5 billion (BKPM, 2023). The overall purchasing power of society towards needs is increasing, thus becoming the Indonesian domestic market, which is very attractive for producers. The increasing income in all provinces in Indonesia is accompanied by the government, which has built toll roads and sea toll infrastructure that support the increasingly smooth distribution of goods (Avci & Akin, 2020; Desai et al., 2004, 2005; Mead, 2020). The development of domestic investment from 2009-2022 is shown in Figure 2.

The size of domestic investment reflects the degree to which the risk will be spread throughout Indonesia. There is a trend towards domestic investment, which is constantly increasing, which shows that there is increasing purchasing power originating from domestic and the rest of the world (exports) and expectations for an increasingly better business world in Indonesia (Alibekova et al., 2023). The development of domestic investment from 2009-2022 is shown in Figure 2.

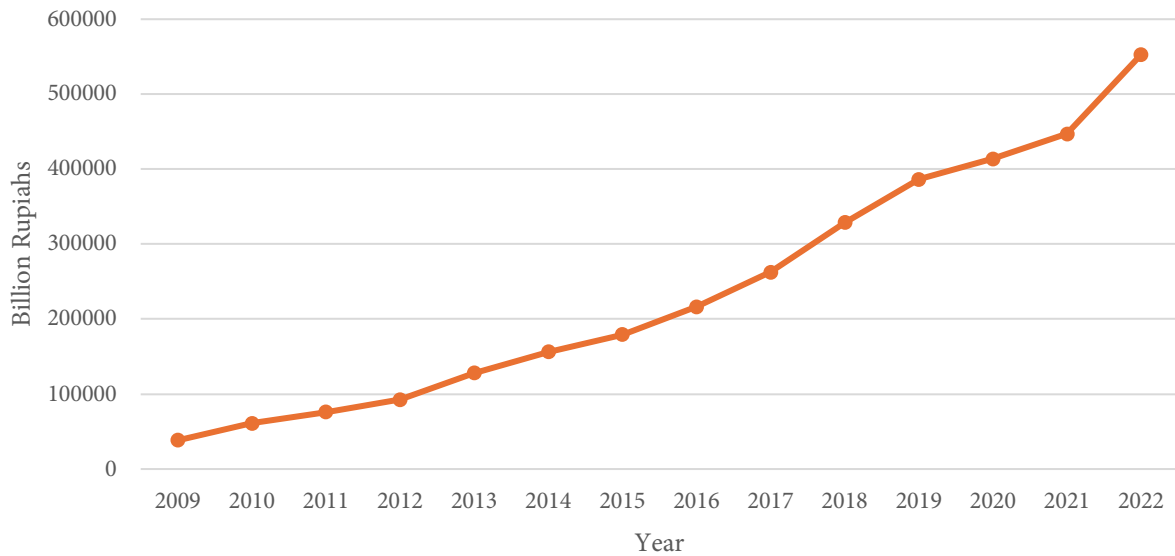


Figure 2. Domestic Investment in Indonesia.

Source: BPS Indonesia, 2023.

Conditions of income equality also encourage the formation of a purchasing power structure for goods/commodities that are close to normal needs. The more equal people's incomes are, the more even the demand will be for products based on people's needs. Over the last 10 years, the Indonesian Gini coefficient has decreased from approximately 40% to approximately 37%, as shown in Figure 3.

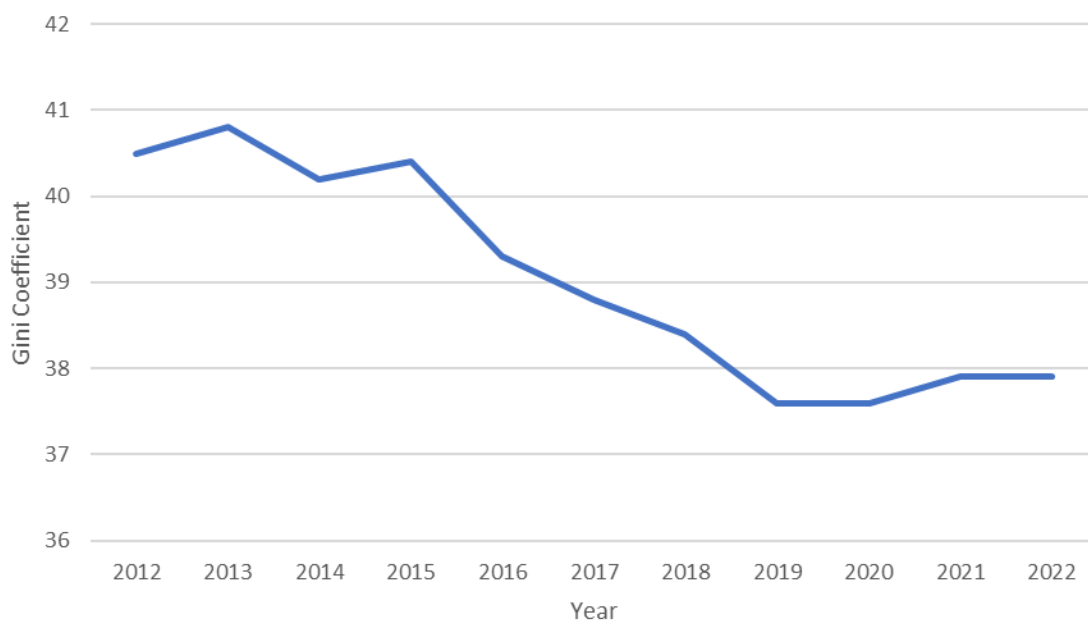


Figure 3. Indonesian Gini coefficient.

Source: World Bank, 2023.

As shown in Figure 3, the Indonesian government is working hard to reduce the Gini coefficient, even though a Gini coefficient above 30% is not ideal. On the basis of the World Bank's measure of

inequality, the distribution of national expenditures in the bottom 40% is 18.24%. According to the regional classification, the percentages of national expenditures in the bottom 40% of urban and rural areas are 17.19% and 21.06%, respectively. The recommendation to promote economic growth to reduce inequality is crucial. In rural areas, where inequality has historically been more pronounced, the positive trend toward improvement is encouraging. This progress signifies that efforts to uplift rural communities are yielding results. However, a sustained focus on equitable policies and targeted interventions remains essential to ensure continued advancement.

In 2022, the average inflation rate in Indonesia was approximately 4.21 percent greater than that in the previous year (Caballero, 2013). The fiscal budget indeed plays a crucial role in shaping inflation. To reduce inflationary fluctuations through energy subsidy mechanisms and spending allocations to stabilize food prices. To reduce inflationary fluctuations through energy subsidy mechanisms and spending allocations to stabilize food prices.

Literacy is the gateway to human capital development for all countries, including Indonesia. Human capital encompasses the collective intellectual and physical attributes of individuals. It includes their knowledge, skills, creativity, health, and abilities. This valuable resource makes a substantial contribution to economic expansion, innovation, and the advancement of society as a whole (Nguyen (2023). The Indonesian government has encouraged literacy programs in all regions, including remote areas (Budiono et al., 2021). Every literate person will automatically learn greater knowledge, from not being able to read at all to being literate and then being able to count and carry out creativity/innovation in their environment (Mankiw et al., 1992; Musibau et al., 2019). This situation has led to a jump in the progress of human capital in Indonesia.

Literacy has also created a mindset in which people care about a better future. Indonesian people are increasingly encouraged to pursue higher formal education. Likewise, they will be easier to mold into loyal and dedicated workers than those the government's literacy program has not touched. They will also be more innovative in terms of production processes and innovative products (Allen, 2003; Budiono et al., 2021). In this way, such workers can care about the environment, the place of work, and the future (Blunch & Pörtner, 2011; World Literacy Foundation (WLF), 2015).

There are several previous research results regarding foreign direct investment (Sijabat 2022; 2023; Belloumi & Alshehry 2018; Nguyen 2022; Meyer & Habanabakize 2018; Kobilov & Kurbonov 2021; Choong & Lam 2010; Bekana 2016; Suliman & Mollick 2009; Paolino 2009; Naude & Krugell 2007). This research highlights the fascinating interplay between GDP, FDI, and domestic investment. These economic factors are intricately connected, and their relationships can significantly impact a nation's growth and development. Furthermore, the literacy variable positively influences FDI, and vice versa. Finally, several research results prove that FDI affects the Gini coefficient negatively and significantly, but the Gini coefficient does not affect FDI. However, the authors still include the Gini coefficient as an independent variable influencing FDI inflow to Indonesia.

Thus, the authors consider independent variables that are thought to affect FDI inflow, namely, the GDRP, domestic investment, the Gini coefficient, and literacy. Therefore, we analyse 4 independent variables and 1 dependent variable. After all, FDI is needed for Indonesia's economic progress. We also care about the domestic and production factor markets in Indonesia. This research was conducted with the following structure: problem background, literature review, methodology and data, analysis and discussion, conclusion, suggestions, and limitations.

1. Literature review

In her empirical study, Sijabat (2022) examined the complex relationships between foreign direct investment, foreign portfolio investment, and gross domestic product in ten ASEAN member nations between 2009 and 2021. These two economic factors are linked, with FDI greatly influencing a nation's economic output. Specifically, GDP influences FDI: A robust GDP can attract foreign investors due to the potential for higher returns and market growth. FDI influencing GDP: Foreign direct investment can contribute to economic growth by injecting capital, technology, and expertise into the host country.

Belloumi and Alshehry (2018) explore the complex connections between domestic capital investment, foreign direct investment, and economic growth in Saudi Arabia from 1970-2015. The findings are based on your methods: Autoregressive Distributed Lag Bounds Testing: The ARDL approach examines the long-term relationship between variables. The fully modified ordinary least squares technique is a method for estimating long-run relationships. Because it incorporates both endogeneity and serial correlation, it is appropriate for analysing the factors that influence economic growth. It addresses the issue of endogeneity by incorporating lagged variables. Canonical cointegrating regression is used to explore the cointegrating relationships between variables.

The results show intriguing relationships between economic factors, particularly the relationship between FDI and nonoil GDP growth, which is a subject of considerable debate and study in economic dynamics. Understanding these dynamics is crucial for informed policy decisions and sustainable development. The findings indicate that fluctuations in nonoil GDP influence FDI, and vice versa. The negative bidirectional causality between the growth of nonoil GDP and domestic capital investment suggests that changes in one variable affect the other, and vice versa. Fluctuations in nonoil GDP impact domestic capital investment, and vice versa, over time, indicating a negative bidirectional causality between nonoil GDP growth and FDI, as well as between nonoil GDP growth and domestic capital investment. Consequently, it can be inferred that FDI and domestic capital investment are interconnected and exert mutual influence on each other in the long run (Majerová & Pražák, 2020).

Nguyen (2022) examines the impact of GDP on FDI inflows over a period of two decades. Nguyen's study focuses on South Asia. Higher GDP growth typically attracts greater FDI due to the availability of investment prospects and potential profits in an expanding economy. Nguyen conducts the unit root test and the lag length and estimates the VAR Model. Additionally, Nguyen tests Granger causality, examines the stability of eigenvalues, and conducts the Johansen test for cointegration.

Meyer and Habanabakize (2018) used the ARDL model to estimate political risk, GDP, and trade openness to collectively shape FDI decisions. The study suggests that countries should work to improve their political risk ratings through existing political and economic unions and embed their natural resource exploitation within a sound institutional framework. South Africa's experience provides valuable insights for other countries seeking to attract foreign investment. Therefore, addressing political risk and promoting policies that attract and retain foreign investment are essential steps toward achieving sustainable economic growth and improving the well-being of citizens in South Africa.

Kobilov and Kurbonov (2021) discovered a positive significant bidirectional relationship between GDP and FDI. More precisely, there is a causal relationship between GDP and FDI, with GDP Granger causing changes in FDI. Additionally, fluctuations in FDI were explained by shocks in GDP,

with GDP accounting for 55.0 percent of the variance in FDI. When choosing the lag length for a VAR (vector autoregressive) model, it is essential to use a parsimonious approach. Parsimony seeks to achieve a balance between the intricacy of a model and its ability to provide clear explanations. The Johansen test is employed to determine the presence of a long-term relationship (cointegration) among various time series variables. Granger causality is a statistical notion that relies on the ability to forecast. It examines the correlation between cause and effect. The VAR model is designed to reflect the interdependencies that exist among different time series variables. The ECM is employed in cases where variables exhibit cointegration. The ECM includes an error correction term that adjusts for deviations from the long-run equilibrium.

A study conducted by Kobilov and Kurbonov (2021) emphasized the significant impact of GDP on FDI inflow in Uzbekistan. When a country experiences robust economic growth (reflected in a high GDP), it tends to attract more FDI. Conversely, FDI contributes to economic growth. Foreign investors contribute capital to local ventures, which leads to the stimulation of economic activities. Policymakers acknowledge the importance of FDI as a catalyst for promoting economic development in Uzbekistan. The findings that domestic investment exerts a more substantial influence on economic growth than FDI does are intriguing. Domestic investment (made by local businesses and individuals) is indeed vital for sustainable growth. It directly fuels economic activities within the country. FDI, while essential, may not always have an immediate effect on local employment or technology diffusion. However, it brings external expertise, access to global markets, and capital infusion. A striking balance between domestic investment and FDI is crucial for holistic economic progress (Meyer, 2021).

Choong and Lam (2010) examine the factors influencing FDI in Malaysia over 37 years, from 1970-2006. Gross FDI inflow is an essential indicator of economic openness and attractiveness to foreign investors. The literacy rate is a measure used to approximate a nation's level of human capital development and education. The trade-to-GDP ratio reflects the relative importance of international trade in a country's economy by dividing the total value of imports and exports by GDP. A comprehensive study investigated the FDI dynamics between Malaysia and the other five ASEAN countries via the multivariate GARCH model. The relationship between FDI inflows and economic growth in host countries is heavily debated. While some studies show a positive impact of FDI on economic growth, others reveal contrasting results. Policymakers view FDI as crucial for development, but other factors, such as human capital and financial depth, also play vital roles (Karaçor et al., 2018). Educational institutions play a pivotal role in producing highly educated communities. Investment in education and opportunities for higher education expansion have become central to economic development agendas in many countries, including Malaysia. Human capital, particularly at the higher education level, generates economic growth by meeting the demands of a technologically advancing labor market. With the Granger causality test, the study revealed that the size of the host market is the most robust determinant of FDI inflow.

Bekana (2016) examined the determinants of FDI inflow to the Ethiopian economy from 1991-2013 in detail. The research focused on both the long-run and short-run forces behind FDI. Factors such as sustained GDP growth, a skilled workforce, high-quality infrastructure, stable economic conditions, and a robust export sector attract FDI. Bekana employed methods such as the ECM formulation, ADF test, and Engel Granger procedure (Bekana, 2016). The implications include policies that encourage innovation, entrepreneurship, and investment in infrastructure that can drive

economic expansion. Investment-friendly tax policies and streamlined regulations also play crucial roles. Stable macroeconomic conditions are attractive to investors. Policymakers should maintain low inflation rates, stable exchange rates, and prudent fiscal policies. A predictable economic environment reduces risks for investors. A skilled workforce is critical for attracting FDI. Policies that invest in education, vocational training, and research and development enhance human capital. Collaboration between educational institutions and industries can bridge skill gaps. Additionally, infrastructure development is vital. Transportation, energy, telecommunications, and logistics investments improve connectivity and reduce business costs.

Suliman and Mollick (2009) find that financial development and trade openness have positive effects on FDI in a region. On the other hand, corruption hurts FDI. Political stability, government effectiveness, and the rule of law significantly attract FDI. They used a fixed effect method, the cross-sectional weights technique (CSW), and seemingly unrelated regression (SUR) weighted least squares. The literacy rate, which reflects essential reading and writing skills, influences FDI inflows. The impact of political and civil rights on FDI inflows varies based on context. There is also a relationship between war incidents and FDI inflows (Suliman & Mollick, 2009).

Additionally, Paolino (2009) examined the relationships among FDI, domestic investment, human development, and economic growth in China. Human development, particularly the literacy rate, significantly influences FDI inflow. The OLS method was used for estimation, covering the analysis period 1977-2007. In summary, the literacy rate serves as a crucial factor of human development and significantly influences FDI in China.

The Arellano–Bond estimator is a generalized method of moments (GMM) estimator introduced by Arellano and Bond (1991) and is a robust econometric methodology used to estimate parameters in dynamic panel data models. Naude and Krugell (2007) employed this methodology in their investigation. The panel data utilized encompass all African countries and span a 20-year period from 1970-1990. Naude and Krugell conducted a study on many factors that influence foreign direct investment (FDI) via the generalized method of moments (GMM) approach. The determinants they considered were government consumption, domestic investment, the inflation rate, political stability, the rule of law, accountability, regulatory load, and literacy rates in Africa.

Although geography itself may not directly determine the attraction of FDI to Africa, other factors, such as location and the institutional environment, play pivotal roles in this process. A new analytical categorization has been established to study the factors that influence the flow of foreign direct investment (FDI) into African nations. This classification system organizes countries according to their economic and institutional characteristics, considering the heterogeneity between them. Effective policies are essential for ensuring proper corporate governance, risk management, and compliance (Michalek, 2023). Political stability is a vital factor influencing FDI. Policymakers must acknowledge the importance of promoting political stability and effective governance to attract long-term FDI.

The Gini coefficient variable is a unique variable. Prior research has demonstrated that FDI inflow has a significant effect on the Gini coefficient. Research results by Ucal et al. (2016), Reezk et al. (2022), Manu (2021), Cho and Ramirez (2016), Vezentan and Neagu (2022), Couto (2018), Harun et al. (2008), and Muntaka et al. (2023) have provided evidence that FDI affects the GINI coefficient rather than the other way around. These findings suggest that the entry of FDI will change the income distribution in the host countries of foreign investment. However, this research aims to challenge this

prevailing notion by exploring the possibility that the GINI coefficient influences a country's FDI inflow. There is currently no standard theory supporting this claim, and consequently, very few studies address this relationship.

The rationale that the Gini coefficient influences FDI inflow lies in the fact that a higher Gini coefficient value signifies a wider wealth gap between the rich and the poor in Indonesia. While this phenomenon is prevalent in many countries, it is particularly pronounced in developing nations where the impoverished population outweighs the affluent minority. This large demographic, which seeks means to improve quality of life, is a desirable workforce that foreign companies are actively pursuing (Daniels, Radebaugh, & Sullivan, 2015).

The relationship between FDI inflow and various economic factors is a topic of significant interest. They are tested by assessing the following hypothesis as follows.

Hypothesis 1: The GDRP positively influences FDI inflow in Indonesia.

Hypothesis 2: Domestic investment positively affects FDI inflow in Indonesia.

Hypothesis 3: The Gini coefficient has an effect on FDI inflow in Indonesia.

Hypothesis 4: Literacy positively influences FDI inflow in Indonesia.

2. Methodology

Because Indonesia consists of many provinces, thousands of islands separated by oceans, different cultures, different religions, and different political views, researchers use panel data so that the analysis results are powerful in terms of benefits and as few limitations as possible (Baltagi, 2021). The researchers obtained secondary data from official institutions from the Central Statistics Agency of the Republic of Indonesia. The data used in this analysis are panel data covering 34 provinces in Indonesia during the 2009-2021 period. The authors used STATA Software (Belotti et al., 2017). The results of the analysis are expected to be comprehensive, detailed, and thorough.

In this research, which uses static panels, fulfilling the classical assumption is mandatory and important because if the classical assumption is not fulfilled, it will cause serious econometric problems. Thus, the analysis results from this research yielded the best linear unbiased estimation (BLUE).

This study incorporates several independent variables. This correlation is a problem because independent variables should exhibit independence. Therefore, the concept of Variance Inflation Factors and their relationship with the R-squared in regression models Equation 1.

$$VIF_i = \frac{1}{(1-R_i^2)} \quad (1)$$

where R_i – multiple correlation coefficient between X_i and the remaining independent variables (p-1). $i = 1, \dots, p$ (independent variables).

When $R_i^2 = 0$, there is a complete absence of multicollinearity in the regression model. In other words, there is no linear relationship between the independent variables (predictors). Each predictor contributes independently to explaining the variation in the dependent variable. However, if $R_i^2 = 1$, it signifies exact multicollinearity. This situation occurs when one or more independent variables are perfectly linearly related to each other. As a result, the regression coefficients become indeterminate, and the model cannot be estimated accurately.

A stationary test is an essential prerequisite for conducting research via the regression method. Levin–Lin–Chu considered the collection of cross-sectional time series data to examine the unit root concept. As the size of the cross-sectional dimension and the time series dimension of the panel data increases, the pooled t-statistic values display specific characteristics. As the dimensions of panel data expand, researchers must consider both parameter heterogeneity and cross-sectional dependency to generate precise estimates and significant insights from their models. (Choi, 2001; Im et al., 2003; Levin et al., 2002). A unit root refers to a stochastic tendency that exists inside a time series. In other words, the series does not return to a consistent average value over time. More precisely, a process can be represented as a sequence of monomials, which are expressions consisting of a single term. As the authors explain in Equation 2:

$$y_{i,t} = \alpha_i + \gamma_i y_{i,t-1} + u_{i,t} \quad (2)$$

Equation (2) can be rewritten as Equation (3):

$$\Delta y_{i,t} = \alpha_i + \pi_i y_{i,t-1} + u_{i,t} \quad (3)$$

A stationary time series has a constant mean and constant variance over time, $H_0: \pi_i = 0$, for all i . The alternative hypothesis suggests that the data are stationary, $H_a: \pi_i \neq 0$, for each i .

On the basis of the literature review and gap research mentioned above, the authors built a research model. The authors suspect that the independent variables GDRP, domestic investment, the Gini coefficient and literacy influence FDI flows to Indonesia. Because this analysis must meet the classic assumption of normality, there are 2 variables that must be naturalized, namely, FDI and domestic investment into $\ln(\text{FDI})$ and $\ln(\text{DI})$. Therefore, all independent variables together are thought to influence FDI flows throughout Indonesia during the period from 2009-2021.

The authors decided to use the Dumitrescu–Hurlin test to test the causal relationship because this technique is more econometrically efficient. Each independent variable and a dependent variable are tested for the extent of cause and effect econometrically (Dumitrescu & Hurlin, 2012). The Granger causality test was developed by Dumitrescu-Hurlin (2012) to test the direction of the causal relationship. This research discusses two stationary variables, x and y , which were observed in 34 provinces over a span of 13 years. For every province, $i = 1, 2, 3, \dots, 34$, and for every year, $t = 2009, \dots, 2021$. Equation (4) is a linear model of mathematical causal relationships:

$$y_{it} = \alpha_i + \sum_{k=1}^K \gamma_i^{(k)} y_{i,t-k} + \sum_{k=1}^K \beta_i^{(k)} x_{i,t-k} + \varepsilon_{i,t} \quad (4)$$

with $K \in \mathbb{N}^+$ and $\beta_i = (\beta_i^1, \dots, \beta_i^K)'$.

The authors simplify the formula, and the individual effect α_i should be defined in the time dimension. The first conditions $(y_{i,-k}, \dots, y_{i,0})$ and $(x_{i,-k}, \dots, x_{i,0})$ are observed in this study. In panel data analysis, the assumption that the lag order K is the same for all cross-sectional units within the panel dataset is a common simplification. This assumption implies that the time lags considered in the model are consistent across all individual units in the panel. The parameters $\gamma_i^{(k)}$ and $\beta_i^{(k)}$ play crucial

roles in our model. It is possible to mathematically represent this model with constant coefficients and individual effects.

In the heterogeneous panel data model, the standardized average statistic $\tilde{Z}_N^{Hnc}$ converges in distribution for $T = 12$ fixed dimensions with $12 > 5 + 2K$, on the basis of the assumed noncausality test. As shown by Equation (5) below, this study employs a maximum lag of up to 2.

$$\tilde{Z}_N^{Hnc} = \sqrt{\frac{N}{2 \times K} \times \frac{(T-2K-5)}{(T-K-3)}} \times \left[\frac{(T-2K-3)}{(T-2K-1)} W_{N,T}^{Hnc} - K \right] \xrightarrow{N \rightarrow \infty} N(0,1) \quad (5)$$

with $\tilde{W}_{N,T}^{Hnc} = (1/N) \sum_{i=1}^N W_{i,T}$.

The Wald test, a statistical method used for hypothesis testing in the context of maximum likelihood estimation, $W_{i,T}$ with the hypothesis $H_0: \beta_i = 0$ and $\beta_i \in R.K$. Therefore, the D-H test can be carried out in the reverse direction between variables, namely, variable y affects variable x . In statistical analysis, establishing whether there is a two-way link between variables sometimes requires evaluating their correlations.

These econometric models for static panels include the pooled regression model, fixed effects model and random effects. The following are the equations and explanations of the 3 types of approaches to static panels. The authors must choose the best model among various alternative models.

If z_i is a constant number member, OLS provides consistent and efficient estimates of the regression coefficients when these assumptions hold. The general α and slope vector β are shown in Equation (6).

$$\ln(FDI)_{it} = GDRP'_{it}\beta_1 + \ln(DI)'_{it}\beta_2 + GINICof'_{it}\beta_3 + Literacy'_{it}\beta_4 + z'_i\alpha + \varepsilon_{it} \quad (6)$$

This model does not account for "provincial" cross sections or time series. In other words, the OLS method is used to process all the entered data. Thus, the OLS method is imperfect because econometric problems arise. z_i is not observed, but it is related to $GDRP'_{it}$, $\ln(DI)'_{it}$, $GINICof'_{it}$, and $Literacy'_{it}$. The pooled OLS model applies ordinary least squares (OLS) methodology to analyse panel data. This model operates under the assumption that there are no unobservable effects particular to each object. This assumption might not always hold true, especially when dealing with panel data. Even though the pooled regression method has been declared fit and appropriate, it is necessary to compare pooled regression and fixed effects through the Chow test. The fixed effect model is shown in Equation 7:

$$\ln(FDI)_{it} = GDRP'_{it}\beta_1 + \ln(DI)'_{it}\beta_2 + GINICof'_{it}\beta_3 + Literacy'_{it}\beta_4 + \alpha_i + \varepsilon_{it} \quad (7)$$

where $\alpha_i = z'_i\alpha$ represents all the observable effects and is used to specify the conditional mean.

The use of fixed effects is a powerful technique to account for unobserved heterogeneity across different groups or entities. Authors encounter multivariate survival time data, where failure times exhibit correlations even in the presence of model covariates. This phenomenon arises from unobserved heterogeneity, which clusters observations on the basis of latent factors not explicitly captured by the model.

In accordance with the previous description, the authors used the Chow test. The Chow test method considers the p value results in the F test in the output of the data process from the fixed effects method. The decision to select a model will be made if the F test probability value is smaller than the tolerance of 5%, then fixed effects will be chosen rather than pooled regression, and if the F test probability value is greater than 5%, then pooled regression will be chosen.

Through the calculation results of the Hausman test, the authors choose the random effects approach, so the following is the econometric equation. This model assumes that the absence of individual heterogeneity is not present and that there is a lack of correlation between variable z_i and the included variables. The model is shown in Equation 8:

$$\ln(FDI)_{it} = GDRP'_{it}\beta_1 + \ln(DI)_{it}'\beta_2 + GINICoeff'_{it}\beta_3 + Literacy'_{it}\beta_4 + \alpha + u_i + \varepsilon_{it} \quad (8)$$

Linear regression is a statistical method employed to establish a mathematical model that describes the relationship between a dependent variable and one or more independent variables. Random effects play a crucial role in hierarchical models, adding realism to our descriptions of complex systems. It specifies that u_i belongs to a group of provinces and combines random elements. The unobserved factors specific to each province that do not exhibit any correlation with the independent variables in the regression model are the GDRP, domestic investment, Gini coefficients and literacy.

The Hausman test is essential for choosing the most appropriate model, either with fixed effects or a random effect, for panel data analysis. The authors made decisions by considering the chi-square probability tolerance value. The Hausman test involves a chi-square (χ^2) comparison of all coefficients between the fixed effects technique and the random effects approach. If the chi-square (χ^2) probability value is below a threshold of 5%, the null hypothesis is statistically supported. In such cases, authors opt for fixed effects and vice versa.

3. Research results

The research utilizes the following data and variables. There are four independent variables, the GDRP, domestic investment, the Gini coefficient, and literacy, while the dependent variable is FDI inflow to Indonesia. Table 2 presents the description of each variable.

Table 2. Statistical Descriptive Statistics.

Variable	Observation	Mean	Standard Deviation	Minimum	Maximum
Ln(FDI)	442	5.33	1.93	0	9
GDRP	442	265,628.20	380,676.20	1347	1856301
Ln(DI)	442	7.20	2.32	0	11
GINICoef	442	0.36	0.04	0.25	0.43
Literacy	442	95.03	5.41	64	100

Source: Data Processing, 2023.

There are 2 variables that must be log naturalized as required by the classic regression assumption that the data must be normal, which means that the data variations take the form of a normal curve. The variables that are logarithmic are FDI and domestic investment. Moreover, the GDRP, the Gini coefficient and literacy are normal, so the data no longer need to be logarithmically transformed. On the basis of Table 2, all variables that meet classical assumptions have average, standard deviation, minimum and maximum variations. Moreover, the relationships among the variables utilized in the study are displayed in Table 3 below.

Table 3. Correlation Matrix.

Variable	Ln(FDI)	GDRP	Ln(DI)	GINICoef	Literacy
Ln(FDI)	1.0000				
GDRP	0.3844*	1.0000			
Ln(DI)	0.4714*	0.5656*	1.0000		
GINICoef.	0.2084*	0.2384*	0.0392	1.0000	
Literacy	0.1869*	0.1022	0.2047*	-0.2982*	1.0000

Note: * indicates statistical significance at the 5% level.

Source: Data Processing, 2023.

According to the variables utilized in the analysis, there is no significant association between the independent variables since their correlation value is less than 0.6. Therefore, the data pertaining to the variables employed are appropriate for regression analysis.

Because this study uses panel data, the provisions for panel data do not have to be met as strictly as classical assumptions are. The authors tested the classical assumptions needed, namely, the multicollinearity test and the stationary test. In the multicollinearity test, the authors used the variance inflation factor (VIF), whereas the Levin–Lin–Chu test used the stationarity test. The results of the multicollinearity test of all the independent variables are listed in Table 4 below.

Table 4. Multicollinearity Test.

Variable	Variance Inflation Factor (VIF)	1/VIF
GDRP	1.59	0.63
Ln(DI)	1.53	0.66
GINICoef	1.20	0.83
Literacy	1.16	0.86
Mean VIF	1.37	

Source: Data Processing, 2023.

The VIF values of all the independent variables are less than 10, so there is no significant correlation between the independent variables. Initially, this method was developed by Quah (1992,1994) and Levin dan Lin (1993). This method is intended for homogeneous panels. In addition, it is used for conditions where there are specific individual effects or heterogeneity between groups. where the conditions require that N/T approaches zero and that both N (cross section) and T (time series) go to infinity. However, this method has weaknesses such as being unable to accommodate heterogeneity between groups. This heterogeneity includes the unique influence of individuals (individual special effects) and different patterns of residual serial correlations.

Table 5. Levin–Lin–Chu Unit Root for the GDRP, Ln(DI), GINICoef, Literacy and Ln(FDI).

Panels : 34 Periods: 13	Unadjusted t	Adjusted t*	p value	H ₀ : Panels contain unit roots. H _a : Panels are Stationary.
GDRP	-6.8836	-6.2192	0.0000	Reject H ₀ , Accept H _a
Ln(DI)	-11.2421	-7.4487	0.0000	Reject H ₀ , Accept H _a
GINICoef	-13.3444	-4.1080	0.0000	Reject H ₀ , Accept H _a
Literacy	-11.4809	-5.9366	0.0000	Reject H ₀ , Accept H _a
Ln(FDI)	-12.5149	-1.9982	0.0000	Reject H ₀ , Accept H _a

Source: Running Data, 2023.

From the explanation in Table 5, all the data tested via the Levin-Lin-Chu method did not obtain unit roots from the data to be analysed and were declared stationary. The probability value of the Levin-Lin-Chu test is less than 1%.

The authors employed the Dumitrescu–Hurlin test (2012) to establish the causal link between variables. The results of the causality test using the D-H test for all independent variables with a dependent variable, or vice versa, are presented in Table 6 below.

Table 6. Dumitrescu–Hurlin test.

Causality of Variables	W-Bar	Z-Bar	Z-Bar Tilde
GDRP $\rightarrow$ Ln(FDI)	2.2653	5.2171 (0.0000)	2.4836 (0.0100)
Ln(FDI) $\rightarrow$ GDRP	0.9449	-0.2271 (0.8204)	-0.8640 (0.3876)
Ln(DI) $\rightarrow$ Ln(FDI)	2.8398	7.5856 (0.0000)	3.9400 (0.0001)
Ln(FDI) $\rightarrow$ Ln(DI)	2.6366	6.7480 (0.0000)	3.4249 (0.0006)
GINICoef $\rightarrow$ Ln(FDI)	1.6719	2.7704 (0.0056)	0.9791 (0.3275)
Ln(FDI) $\rightarrow$ GINICoef	3.0269	8.3573 (0.0000)	4.4144 (0.0000)
Literacy $\rightarrow$ Ln(FDI)	0.9995	-0.0021 (0.9983)	-0.7257 (0.4681)
Ln(FDI) $\rightarrow$ Literacy	4.0347	12.5122 (0.0000)	6.9692 (0.0000)

Source: Data Processing, 2023.

The GDRP is the income received by the community, which shapes market purchasing power. Furthermore, in accordance with market mechanisms, people's purchasing power will cause market demand to shift outwards, meaning that the law of demand is violated. Increasing domestic market demand will invite foreign companies to enter the Indonesian domestic market. Thus, FDI inflow is a result of increasing the GDRP throughout Indonesia. The test results with the D-H test indicate that the Z-Bar and Z-Bar Tilde significance values are smaller than 5%, so it is concluded that the GDRP influences FDI significantly. The results of this research are supported by Nguyen (2022), Choong and Lam (2010), and Bekana (2016). Therefore, the expected hypothesis is that GDP affects FDI inflow positively and significantly.

FDI inflow to Indonesia is investment in Indonesia originating from abroad. The existence of FDI inflow will encourage a better investment climate. Incoming foreign investment will require local physical capital and domestic labor, which means that the demand for local capital and job opportunities increases so that people's income, in this case, the GDRP, increases. Therefore, rapid FDI inflow will encourage the GDRP throughout Indonesia. However, on the basis of the D-H test calculations for the panel data in this research, the Z-bar and Z-bar Tilde p values are statistically significant at >5% tolerance, so they are not statistically significant. This confirms that, causally, the GDRP affects only FDI inflow and not vice versa. The results of this test are not in line with the findings of Sijabat (2023) and Paolino (2009), who state that FDI and GDP have a bidirectional causal relationship.

Furthermore, domestic investment will encourage demand for goods and physical capital as well as opening new jobs due to the expansion of domestic companies so that people's income increases significantly. The expansion of domestic investment shows that investment activity in Indonesia in the business sector is "profitable and safe from risk", which is what directly encourages FDI inflow to Indonesia to increase. Then, increasing purchasing power will shift market demand, thereby attracting FDI inflow. Testing with the D-H test revealed that the p value of the Z-bar and Z-bar Tilde tests was statistically significant below 1% tolerance. The results of this study are in accordance with those of Naude & Krugell (2007).

Is there a causal relationship between DI and FDI? Furthermore, the authors believe that the heavy FDI inflow occurs because foreign investors consider that investment in Indonesia is safe and has low risk. Automatically, FDI opens employment opportunities, and the use of capital increases people's income and purchasing power for all goods and services on the market. Thus, the behavior of foreign entrepreneurs is followed by domestic entrepreneurs in investing to expand production. The DHPC analysis provides empirical evidence supporting the bidirectional relationship between FDI and domestic investment, emphasizing their pivotal roles in regional economic performance. This shows that there is mutual causality in domestic and foreign business activities by investors, meaning that a greater economic business situation will mutually encourage a friendly situation toward foreign investment; conversely, domestic investors will be encouraged by the greater condition of FDI inflow to Indonesia.

A higher Gini coefficient shows that people's income is becoming more unequal. On the other hand, the more equal people's income is, the lower the Gini coefficient value is, and the better the purchasing power structure is. This will invite FDI to Indonesia. The results of the D-H test calculations reveal that the significance value of the Z-Bar is lower than 5%, whereas the Z-Bar Tilde value is 0.978, which is not very good, and the probability value is less than 35%. The next test is to reverse the direction of the dependent variable FDI toward the independent variable Gini coefficient. FDI inflow to Indonesia will reduce the value of the Gini coefficient, meaning that the income of the poor will increase through expanding employment opportunities in foreign companies. Foreign entrepreneurs pay salaries to Indonesian workers on the basis of their economic value so that the Gini coefficient decreases.

Literacy is an indicator of human capital for domestic labor. Domestic workers want to change their fate through new jobs or increasing levels of old jobs from multinational companies. Foreign entrepreneurs themselves need skilled workers to operate machines and equipment in the increasingly complex multinational companies currently operating in Indonesia. Therefore, in this way, FDI flows rapidly into Indonesia. The increasingly rapid FDI inflow demands the ability of a skilled workforce to run multinational companies. Because the need for labor is such, workers are encouraged to increase their knowledge and skills. In this way, the literacy of workers and prospective workers must automatically increase. All Z-Bar and Z-Bar Tilde significance values are less than 5%.

The results of the Dumitrescu–Hurlin test indicate that the independent variables, namely, the GDRP, domestic investment, and the Gini coefficient, have a significant influence on FDI inflow to Indonesia. This is supported by the W-Bar value being greater than 1.6, suggesting a reasonable suspicion of the independent variables impacting the dependent variable. The only exception is the independent variable literacy, which has a W-Bar value of 0.9995. Foreign corporations employ Indonesian labor for practical reasons, therefore creating a need for improved literacy to facilitate the

presence of foreign enterprises in Indonesia. Thus, a highly literate workforce ensures the success of international corporations operating in Indonesia. Thus, it may be inferred that the majority of the independent variables have a statistically significant effect on the dependent variable, FDI inflow.

Data processing was carried out via the pooled method. All the data were significant, and the goodness-of-fit test was appropriate. However, to further validate the analysis, it was necessary to conduct the Chow test by comparing pooled regression with fixed effects regression. The F test leads to the conclusion that fixed effects regression is superior to pooled regression. Additionally, the Hausman test plays a crucial role in econometrics for guiding the choice between fixed effects and random effects models. Table 7 shows the Hausman test data processing.

Table 7. Hausman test results.

Variables	Coefficients		(b-B) difference	Sqrt(diag(V _b -V _B)) S.E.
	(b)FE	(B)RE		
GDRP	4.33e-07	7.29e-07	-2.95e-07	5.18e-07
Ln(DI)	0.17496	0.21050	-0.03554	0.01335
GINICoef	8.34364	9.11822	-0.77457	0.94449
Literacy	0.18283	0.12252	0.06031	0.02432
Chi2(3) = 7.40			Prob>chi2 = 0.0602	

Source: Running Data, 2023.

Table 6 shows the results of data processing via the Hausman method. The Chi2(3) value is 7.40, and the probability value of Chi2 = 0.0602 exceeds the tolerance of 5%, so it can be concluded that the random effects regression model is better than the fixed effects regression. Therefore, the random effects model is the best for analysis in this research. Furthermore, completing the regression via the latest random effects method means that the method has been refined, as shown in Table 8 below.

Table 8. Random Effects GLS Regression for Ln(FDI).

Cross Sectional Time-Series FGLS Regression					Conclusion
Coefficients: Generalized Least Squares		Number of obs: 442			
Panels: homoscedastic		Number of groups: 34			
Correlation: No Autocorrelation		Time Periods: 13			
Wald Chi2(4): 181.54		Probability>Chi2: 0.0000			
Ln(FDI)	Coefficient	Std. Error	z	P> z	
GDRP	5.44e-07	2.56e-07	2.13	0.033	Reject Ho
Ln(DI)	0.305872	0.041078	7.45	0.000	Reject Ho
GINICoef	10.71777	2.157477	4.97	0.000	Reject Ho
Literacy	0.059009	0.015400	3.83	0.000	Reject Ho
Constant	-6.478785	1.84507	-3.51	0.000	Reject Ho

Source: Processing Data, 2023.

The coefficient value of the independent variable parameter GINICoef is the largest, with a value of 10.72. This parameter's coefficient is the marginal effect component on FDI inflow. Moreover, the smallest parameter coefficient is the GDRP parameter coefficient, which is only 0.000000544. This means that the GDRP variable has a marginal effect on FDI, which seems statistically small from this research model. However, this coefficient is positive with respect to the hypothesis.

On the basis of Table 7, the model suitability test result with Wald Chi2(4) is 181.54, and the probability value is 0.0000, so the best model used is appropriate. Through partial testing of each variable with the Z test, they reject Ho. All the variables used with Z test probability values are below

the limit value of 5%, so it can be concluded that the independent variables GDRP, domestic investment, the Gini coefficient, and literacy significantly influence FDI inflow. Each variable can be described with a scenario on the basis of the findings from the data processing mentioned above. Two independent variables need to be discussed further, namely, the GDRP and domestic investment, because these two variables have similar behavior.

The coefficient α_2 represents the growth rate of FDI inflow to Indonesia in US dollars for every billion rupiahs. The GDRP parameter coefficient value is 0.000000544 and is positive according to the expected sign of the research hypothesis. The GDRP reflects the purchasing power of all demand for goods and services in each region. The GDRP parameter coefficient shows that an increase of 1 billion rupiahs will increase FDI inflow growth by 5.44×10^{-7} percent in million US dollars. Market demand increases because of the GDRP, so FDI inflow also increases. This situation creates a multiplier effect in the macroeconomy.

The three efficient $\alpha_{3,it}$ coefficients explain the elasticity of FDI due to the increase in domestic investment in each province in Indonesia. The elasticity coefficient (formula 9) indicates that a one percent increase in domestic investment in billion rupiahs will increase FDI inflow by 0.3 percent in million US dollars.

$$\alpha_{3it} = d\ln(FDI)/d\ln(DI) = \frac{\frac{\Delta FDI}{FDI}}{\frac{\Delta DI}{DI}} \quad (9)$$

The elasticity coefficient value for domestic investment in FDI is 0.3, which is in the range of 0-1, so it is included in the inelastic category. Therefore, a one percent increase in billions of rupiahs in domestic investment will increase FDI inflow by 0.3 percent in millions of US dollars throughout Indonesia. Because the elasticity value of FDI inflow is inelastic, investment policy will have difficulty increasing FDI inflow. The findings of this study are consistent with those of Paolino (2009), Sijabat (2023), Kobilov and Kurbonov (2021), and Naude and Krugell (2007).

Foreign and domestic investment in Indonesia from 2020 amounted to 826,3 trillion rupiahs; in 2021, it amounted to 901,0 trillion rupiahs; and in 2022, it amounted to 1,207,2 trillion rupiahs. This phenomenon shows sequential growth over 2 years, from 9.04% per year to 33.98% per year, despite the COVID-19 pandemic. Additionally, from January–June (Semester I) 2023, investment realization totaled 678.7 trillion rupiahs, representing a 16.1% increase over the same time in 2022. Consequently, 849,181 persons were absorbed into the workforce. This achievement reached 48.5% of the investment realization target in 2023, which was set at 1,400 trillion rupiahs. (BKPM, 2023).

Every increase in the Gini coefficient by one unit will cause an increase of 10.72% in FDI in millions of U.S. dollars. The more economic inequality that occurs in a country, the greater the degree to which foreign investment will increase. Even though an increase in the Gini coefficient will worsen the purchasing power structure of the Indonesian domestic market, FDI inflow to Indonesia is due to the availability of abundant and cheap economic resources. This situation of increasing inequality implies that the poor still have many people and are willing to pay low wages. In the last 2 years, there has been a jump in FDI inflow to areas with large natural resources (endowments), such as Sulawesi, Ambon, and Papua (eastern Indonesia). This happens because the multinational corporation wants to obtain economic resources at a low cost to achieve minimum costs and increase its competitive advantage automatically. (Daniels et al., 2015).

In 2022, the poverty rate in rural areas will be 12.36% higher than that in urban areas, which is 7.53%. The absolute number of poor people in Indonesia was 26.36 million, while the population vulnerable to becoming poor was 112 million in September 2022. The main contributor to poverty in Indonesia is inflation in the food and energy sectors; this has consequences for the policies that need to be made by the government. Therefore, the total number of poor and vulnerable people is 138.36 million people, or approximately 50% of the total population of Indonesia. This dualistic situation occurs in Indonesia; approximately 50% of poor people are involved in the industrial sector. Therefore, poor groups who are willing to earn low salaries continue to exist.

Groups of poor people involved in the production process in these manufacturing companies are easily influenced by political and social issues. This group easily bribes and influences other parties to bring them to the will of the political elite. Often, welfare issues raised by certain elites, these poor groups, cause labor demonstrations to drag on, making entrepreneurs feel worried about the demands and protests placed on their companies. Therefore, entrepreneurs will consider building factories in areas that are safe for their businesses in Indonesia.

The literacy parameter coefficient of 0.059 shows that every one-unit increase in the literacy rate will increase 0.059% of the US dollar FDI inflow to Indonesia in relative terms. Through the results of this research, it has been proven that literacy has supported FDI inflow to Indonesia on the basis of the results of research by Choong and Lam (2010), Bekana (2016), Suliman and Mollick (2009), Paolino (2009), Naude and Krugell (2007). This literacy component, as a human capital component, has been proven to attract FDI to Indonesia. However, it is not the highest in influencing FDI compared with other independent variables, such as research results from Paolino (2009). However, foreign investors still consider guaranteeing productivity from human resources, which comes from increasing literacy.

Over the last decade, the Indonesian government has had a literacy program for the community. First, the National Movement to Accelerate the Achievement of Nine Years of Compulsory Basic Education and Eradicate Illiteracy with the motto Literacy Creates Strength. The government has established Community Learning Centers and other nonformal education networks, and these programs have quickly achieved widespread coverage, with 7,073 locations serving more than 75,000 villages. (Kwilinski et al., 2023). Second, increasing digital literacy and including digital finance in the community is ongoing. According to the results of the 2022 National Survey on Financial Literacy and Inclusion, the gaps between the level of literacy and financial inclusion are 49% and 85%, respectively. This statement shows that there is still a gap between people who use financial products and services but are not very literate about the financial products and services they use.

Conclusions

Therefore, by processing cross-sectional panel data for all provinces and time series for 13 years from 2009-2021 via the best random effects model approach, the authors prove that the independent variables Gross Domestic Regional Products, Domestic Investment, GINI Coefficient, and Literacy influence FDI inflow to all provinces in Indonesia.

The development of gross domestic regional products reflects the development of people's purchasing power, which will attract FDI inflow to Indonesia. The government's discoveries of natural resources and changes in mineral policies, such as nickel and others, have contributed to Indonesia's state revenues. Improvements in education and health service facilities have increased human capital

and prevented residents from going to school and seeking treatment abroad, thereby reducing outbound financial flows.

It is suspected that the coefficient of the Gini coefficient is ambiguous as to whether it is positive or negative towards FDI inflow. The coefficient of the Gini coefficient is negative, which means that the relationship between the two variables is opposite, indicating that foreign investors will consider a lower Gini coefficient value, indicating a more even income range between the rich and the poor. This is a hope that shows that the income structure and purchasing power are improving so that it will attract more FDI to Indonesia and vice versa. There is a finding that is novel from this research, namely, the coefficient of the Gini coefficient, which has a positive value of 10.77, which means that every one unit increase in the Gini coefficient will increase FDI by 10.77% in million US dollars. The greater the Gini coefficient is, the greater the income of the community, the greater the number of rich groups, and the greater the number of poor groups. (Daniels et al., 2015).

The expected parameter coefficient value of the Gini coefficient variable is negative, so the Gini coefficient variable and FDI to Indonesia are in the same direction. Our findings are that the parameter coefficient of the independent variable of the Gini coefficient is positive. This finding is not in the direction expected in the model or theory. Therefore, the authors conclude that three types of gaps exist: theoretical gaps, practical knowledge gaps, and empirical gaps. There are 10 findings by the World Bank regarding Indonesia's rapid recovery, which have led foreign investors to continue to believe in the future of the Indonesian economy (The World Bank, 2022). First, the Indonesian economy experienced an acceleration in growth of 3.7 percent at the end of 2021 as the country emerged from the COVID-19 delta wave. Furthermore, Indonesia's economic growth increased to 5 percent (yoy) in 2022. Second, large export-oriented companies and businesses with high value-added services have recovered faster than SMEs have. Third, the budget deficit narrowed in 2021 (from 6.1 percent of GDP in 2020 to 4.6 percent in 2021) because of income recovery and slowing spending. Fourth, with better consumer confidence and trade terms, Indonesia's economic growth is projected to reach 5% by 2022. Fifth, a structural policy reform programme is needed to support growth and reduce dependence on short-term macro stimuli to restrain prices from cost-push inflation pressures. Sixth, structural reforms, namely, taxation, the business environment, downstream industry development, and the financial sector, are needed. Seventh, policies that have the opportunity to address the main constraints of the financial sector are needed. Eighth, expanding lending and using financial services through new products and services provides access to finance and facilitates the transition to a more sustainable economy. Ninth, digital finance, competition, and healthy financial infrastructure are key in allocating resources more efficiently. Tenth, financial sector stability plays an important role in efficiently allocating economic resources.

Literacy is a component of human capital and a labour production factor for companies to produce consumer goods and services. Every company is looking for this productivity in its strategic role for survival and competition in the market. Workers who have this literacy will find it difficult for competing companies to imitate. If competing companies can imitate, however, the company will incur many costs. The development of market demand, which is always changing in terms of the quantity and variety of products, truly requires workers with high literacy.

This research has several limitations. Although researchers have employed the static panel methodology for further analysis, an alternative methodology exists that utilizes a dynamic panel approach incorporating the lagged dependent variable. This dynamic panel methodology allows for

the prediction of both short-term and long-term effects and their respective elasticities. Two widely used techniques for dynamic panel analysis are the generalized method of moments (GMM) by Arellano–Bond Estimation (1991), the difference generalized method of moments (GMM), and Blundell & Bond (1998), the system GMM estimator (Law, 2018).

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Efficiency of Full and Fractional Factorial Designs in Quality Management: A Case Study on Identifying Key Adhesion Factors

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Abstract

The Design of Experiments (DoE) method is a fundamental tool in quality management, providing a structured approach to process optimisation, reducing variability, and identifying key factors that influence outcomes. By systematically planning, executing, and analysing experiments, DoE enables quality management professionals to enhance product performance and consistency. The aim of this study is to compare the effectiveness of full factorial and fractional factorial experiment designs in quality management, specifically in identifying statistically significant factors that impact the adhesion properties of thermoplastic polyurethane (TPU) film with an acrylic-silicone adhesive, applied to laboratory glass with standardised parameters. The methodology comprises laboratory experiments designed to determine significant variables influencing adhesion, followed by statistical analysis using Minitab software. Both experiment types revealed the same primary factor as statistically significant. However, the fractional factorial design omitted additional significant factors due to data reduction, which led to some information loss. Despite this limitation, the fractional factorial design demonstrated high efficiency in terms of resource utilisation, including time and cost savings, while maintaining essential insights with minimal loss of valuable data. The findings contribute theoretically to the field of quality management, underscoring the comparative advantages and limitations of fractional factorial designs in scenarios where resources are constrained. Practically, this study provides guidance for quality management practitioners, indicating that while fractional factorial designs are cost-effective and time-efficient, they require meticulous data analysis to ensure the completeness and accuracy of findings, especially in complex experimental settings where missing critical information may impact decision-making.

Key words

design of experiments (DoE), fractional factorial experiment, full factorial experiment, quality management, process optimisation, adhesion properties, thermoplastic polyurethane (TPU)

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Introduction

Production processes and products generate substantial amounts of data, which reveal potential new optimisation opportunities within quality management. However, the abundance of coexisting factors often makes it challenging for process owners to detect key quality-related events. This difficulty arises from errors in data collection, data multiplicity, or misinterpretation. To accurately capture the cause-effect relationships within processes and identify statistically significant factors, it is essential to create conditions that support the identification of such critical events.

The Design of Experiments (DoE) methodology, as in other scientific disciplines, has its own terminology, methodology, and scope of study. The discipline's name itself indicates that it is focused on experimental methods (Lazić, 2004). DoE should be understood as a comprehensive statistical tool designed for managing and optimising process and product quality. This approach allows for the modelling and optimisation of processes by identifying statistically significant factors that have a substantial impact on quality management. The added value of experimental design lies in determining optimal parameter values, enabling a more intensive focus on quality within process or product management. Through the simultaneous manipulation of multiple input factors, DoE enables the study of their interactions, which might otherwise be overlooked if only one factor were manipulated at a time (One Factor at a Time – OFAT) (Tanco et al., 2008). This characteristic is particularly advantageous when more than one factor is suspected to influence the experimental outcome (Zohrevandi & Bashiri, 2014). In terms of experiment design, models are generally divided into two main groups: full factorial and fractional factorial experiments (Antony, 2014; Kechagias et al., 2017). A full factorial experiment tests all relevant factor combinations at selected levels, while a fractional factorial experiment evaluates only a subset of combinations, potentially omitting higher-order interactions (McBurney & White, 2007). The fractional factorial model is primarily used when resources, such as time or budget, are limited, which often leads to the full factorial model being overlooked or rarely implemented (Mønness et al., 2007).

The number of runs in a full factorial experiment can be significant and grows exponentially. For example, an experiment with seven variable factors requires 128 runs (Zhu, 2005). The fractional factorial model allows a substantial reduction in the number of runs, although it generates an alias structure, where factors may interact with higher-order terms, complicating the interpretation of results. This complexity underscores the importance of thorough analysis to distinguish between the influence of a primary factor and the effect of interactions when assessing the sources of variability (Minitab 21 Support; Yang & Draper, 2003).

1. Literature review

The issue of quality has long attracted the attention of researchers striving to understand and optimise production processes (Anguo, 2004; Shammot, 2011). Quality can be defined as a set of characteristics enabling a product or service to meet user needs and stand out among competitors (Saxena & Srinivas Rao, 2019). It encompasses not only the product itself but also the entire process of its creation, requiring the involvement of all participants. In a philosophical context, particularly within the framework of Hegel's laws of dialectics, quality is interconnected with the category of quantity. In practice, this means that changes in quantitative metrics within the production process can influence product quality. For example, an increase in production volume without consideration for resources and control may lead to a decline in quality. Consequently, quality management serves as a key tool for maintaining balance between the quantitative and qualitative characteristics of products.

Recent research also pays considerable attention to various aspects of quality management in the context of sustainable development, digitalisation, and entrepreneurship. Quality management is explored from the perspective of sustainable development, emphasising the importance of maintaining balance across economic, environmental, and social factors (Acheampong et al., 2023; Chen et al., 2024; Kwilinski & Trushkina, 2023; Kwilinski & Kardas, 2023, 2024; Kwilinski et al.,

2023a, 2023b, 2024b, 2024d; Lyulyov et al., 2024a, 2024b; Mlaabdal et al., 2024). In the context of digitalisation, quality management extends to virtual spaces and digital processes, which are increasingly pivotal in modern production (Acheampong et al., 2023; Ayala-Mora et al., 2023; Climent et al., 2024; Eisinger Balassa et al., 2024; Furelid Tellnes et al., 2024; Infante-Moro et al., 2022a, 2022b, 2023; Kamińska-Witkowska & Kaźmierczak, 2024; Khan et al., 2022; Kwilinski, 2019, 2024; Kwilinski et al., 2023c, 2024a, 2024c, 2024d; Lis, 2021; Lugito et al., 2024; Lyulyov et al., 2024a, 2024c; Maheshwari, 2024; Nguyen et al., 2024; Strielkowski et al., 2024; Wahyundaru et al., 2024; Wu et al., 2024). Meanwhile, entrepreneurship is investigated in the context of system sustainability from the perspective of business adaptability and the adoption of innovative approaches to quality maintenance (Anguo et al., 2004; Baldi, 2020; Batz Liñeiro et al., 2024; Chygryn et al., 2024; Dacko-Pikiewicz, 2019a, 2019b; Erden Ayhun et al., 2024; Khalid & Kot, 2021; Lei et al., 2024; Nadason et al., 2024; Rajiani & Kot, 2020; Szczepańska-Woszczyna, 2018; Szczepańska-Woszczyna & Gatnar, 2022; Shikhli et al., 2024; Solórzano Solórzano et al., 2024; Szczepańska-Woszczyna & Muras, 2023; Wróblewski & Dacko-Pikiewicz, 2018; Wolniak et al., 2024; Wróblewski et al., 2017; Zane & Zimbhoff, 2018; Zatar, 2022; Zimbhoff, 2023; Zimbhoff & Jorgensen, 2019; Zimbhoff et al., 2017, 2021). These research areas highlight the relevance of an interdisciplinary approach to quality management for maintaining stability and optimising processes at all levels.

Modern approaches to quality management focus not only on the final stages of product release but also on all phases of the production process, including design, development, testing, and implementation (Bucko et al., 2022). This comprehensive focus is essential for both small manufacturing firms and large-scale operations, as product quality and process efficiency require continuous monitoring and adaptation to evolving conditions.

The Design of Experiments (DoE) method is a statistical tool in quality management that enables the quantitative assessment of factor effects and interactions to optimise process parameters (Alagumurthi et al., 2006; Freiesleben et al., 2020; Jadhav & Sawant, 2024; Lee et al., 2022). In various industries, such as pharmaceuticals (Fukuda et al., 2018; Politis et al., 2017), chemistry (Murray et al., 2016; Heidari-Rarani et al., 2022), and medicine (Dong et al., 2008; Buang et al., 2014; Freitas et al., 2021), DoE supports the development of models aimed at quality improvement. Quality management across all phases—from design to testing and implementation—requires reliable data analysis tools, such as Minitab and Design Expert, which provide high levels of predictive accuracy (Ermergen & Taylan, 2024; Kwashabawa, 2021).

Based on the literature review, authors like Zohrevandi and Bashiri (2014), Kechagias et al. (2017), and Jankowski et al. (2016) emphasise the advantages of fractional factorial designs over full factorial designs. Both approaches yield similar results; however, fractional factorial designs are more resource-efficient, reducing time and cost, which is particularly valuable for large-scale processes.

While the Design of Experiments (DoE) method is a fundamental tool in quality management, providing a structured approach to process optimisation and variability reduction, several gaps persist in current research. Firstly, there is limited examination of the comparative effectiveness of full factorial and fractional factorial experiment designs in identifying statistically significant factors within quality management. Secondly, research is lacking on the potential loss of information inherent in fractional factorial designs, especially in cases where analytical precision is critically important. Additionally, there is a shortage of studies focused on the application of DoE for assessing the adhesion properties of specialised materials, such as thermoplastic polyurethane (TPU), with various adhesive types.

The aim of this study is to conduct a comparative analysis of the effectiveness of full and fractional factorial experiment designs in quality management, with a particular emphasis on identifying statistically significant factors that influence the adhesion properties of TPU film with an acrylic-silicone adhesive, applied to laboratory glass under standardised parameters.

The article is structured as follows: The introduction provides the theoretical foundation and significance of the Design of Experiments (DoE) method in quality management. Section 1 explores

the core concepts and advantages of DoE, including definitions of full factorial and fractional factorial experiments. Section 2 details the research methodology, comprising laboratory experiments and statistical analysis conducted using Minitab software. Section 3 presents the results in the form of a comparative analysis between full and fractional factorial experiments, highlighting the differences and unique aspects of each approach. The discussion in Section 4 analyses the findings and discusses their implications for quality management, indicating the effectiveness and limitations of the two experimental methods. Finally, the conclusion summarises the key findings and offers practical recommendations for implementing DoE methods in resource-constrained environments.

2. Methodology

The research, conducted to identify the differences resulting from full factorial and fractional experimentation, adopts a quantitative research strategy. Data analysis was performed using Minitab 21.4.1, a statistical software package with a collection of programs designed to execute analyses with high numerical accuracy. This software utilises Automated Machine Learning tailored for both binary and continuous responses, drawing on capabilities from the Predictive Analytics Module. Specifically crafted to enhance business operations, Minitab offers user-friendly options for entering and manipulating statistical data, recognising patterns, and conducting thorough analyses to address practical business issues. It simplifies data analysis processes, making it well-suited for statistical evaluations at the business level. Minitab also includes visual tools, such as histograms, boxplots, and scatterplots, which assist professionals in performing statistical analyses more effectively and deriving insights from their data. Additionally, it enables users to compute descriptive statistics for their datasets. Today, Minitab is widely recognised as a prominent commercial application used in Lean Six Sigma projects (Alagić, 2021).

In alignment with the study's objective of highlighting differences between the two experimental models, the laboratory research focused on a case study measuring the adhesion strength of thermoplastic polyurethane (TPU) film coated with a hybrid adhesive (acrylic-silicone) applied to laboratory glass under standardised conditions. Four variable factors—material batch, glass preparation, application time, and curing time—were tested at two levels (-1 and +1), generating 16 independent runs (2^4) for the full factorial experiment. For the fractional factorial model, the number of runs was reduced to 8 (2^{4-1}).

The limitations of the study include measurements performed by a single laboratory technician, the use of one batch of laboratory flat glass (100 x 50 x 4 mm), ambient conditions controlled at $22.3^\circ\text{C} \pm 0.1$ with $67\% \pm 1$ humidity, and the fact that adhesion force measurements were performed using an Axis force meter, model FB, on an automatic tripod, model STAH. Additionally, TPU film samples were cut into strips of 15 cm length and 2.5 cm width and adhered to the glass surface using a generated test matrix that accounted for the individual levels of variable factors. The prepared test specimens were mounted on the instrument's tripod and then attached to the actuator's automatic gantry gripper. The speed of the automatic gantry was kept constant at -20 mm/s for each run.

3. Research results

The Results section is organised into three key areas. Section 3.1 provides a detailed analysis of the data generated by the full factorial experiment, whereas Section 3.2 examines the relationships identified within the fractional factorial experiment. Finally, Section 3.3 characterises the differences between the two approaches, with specific reference to the presented case study.

3.1. Full factorial experiment

The premise of the full factorial experiment was to comprehensively reveal all interactions and main effects resulting from the manipulation of variable factors at two levels. The batch of material, method of application, substrate preparation, and measurement time were identified as independent variables (Table 1). Expert knowledge of polymeric materials allowed the conclusion that the method of assembly, specifically the use of gel, could have a decisive influence on the activation of the acrylic-

silicone adhesive. Other levels of the independent variable factors were selected based on process observation and quality issues identified within the application area.

Table 1. Levels of independent experiment variables.

Variable Factor	level (-1)	level (+1)
A: batch	1	2
B: application	without gel	gel
C: surface preparation	without preparation	surface degreasing
D: measurement after x	12h	24h

Source: own elaboration.

The full factorial experiment, targeting four variable factors tested at two levels, generated 16 independent runs (2^4). The complete test matrix and the resulting adhesion strength measurements for the full factorial model are presented in Table 2. It should be emphasised that the full factorial experiment does not account for the aliasing phenomenon, which can potentially lead to distortions and, ultimately, to the misinterpretation of statistically significant factors or interactions.

Table 2. Test matrix with results of the full factorial experiment.

Run Order	A	B	C	D	N	Run Order	A	B	C	D	N
1	-1	-1	-1	-1	7.0	9	1	1	-1	-1	23.5
2	-1	1	1	1	19.0	10	1	-1	-1	1	19.3
3	-1	-1	1	1	13.5	11	1	1	1	1	23.8
4	-1	1	-1	1	11.3	12	1	-1	1	-1	22.5
5	-1	-1	-1	1	8.4	13	1	-1	1	1	22.0
6	-1	1	-1	-1	8.5	14	1	1	-1	1	23.6
7	-1	-1	1	-1	12.0	15	1	-1	-1	-1	11.0
8	-1	1	1	-1	13.0	16	1	1	1	-1	23.5

Note: A – batch; B – application; C – surface preparation; D – measurement after x; N – result.

Source: own elaboration.

A statistical analysis of the variable factors, selected as potentially relevant based on expertise and process knowledge, revealed values for all possible main effects and interactions at the levels shown in Table 3. Statistical modelling of the obtained results was conducted using Minitab 21.4.1.

Table 3. Values of main effects and interactions; full factorial experiment.

Variable Factor	Effect	Coef
Constant		16.37
A: batch	9.563	4.781
B: application	3.813	1.906
C: surface preparation	4.588	2.294
D: measurement after x	2.488	1.244
A: batch*B: application	1.088	0.543
A: batch*C: surface preparation	-0.987	-0.494
A: batch*D: measurement after x	-0.437	-0.219
B: application*C: surface preparation	-1.488	-0.744
B: application*D: measurement after x	-0.187	-0.094
C: surface preparation*D: measurement after x	-0.663	-0.331
A: batch*B: application*C: surface preparation	-2.013	-1.001
A: batch*B: application* D: measurement after x	-1.663	-0.831
A: batch* C: surface preparation* D: measurement after x	-1.488	-0.744
B: application *C: surface preparation*D: measurement after x	1.513	0.756
A: batch* B: application*C: surface preparation*D: measurement after x	0.738	0.369

Source: own elaboration.

The data presented in Table 3 identify the batch variable factor as the most influential main effect, with its observed effect size nearly double that of the next most significant factor—surface preparation. To clearly identify which factors are statistically significant in this study, the data are

displayed in a Pareto Chart (Figure 1) and a Normal Probability Plot (NPP, Figure 2). While both charts highlight individual effect sizes, the NPP also indicates the direction of each effect, whereas the Pareto Chart displays only absolute values.

Applying the Pareto principle, an α level of 20% was selected as the threshold for the probability of a false alarm. The α coefficient, alongside the experimental effect sizes, establishes a "water line" on the charts. All main effects and interaction effects falling below this line are considered statistically insignificant.

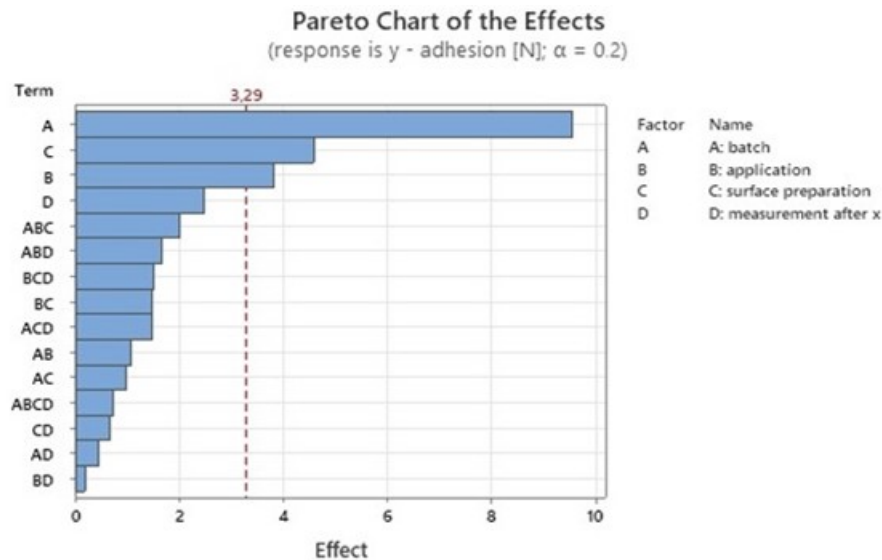


Figure 1. Pareto chart with relevance of factors of the full factorial experiment.
Source: own elaboration.

The data presented in Figure 1 correspond with the values in Table 3. Notably, in addition to the primary effect of the material batch, there are additional effects above the significance threshold, specifically for surface preparation and application. Figure 1 clearly indicates that factor D is not a critically influential parameter in contributing to variability within the experiment and, by extension, within the overall process. Furthermore, it should be highlighted that none of the interaction effects reach statistical significance.

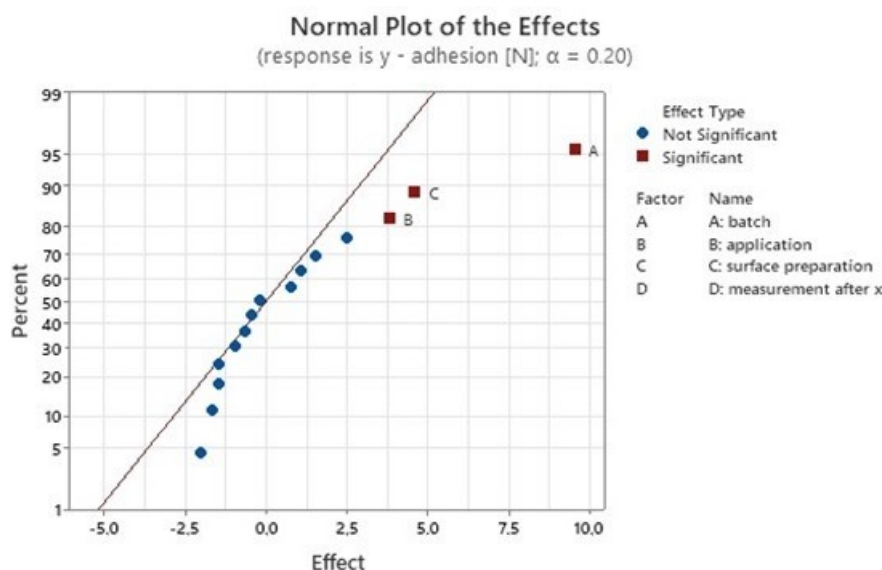


Figure 2. Normal Probability Plot – full factorial experiment.
Source: own elaboration.

Based on the experiment conducted and the calculated values of statistically significant factor effects, main effect charts were prepared, as shown in Figure 3. Referring to the conclusions of the case study, it is essential to highlight the absence of interaction between the factors, a finding that is primarily supported by Figure 1, where interactions are shown to be statistically insignificant.

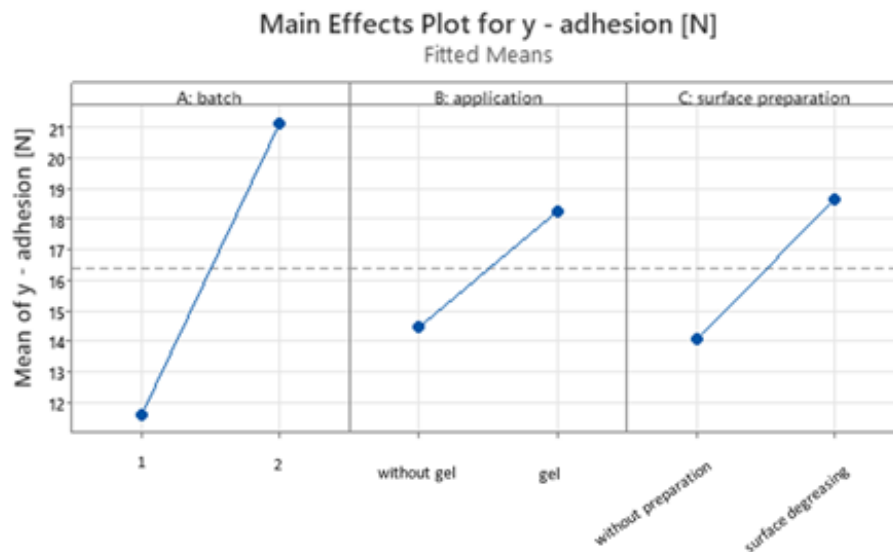


Figure 3. Graphs of the effects of the main factors A, B and C – full factorial experiment.
Source: own elaboration.

In interpreting the graph above—Figure 3—it is clear that changing the level of factor A, "batch," from (-1) to (+1) (i.e., from batch 1 to batch 2) leads to an average increase in adhesion, rising from 11.59 to 21.15 N. For the second factor, B, "applique," shifting the level from (-1) (no gel) to (+1) (assembly with gel) results in an average adhesion increase from 14.46 to 18.28 N. Similarly, for factor C, "surface preparation," changing from level (-1) (mounting the film without prior surface preparation and degreasing) to (+1) yields an average increase in adhesion strength from 14.08 to 18.66 N.

3.2. Fractional experiment

Similar to the full-factorial experiment, the fractional experiment involved testing four variable factors at the predetermined levels outlined in Table 1. Although the same factors were tested, the fractional experiment produced only 8 runs (2^{4-1}). The study's assumptions were identical to those of the full factorial experiment model.

To ensure full reproducibility and maintain a focus on comparing the two experimental models, the same data were applied for each individual run in the fractional experiment as in the full factorial experiment. The test matrix and the adhesion force results obtained from the fractional experiment are presented in Table 4.

Table 4. Test matrix with results of the fractional experiment.

Run Order	A	B	C	D	N	Run Order	A	B	C	D	N
1	-1	-1	-1	-1	7.0	5	1	1	-1	-1	23.5
2	-1	1	-1	1	11.3	6	1	1	1	1	23.8
3	-1	1	1	-1	13.0	7	1	-1	-1	1	19.3
4	-1	-1	1	1	13.5	8	1	-1	1	-1	22.5

Note: A – batch; B – application; C – surface preparation; D – measurement after x; N – result.

Source: own elaboration.

In the fractional experiment conducted, it is essential to note the presence of aliasing, which means that in this fourth-order resolution analysis, the main factor is confounded with third-order

interactions ($A=BCD$). Additionally, second-order interactions are confounded with other interactions of the same order ($AB=CD$).

Statistical analysis of the variable factors, using the fractional experiment test matrix, revealed main effect values and interactions at the levels detailed in Table 5.

Table 5. Values of main effects and interactions; fractional experiment.

Variable Factor	Effect	Coef.
Constant		16.74
A: batch	11.075	5.538
B: application	2.325	1.163
C: surface preparation	2.925	1.463
D: measurement after x	0.475	0.238
A: batch*B: application	0.425	0.213
A: batch*C: surface preparation	-1.175	-0.588
A: batch*D: measurement after x	-1.925	-0.963

Source: own elaboration.

The data in Table 5 indicate that the strongest main effect remains the variable factor A: batch of material, as observed in the full-factorial experiment. The effect value for this factor is nearly four times that of the second factor, C: surface preparation. Importantly, due to the fractional model of the experiment, the main factor A is confounded with the third-order interaction BCD. Given that none of the individual factors forming this interaction are statistically significant, and that the interaction itself does not exhibit strong statistical significance overall, the confounding effect can be considered negligible.

In addition to the values presented in Table 5, the data are visualised in a Pareto chart (Figure 4) and a Normal Probability Plot (Figure 5). Following the Pareto principle, a significance level of 20 per cent was set as the value of α (probability of false alarm).

The data shown in Figure 4 correspond to the values presented in Table 5. It should be noted that, for the fractional experiment, only the variable factor A: batch of material, was identified as statistically significant.

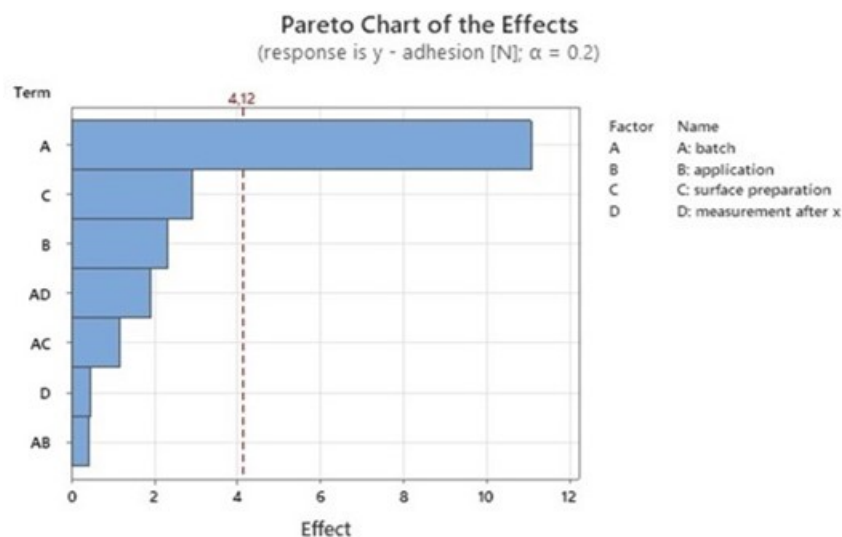


Figure 4. Pareto chart with relevance of factors of the fractional experiment.

Source: own elaboration.

These observations are further confirmed in Figure 5.

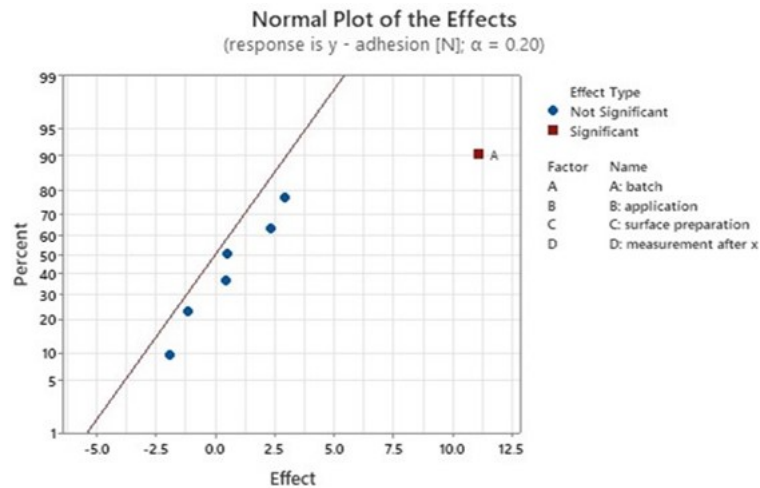


Figure 5. Normal Probability Plot – fractional experiment.

Source: own elaboration.

Based on the fractional experiment conducted and the results obtained, a main effects plot for factor A: material batch was generated, as shown in Figure 6.

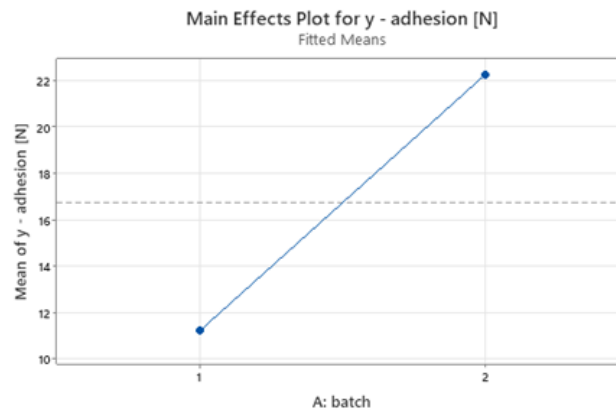


Figure 6. Graphs of the effect of the main factor A – fractional experiment.

Source: own elaboration.

Figure 6 demonstrates that for the main effect A: batch of material, shifting the level from (-1) for batch 1 to (+1) for batch 2 results in an increase in the mean adhesion strength from 11.2 N to 22.28 N.

3.3. Comparative analysis of the full factorial and fractionated experiment

The comparative analysis conducted between the full factorial and fractional experiments revealed some differences in identifying statistically significant factors that critically influence process variability. The full factorial experiment offers higher precision and a more standardised approach, as it includes all possible factor combinations. In contrast, the fractional experiment requires more sophisticated statistical analysis due to its limited number of combinations, which introduces the aliasing phenomenon. Notably, the higher the resolution level, the more robust a given factor or interaction appears within the aliasing structure.

Reviewing the effect values obtained from both experimental models highlights that, unlike the fractional experiment, the full factorial model identifies factors beyond A: material batch—specifically, B: application and C: surface preparation—as statistically significant (as shown in Tables 3 and 5). This disparity may lead to less precise control of the process when relying solely on fractional data, which identifies only the material batch factor as significant.

To undertake optimisation for the presented case study, it is essential first to standardise adhesion values across the individual material batches, particularly focusing on factor A.

4. Discussion

This study provides an in-depth comparative analysis of full and fractional factorial designs, specifically highlighting the differences in their utility, precision, and application suitability in quality management. A prominent takeaway from this research is the nuanced trade-off between the depth of insights afforded by the full factorial design and the efficiency provided by the fractional factorial approach. Full factorial designs offer a robust and detailed analysis, as each factor and interaction can be examined in isolation, eliminating confounding effects due to aliasing. This clarity is critical in fields where understanding the exact impact of each variable on outcomes is essential, particularly in quality-sensitive industries like pharmaceuticals or advanced materials (Politis et al., 2017; Fukuda et al., 2018). The results of this study underscore the full factorial design's capacity to provide a more granular understanding of factor interactions, a requirement in cases where subtle variations in process parameters may influence product efficacy or safety.

However, as Mønness et al. (2006) point out, the practicality of full factorial experiments is often constrained by resource limitations, as the approach can demand a substantial number of experimental runs, especially with an increasing number of factors. In contrast, fractional factorial designs, while inherently simpler, face limitations due to the aliasing of interactions. The results presented in this study demonstrate how the fractional design, despite its efficiency, omitted some interactions and secondary factors that the full factorial design was able to identify. These findings corroborate Mønness et al.'s (2006) suggestion that while fractional factorial experiments provide an effective initial screening tool, they may require supplementary experimentation to achieve the accuracy necessary for critical applications. This aligns with recommendations by Marrubini et al. (2020), who advocate for the use of fractional designs primarily for screening purposes, especially when the number of factors exceeds manageable levels for full factorial analysis.

This study also highlights the unique role of expertise in experimental design selection. Given the dependency of fractional factorial designs on assumptions about factor significance, domain knowledge becomes essential in guiding the design and interpreting its results effectively. Knowledge of material properties, process conditions, and expected factor interactions can inform decisions on which interactions to alias, thereby maximising the relevance of findings even within the constraints of fractional factorial designs. As demonstrated, the expertise in this study allowed for the prioritisation of main factors over less impactful interactions, thus aligning with strategic goals without sacrificing critical data.

In terms of practical implications, this research reinforces the idea that full factorial designs are ideal for applications requiring high precision and comprehensive factor analysis, whereas fractional factorial designs serve as a valuable cost-effective alternative in resource-limited environments. Quality management teams can utilise the findings of this study to determine the optimal experimental approach based on their specific process requirements, balancing the need for detailed insights against resource availability. Importantly, fractional factorial designs can be augmented with complementary analytical techniques or follow-up experiments to validate the primary findings, as suggested by this study's results on TPU adhesion properties.

Overall, this study contributes valuable insights to the discourse on experimental design in quality management, confirming that while both full and fractional factorial designs have distinct benefits, their selection must be strategically aligned with process demands, resource constraints, and desired outcome accuracy.

The limitations of this study primarily relate to the specific conditions and materials utilised, which may impact the generalisability of the findings. The experiments were conducted with a single batch of TPU material and under controlled laboratory conditions, including a constant temperature and humidity level, which do not fully reflect the variability encountered in real-world production environments. Additionally, the study employed a limited number of variable factors, focusing on four primary factors at two levels each. Expanding the number of factors or levels could yield further insights but would likely necessitate a higher number of runs, impacting resource demands.

Furthermore, the reliance on fractional factorial design introduces aliasing, which may obscure the significance of certain interactions in more complex processes. Future research could address these limitations by testing a broader range of materials, environmental conditions, and variable factors to enhance the applicability of the findings across diverse industrial contexts.

Conclusions

The interpretation of this study's results highlights the complex interplay between quality (K) and quantity (Q), a relationship rooted in philosophical principles such as Hegel's dialectics, where quantitative changes can lead to qualitative shifts. In the context of the experimental design, both full factorial and fractional factorial models underscore this connection, as manipulating quantitative aspects, such as the number of runs or the levels of factors, directly impacts the quality of the insights obtained. The full factorial approach, by accounting for all possible interactions, exemplifies how a comprehensive examination of quantity leads to a qualitatively richer understanding of the factors influencing TPU film adhesion. Meanwhile, the fractional factorial design, though less exhaustive, showcases that even a reduced quantitative approach can yield significant insights when guided by well-chosen factors, reflecting a strategic balance between K and Q. This dual approach, therefore, illustrates how quantitative and qualitative aspects of quality management can be aligned to maximise efficiency and depth within practical limitations.

The Pareto principle further enhances the interpretation of these findings, suggesting that only a select few factors in a quality management process may account for the majority of the outcomes. This principle aligns with both full and fractional factorial designs, where focusing on the most impactful factors—like material batch and surface preparation—enables a high return on quality insights with fewer resources. The Pareto approach thus reinforces the balance between quantity and quality, as it allows quality managers to concentrate on critical factors, ensuring effective quality improvements while conserving resources. In practice, adopting this rule can streamline the experimentation process, targeting only those factors with the greatest influence on outcomes, which is particularly beneficial in resource-constrained environments.

From a sustainable development perspective, the findings contribute to the broader discourse on responsible resource utilisation and efficient process optimisation. The fractional factorial experiment offers a compelling case for resource efficiency, aligning with sustainable development goals by minimising the consumption of time, materials, and energy while still providing valuable data for decision-making. Such efficiency is especially relevant in the modern industrial context, where sustainability considerations demand approaches that balance thorough analysis with resource-conscious practices. This study supports the notion that fractional factorial designs, when employed judiciously, can serve as an effective tool in sustainable quality management, where the essential trade-off between depth and resource conservation must be carefully managed.

The integration of advanced data-processing tools like Minitab into quality management practices further emphasises the evolving role of technology in handling large and complex datasets. Automated Machine Learning (AutoML) and predictive analytics modules within such software enable quality professionals to analyse vast amounts of data with enhanced accuracy and speed, bridging the gap between traditional statistical analysis and modern big data approaches. The ability to process and visualise data with tools such as Pareto charts, normal probability plots, and main effect charts exemplifies how new technologies empower organisations to interpret complex data structures more effectively. This capability is critical in today's data-rich environments, allowing companies to refine quality management strategies and extract insights that might otherwise remain obscured in extensive datasets.

To advance these insights, further studies could explore how big data analytics can enhance factorial experiment designs, especially in managing and interpreting large-scale industrial data with real-time adjustments for quality management. Investigating how fractional factorial models perform under machine learning-based optimisation could provide an innovative framework that extends the

traditional DoE approach into the realm of adaptive quality management. Additionally, future research could delve into the application of the Pareto principle in dynamic quality environments, exploring adaptive models that identify and prioritise key factors as conditions fluctuate. Such research would serve to better align the theoretical underpinnings of quality and quantity relationships with practical applications in sustainable development and big data-driven environments.

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