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Eco-innovation at the firm-level in Norway:
Drivers and implications.

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Abstract

The aim of this thesis is to deploy two key concepts within the theory on the resource-based view of the firm—the resources and dynamic capabilities aspects—to study not only the antecedents of eco-innovation at the firm level, but also the conceptualisation of eco-innovation as a dynamic capability. As popular as this theory has been in innovation studies, its extension to eco-innovation research remains incomplete regarding how particular resources, such as knowledge, are acquired and combined and how dynamic capability is defined. This thesis investigates to what extent different forms of knowledge play a role in driving eco-innovation, especially when it comes to the geography of collaboration and knowledge complementarity. Additionally, it also studies whether engaging in eco-innovation is a dynamic capability that can provide resilience and responsiveness to a firm during an external shock. This study is carried out to better enable policymakers, academics and, perhaps more importantly, firm managers to understand the challenges and advantages of engaging in eco-innovation. Adopting a quantitative approach and utilising three different datasets generated from surveys carried out in Norway, the results show a complex relationship between eco-innovation and regional and international synthetic and analytical knowledge collaboration. In addition, when it comes to eco-innovation, although synthetic and analytical knowledge are both relevant, these two forms of knowledge substitute for each other rather than being complementary. Furthermore, conceptualising eco-innovation as a dynamic capability, the results show that not only were eco-innovation firms more positively affected by COVID-19, but they also responded more innovatively in other aspects of their operations as a direct response to the pandemic. This study informs the theoretical understanding of eco-innovation and how it relates to dynamic capabilities, especially during times of external shock. Additionally, it also informs the empirical understanding of the relevance for eco-innovation of analytical and synthetic knowledge, its geography of acquisition and its complementarity.

Sammendrag

Målet med denne avhandlingen er å anvende to sentrale begreper innenfor teorien om ressursbasert syn på selskapet – ressurser og dynamiske evner – for å studere ikke bare forutsetningene for økoinnovasjon på selskapsnivå, men også konseptualiseringen av økoinnovasjon som en dynamisk evne. Selv om denne teorien har vært populær innen innovasjonsstudier, gjenstår det en ufullstendig utvidelse til forskning på økoinnovasjon når det gjelder hvordan spesifikke ressurser, som kunnskap, er ervervet og kombinert, og hvordan dynamiske evner er definert. Vi spør i hvilken grad ulike former for kunnskap spiller en rolle i å fremme økoinnovasjon, spesielt når det gjelder geografien for samarbeid og komplementaritet av kunnskap. Videre spør vi om deltakelse i økoinnovasjon er en dynamisk evne som kan gi motstandskraft og evne til å tilpasse seg for et selskap under eksterne sjokk. Vi studerer dette for å bedre ruste beslutningstakere, akademikere og kanskje enda viktigere, selskapsledere, til å forstå utfordringene og fordelene med deltakelse i økoinnovasjon. Ved å ta i bruk en kvantitativ tilnærming og utnytte tre forskjellige datasett generert fra undersøkelser utført i Norge, viser vi en kompleks sammenheng mellom økoinnovasjon og regional og internasjonal syntetisk og analytisk kunnskapssamarbeid. Vi viser også at når det kommer til økoinnovasjon, selv om syntetisk og analytisk kunnskap begge er relevante, så erstatter disse to formene for kunnskap hverandre heller enn å være komplementære. Videre, ved å konseptualisere økoinnovasjon som en dynamisk evne, viser vi at ikke bare ble selskaper som engasjerte seg i økoinnovasjon påvirket mer positivt av COVID-19, men de svarte også mer nyskapende på andre områder av driften som en direkte respons på pandemien. Denne studien gir innsikt i vår teoretiske forståelse av økoinnovasjon og hvordan det forholder seg til dynamiske evner, spesielt i tider med eksterne sjokk. Dessuten gir den også innsikt i vår empiriske forståelse av relevansen for økoinnovasjon av analytisk og syntetisk kunnskap, dets ervervets geografi og dets komplementaritet.

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Acknowledgements

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List of publications

This dissertation is based on the following three articles:

Article 1 Vai, F. J. (2021). Regional and international inter-organizational STI and DUI collaborations as carriers for eco-innovation. *Regional Studies, Regional Science*, *8*(1), 402-419.

Article 2 Vai, F.J. Does combining analytical and synthetic knowledge benefit eco-innovation? Evidence from Norway. *Business Strategy & the Environment,* (resubmitted after minor revisions)

Article 3 Vai, F.J., Aarstad, J. How Eco-innovative firms were affected by and responded to the unexpected external shock of the COVID-19 pandemic. *Cleaner Production Letters,* (resubmitted after minor revisions)

1. Chapter 1: Introduction

The increasing global concern about the impact of firms on the environment, especially in the areas of pollution, overexploiting natural resources and the overarching issue of climate change, has amplified calls for firms to play an increased role in mitigating the negative externalities of their activities. Firms are increasingly focused on mobilising their resources to address these challenges through innovation. However, not all innovations have a positive effect on the environment. Accordingly, researchers, policymakers and firm managers have turned their attention from innovation in general to a strain of innovation commonly referred to as eco-innovation (EI). Simply put, EI includes innovations that have fewer negative impacts on the environment. Although global agreement on goals to avoid looming environmental disasters has been touted politically as victories, there is rising concern that efforts to meet these goals are woefully inadequate. The present thesis highlights what drives EI at the firm level, which may influence measures for both policymakers and firm managers that can lead to the promotion of more EI. In addition, the current thesis also studies the implications of engaging in EI, which may motivate firms to adopt an EI strategy because it is beneficial not only for the environment, but also for firm resilience and responsiveness during times of external shock. This is important because as we continue to address our negative impact on the environment, we must also become accustomed to sudden external shocks, such as pandemics, which are predicted to become more frequent.

Research into what drives or promotes EI at the firm level has flourished in the past few decades. Research has generally approached the drivers of EI from three perspectives: regulatory push/pull, market pull and technology push. Despite this profusion of research, EI remains a challenge for many firms because the resources required, such as knowledge, often lie outside their existing resource base. How these resources are acquired or reconfigured for EI also continues to call into question the applicability of traditionally held theoretical perspectives developed through the study of innovation in general. In addition, the transition to EI is complicated by uncertain markets during times of global disruption, perhaps causing some hesitation for firms to engage in such activities.

Although the literature has advanced the understanding of the factors that firms should focus on to encourage EI, there are questions that remain unanswered. Therefore the present thesis aims to address gaps in the literature regarding EI at the firm level through the following overarching research question: What are the drivers and implications of EI in Norway?

1.1. Research questions

Although there is general agreement about the important role of knowledge as a driver for EI (Aarstad & Jakobsen, 2020; González-Moreno et al., 2019; Kobarg et al., 2020; Marzucchi & Montresor, 2017), the literature has not extensively explored certain important aspects of where that knowledge comes from.[1] An aspect that has attracted very little attention is that, for EI, the two different forms of knowledge—analytical and synthetic—may have very different geographical dimensions.[2] Attributing a geographic dimension to the transfer of knowledge has been linked to the literature on innovation modes, which describes two particular approaches that firms utilise in their learning and innovation activities (Jensen et al., 2007). Each of these innovation modes is very much dependent on a particular form of knowledge. The science and technology–based innovation (STI) mode depends on analytical knowledge, which is a form of knowledge generated through R&D and other scientific activities. This form of knowledge is easily documented, aiding its transfer, regardless of geographic proximity. The DUI mode (innovation based on learning-by-doing, using, interacting) depends on synthetic knowledge, a form of knowledge generated normally through face-to-face interactions. This aspect of synthetic knowledge may restrict its transfer to a regional geographic dimension.

Regarding analytical knowledge, there is a proposition that the types of interactions that generate this form of knowledge are generally carried out internationally or through 'global pipelines' (Aarstad et al., 2016a; Bathelt et al., 2004). Establishing these pipelines between firms and universities or other analytical knowledge

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[1] Article two of the present thesis also confirms the importance for EI of both analytical and synthetic knowledge, regardless of how it is acquired. See Table 3 subsection 4.1.2.

[2] This relationship is discussed further in subsection 2.6.

partners implies a high cost both of money and time. This gives rise to a situation in which firms attempt to maximise their value by establishing links, usually through collaboration, with 'global nodes of excellence' rather than regional collaboration partners (Fitjar & Rodríguez-Pose, 2013).[3] Synthetic knowledge acquisition, on the other hand, is generally considered to be achieved through local or regional interactions with collaboration partners such as suppliers, customers and competitors (Doloreux et al., 2020). Empirical evidence supporting this proposition is mixed. Some studies have shown a limited role for close geographic proximity in establishing analytical collaboration links between firms and universities for general innovation (Smith, 2007) and that collaboration with regional partners for either analytical or synthetic knowledge is not conducive to innovation (Fitjar & Rodríguez-Pose, 2013). However, other studies suggest that both intraregional and extra-regional interactions are relevant for acquiring analytical and synthetic knowledge for innovation (Doloreux et al., 2020; Parrilli & Alcalde Heras, 2016). Although the EI literature has emphasised the critical role that regional relationships play in driving EI (Arranz et al., 2019; Horbach, 2014), the exact role that geography plays in knowledge acquisition remains unclear. This lack of clarity is underlined by studies showing the importance for EI of analytical knowledge that comes from distant places (Galliano et al., 2019; Ocampo-Corrales et al., 2020). Understanding the relevance for EI regarding where knowledge is acquired from has important implications for policymakers when it comes to policies targeted at encouraging collaborative relationships at specific geographic levels. In addition, such an understanding is vital for firm managers evaluating investments in both money and time in establishing those relationships. To explore this issue, the first research question in this thesis is formulated as:

> *RQ1: Which geographic dimension of analytical and synthetic knowledge collaboration is important for EI?*

[3] The exceptions are where those regional analytical partners are considered to be at the forefront of R&D and innovation, such as Silicon Valley, and some prominent universities, such as Oxford.

Although both analytical and synthetic knowledge seem to be important drivers for EI, there has been a longstanding assertion that combining these two forms of knowledge is the optimal approach for innovation (Jensen et al., 2007). Although this assertion has been enthusiastically embraced by innovation studies, recent empirical evidence points to a substitution rather than complementary effect between analytical and synthetic knowledge (Haus-Reve et al., 2019). In addition, the promotion of knowledge combination seem to neglect that, in practice, firms generally lean on either one or the other type of knowledge (Asheim et al., 2019; Hansen, 2015). Although there have been indications that substitution effects between analytical and synthetic knowledge are also the case for EI (Marzucchi & Montresor, 2017), knowledge combination is still widely embraced as the preferred approach (Sanni & Verdolini, 2022). For policymakers and firm managers, this issue has clear implications in terms of how to focus policy measures for the former and where to invest firm resources for the latter. To provide answers to this issue, the second research question in this thesis is formulated as:

> *RQ2: Are firms that combine analytical and synthetic knowledge more eco-innovative than firms that do not?*

Furthermore, the present thesis aims to progress beyond the specific analysis of knowledge resources to explore the implications of aligning firm resources with a specific organisational EI strategy. This issue is approached from the dynamic capabilities (DC) perspective, which describes a firm's ability to reconfigure its resources to respond to changes in its external environment (Teece, 2007; Teece et al., 1997). A firm strategy that results in successful EI is conceptualized as an expression of a form of DC. The argument for this is that adopting a strategy that results in successful EI requires fundamental organisational and structural changes that instil a distinct form of DC. A DC that not only allows EI firms to constantly respond to changes in their normal business environment, but that should also allow them to mitigate the effects of an extreme and unexpected external shock. To study this aspect of EI and address the 'implications' aspect of the overall research question, the third research question in this thesis is formulated as:

RQ3: Were eco-innovative firms more positively affected, less negatively affected and more innovative during the COVID-19 crisis?

1.2. Knowledge gaps and contributions

The research gaps that the present thesis aims to address are not only theoretical, but also gaps in knowledge in the literature because of limitations imposed by availability of data. Quantitative studies that empirically contribute to advancing knowledge are often limited by insufficient data, bias through a variety of statistical issues or limited to a particular context or timeframe, hence hindering useful generalisations to other contextual settings.

The innovation mode literature often differentiates between radical and incremental innovation (Fitjar & Rodríguez-Pose, 2013), product and process innovation (González-Pernía et al., 2015) or technological and nontechnological innovation (Doloreux et al., 2020; Parrilli & Alcalde Heras, 2016). Very rarely has research considered the impact of innovation modes on EI (Marzucchi & Montresor, 2017). This thesis contributes by providing insights into the geography of knowledge acquisition for EI, as well as whether the combination of analytical and synthetic knowledge is beneficial for EI. This contribution also addresses calls to investigate the relationship between innovation modes and innovation types in different countries and contexts (Doloreux et al., 2023; Parrilli et al., 2020). The findings show that, for Norwegian EI firms, geographically speaking, synthetic knowledge—or the DUI—mode is significant, and it is not strictly regionally restricted because international synthetic collaboration partners are also important for process EI. In addition, regional collaboration partners generating analytical knowledge—or the STI mode—show limited relevance. These findings challenge established notions on the geography of such forms of knowledge collaboration and raise context-specific questions about the role innovation modes play in EI in Norway.

Second, when considering internal or external innovation modes (Doloreux et al., 2023; Marzucchi & Montresor, 2017), the results find that both are important for EI. This result provides nuance to the discussion on the tendency of regions such as

Norway and Denmark, countries often referred to as a ‘positive innovation paradox’, to rely on external DUI modes for innovation.[4]

Third, as aforementioned, the general consensus in the innovation and EI literature is that combining these different forms of knowledge is the optimal approach (Tsouri et al., 2022). This thesis contributes empirical evidence that shows that this is not the case for EI. Whereas Marzucchi and Montresor (2017) already made similar observations in relation to combining internal and external forms of knowledge in the manufacturing sector in Spain, the results from this thesis advance this further. The results show that, in Norway, this substitution effect exists not only across firm borders, but also with combining different forms of knowledge that are generated internally. In addition, this effect exists even when controlling for industry and is persistent over time, given that the analysis was carried out on panel data. These findings underline the observations made by Cohen and Levinthal (1990) about the difficulties in absorbing new knowledge, which is different from a firm’s existing knowledge base.

Finally, this thesis contributes by informing the theory of the resource-based view (RBV) of the firm, specifically in the conceptualisation of the concept of DC. It does this by addressing calls for a more dynamic evaluation of EI (Hazarika & Zhang, 2019) by looking beyond EI as the result of a static firm-level resource input. This perspective sees the adoption of EI, if pervasive enough, as one that changes a firm beyond human resources and physical composition to significantly altering the organisation and the structure of the firm (Carrillo-Hermosilla et al., 2019; Del Río, Carrillo-Hermosilla, et al., 2015). Expressed as DC, empirical evidence is provided that shows that firms that have successfully introduced EI as a measure of pervasiveness can indeed significantly contribute to these firms’ resilience to external shocks. More importantly, the results also provide empirical evidence that these firms respond more by introducing innovations in other aspects of their

[4] Positive paradox regions also include regions such as the Italian industrial districts and the Basque Country in Spain. It describes a situation where regions are capable of generating high innovation and economic output compared with others relative to a given amount of input such as R&D expenditure (Parrilli & Alcalde Heras, 2016).

operations compared with other firms. This elevates the conceptualization of DC beyond a firm's ability to reorganize its resources to respond to changes in its environment, to elaborate on EI induced DC responding specifically by being more innovative. These findings provide an additional dimension to the measurement of the concept of DC because very little mention is made of sustainability and, more specifically, EI in either management or innovation literature (see Loureiro et al., 2021 for a review of proposed measures).

1.3. Overview of articles

Article 1: Vai, F. J. (2021). Regional and international interorganisational STI and DUI collaborations as carriers for eco-innovation.

Using a 2018 survey of 1001 Norwegian firms primarily based on the west coast, the paper addresses RQ1 and studies the relevance of regional and international collaborations for analytical and synthetic knowledge for EI. The results uncover some interesting findings regarding the relevance of both regional and international synthetic knowledge collaboration. The findings show that, although regional synthetic knowledge collaboration is relevant for both product EI and process EI, for the latter, it is not regionally restricted. In addition, although there are some indications that regional analytical knowledge collaboration is important, it is noticeably less so both at the regional and international levels when comparing EI to non-EI. Although these findings contribute to the discussion on innovation modes and geography of knowledge collaboration specifically, they also reveal some important insights regarding which geographic level is important for knowledge collaboration for EI in Norway.

Article 2: Vai, F. J. Does combining analytical and synthetic knowledge benefit eco-innovation? Evidence from Norway.

The paper utilises an unbalanced panel dataset from five waves of the Norwegian Community Innovation Survey (CIS; 2008–2016), addressing RQ2 by testing the idea of knowledge complementarity. Innovation and EI studies have promoted the combination of heterogeneous knowledge as a path to successful innovation. The paper shows that, framed as analytical and synthetic knowledge, these combining analytical and synthetic knowledge does not seem conducive for EI. Rather than complementarity, the analysis reveals a general substitutive effect between analytical and synthetic knowledge. Although not completely abandoning the idea of complementarity, the paper urges caution for policy makers and firm managers considering analytical and synthetic knowledge combination as a successful path to EI.

Article 3: Vai, F. J., Aarstad, J. How Eco-innovative firms are affected by and respond to the unexpected external shock of the COVID-19 pandemic.

Using the results from the Norwegian CIS 2020 carried out during the Covid-19 pandemic, the paper studies how firms that had introduced a product/service EI or process EI, here conceptualised as DC, was affected and responded to the pandemic. Although these EI firms were not completely immune to the negative effects of the pandemic, the results show that they were significantly more positively affected than other firms. Furthermore, they were significantly more innovative in other aspects of their operations as a direct response to the pandemic than other firms.

2. Chapter 2: Theoretical Framework

This chapter outlines some of the more important literature on the drivers of EI, with a particular focus on firm-level drivers, of which the present thesis is centred. In addition, it elaborates on key theoretical concepts through which the drivers of EI have been explored. Please refer to each of the three articles of the current thesis for a more detailed literature review relevant to the specific aspects of EI under investigation.

2.1. The development of the concept of Eco-innovation

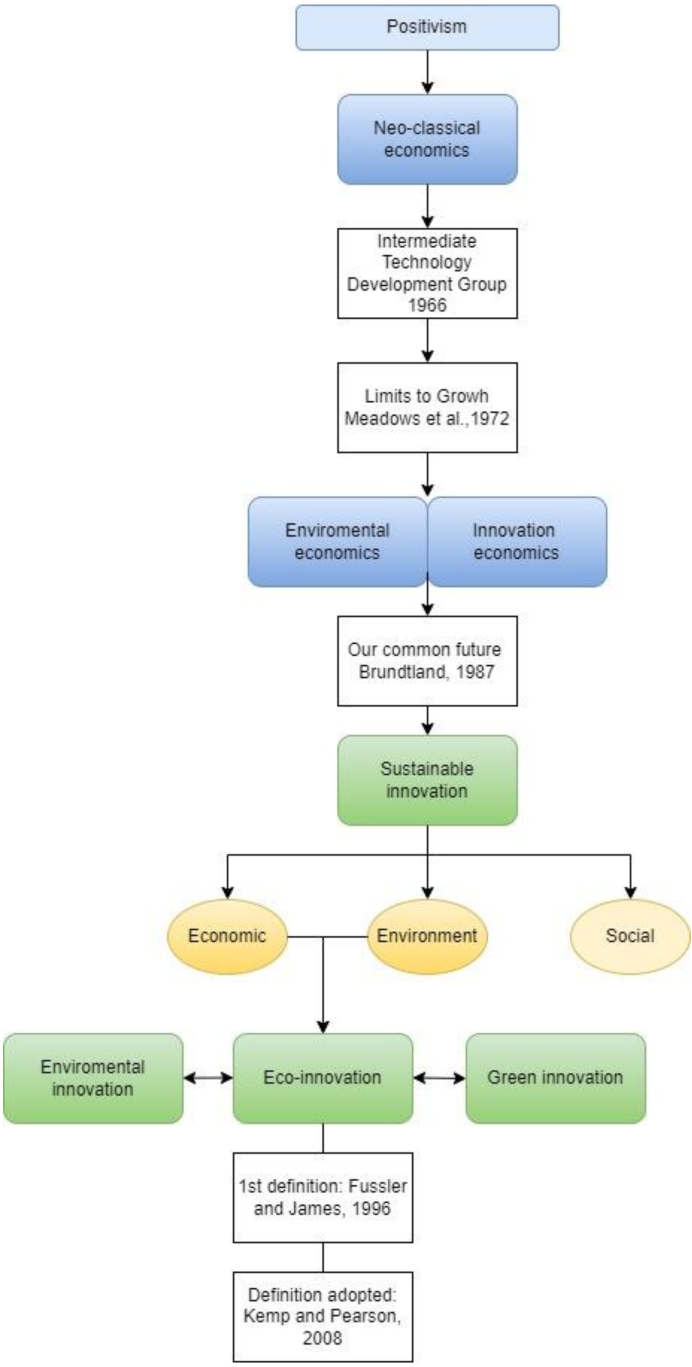

Figure 1: Development of the discourse of eco-innovation. Own elaboration.

Figure 1 summarises the development of the concept of EI, highlighting important events throughout the years. This development is elaborated on below.

Generally, the discourse on the concept of EI, which is grounded in positivism (Pansera, 2012), has evolved from techno-centrism towards eco-centrism (Hazarika & Zhang, 2019; O'Riordan, 2002). Advocates of techno-centrism or the 'neoclassical economics school' believe that market-driven technology development can also achieve sustainable development goals by overcoming any limitations imposed by environmental depletion and degradation. This view supports ecological modernisation as a collaborative approach between business and government to developing technology as a profitable venture (Dryzek, 2022). The discussion on the origins of the concept of EI often mentions the late 1960s as an important point in time when the concept of innovation intersected with that of sustainability. In 1966, Ernest F. Schumacher introduced the concept of 'intermediate technology' or 'appropriate technology' when he cofounded the Intermediate Technology Development Group. This concept emphasised the meeting of economic goals with minimum resource consumption and reduced negative impacts on the environment. In 1972, the controversial report 'Limits to Growth' (Meadows et al., 1972) was published, which expressed great scepticism towards this techno-centric confidence in technology. It emphasised that the exponential growth in population, production and consumption of non-renewable natural resources was unsustainable, even with technology. Despite this, key figures of neoclassical economics maintained that the report did not account for the comparable exponential growth of technological progress coupled with capital accumulation and increased productivity, which would offset any environmental limitations (Solow, 1974). These debates led to the emergence of two disciplines: environmental economics, which focuses on the issue of environmental externalities and the management of natural resources, and ecological economics, which focuses on the interrelatedness between the economic system and global ecological system (Munda & Munda, 1997). Although these two approaches differ on several points, they both agree on the role that technology plays in achieving sustainability. Eco-centrism, on the other hand, repositions the focus away from human economic interests to prioritise the intrinsic value of the natural world, which must take precedence if long-term sustainability is to be achieved.

In 1987, the United Nations World Commission on Environment and Development released its highly influential 'Our Common Future', which is also referred to as the

Brundtland report, hence officially defining the concept of sustainable development. The report specifically stated that technological innovations need to be enhanced in such a way that they reduce environmental impacts. Development should meet 'the needs of the present without compromising the ability of future generations to meet their own needs. The concept of sustainable development does imply limits – not absolute limits but limitations imposed by the present state of technology and social organization on environmental resources and by the ability of the biosphere to absorb the effects of human activities' (Brundtland, 1987, p. 24). The Brundtland report has been broadly considered to be eco-centric, but it leans towards being more techno-centric in its detailed propositions. For instance, it specifically stated that the limits to development and growth are essentially linked to technological limitations, hence stressing that environmental limitations can be overcome with socio-technological changes.

Since the Brundtland report coined the phrase 'sustainable innovation', various other terms such as EI, green innovation and environmental innovation have been used. However, when comparing these various terms, it seems that sustainable innovation implements the three key aspects of economic, ecological and social, while the others only focus on economic and ecological aspects (Schiederig et al., 2012). This differentiation is illustrated in Figure 1. It is important to note this difference because, in certain circumstances, meeting economic and ecological goals may have some negative social consequences (Horbach, 2019). Some researchers have further attempted to differentiate between EI that focuses on both economic and ecological aspects and green and environmental innovation that focuses solely on ecological aspects (Ghisetti & Pontoni, 2015). Despite this, there is general agreement that these three terms have been used in the literature interchangeably and that they fundamentally conform to the same definition (Hazarika & Zhang, 2019; Horbach, 2019; Schiederig et al., 2012), with very few exceptions. In the current thesis, the term EI is adopted.

2.2. A definition of eco-innovation

Credited with one of the first references to the term EI to appear in the literature, Fussler and James (1996) used the term to refer the process of developing new products, processes or services which provide customer and business value but significantly decrease environmental impact. Since this definition was proposed, numerous attempts have appeared (see for example Díaz-García et al., 2015 for an overview of definitions). Many of these definitions either require the positive impact on the environment to be a motivation or effect of the innovation. Whereas the motivation or "intention" seems to be the narrower approach, one of the issues identified is that as firms move from end-of-pipe solutions to more product innovations and integrated approaches, the environmental motivation becomes entangled with other motivations making it difficult to separate (Carrillo-Hermosilla et al., 2010). It should also be noted that the alternative approach of focusing on the environmental impact rather than the motivation is not without its challenges. Although there has been some debate about whether the intention or result is a better measure of EI, the consensus is that it can sufficiently be measured by either (Del Río et al., 2016; Díaz-García et al., 2015; Horbach et al., 2012).

The present thesis adopts the definition of EI proposed by Kemp and Pearson (2008, p. 7):

> the production, application or exploitation of a good, service, production process, organisational structure, or management or business method that is novel to the firm or user and which results, throughout its life cycle, in a reduction of environmental risk, pollution and the negative impacts of resource use (including energy use) compared with relevant alternatives.

This definition of EI, which is based on the Oslo Manual's (OECD & Communities, 2005) definition of innovation, was proposed as one that better reflects the nuance of EI that earlier definitions, such as that by Fussler and James (1996), did not fully elaborate on. There are several important things to note about this definition. First, the evaluation of EI is focused on environmental performance because this also encompasses the positive effects on the environment of other types of innovation (Kemp & Pearson, 2008). Second, rather than the innovation having notions of something new, it allows for the adoption of innovations that may have been created by others, which implies a focus on the diffusion of innovation (Horbach et al., 2012). Third, it also implies an analysis based on the full life cycle of the innovation

(Díaz-García et al., 2015). Finally, an innovation is an EI if its negative effect on the environment is less compared with relevant alternatives, again emphasising that there is no requirement that it be new.

2.2.1. Forms of EI

At the firm level EI can be related to many aspects of a firm's business as stated in the definition given above. The products and services it offers, the processes required to produce those products and services as well as its organizational routines. Firms can for example introduce EI through the reduction of material, both in the production of products but also in the packaging leading to less waste for the consumer to dispose of. Products and services could also be designed to reduce the environmental impact of the consumer by reducing pollution through its use, electric cars being the obvious example. The introduction of products and materials that can influence the behavior of consumers and relate EI to concepts such as circular economy gives ample opportunity for firms.[5] This approach can take the form of materials and components that be recycled, reused or repurposed. This approach also has the potential of changing firm behavior by taking a more long-term perspective to products and processes. The reduction of energy used in firm processes, through more efficient organization and routines and the purchase and use of more efficient machinery and energy sources also offers opportunities for firms to reduce their impact on the environment.

Although often evaluated through more concrete concepts such as product and processes, an EI strategy for a firm also encompass organizational aspects not directly related to products and processes. Such measures can also be as simple as installing sensors that turn off lights and equipment that is not in active use. One could for example also imagine firms introducing measures that reduce its

[5] In more recent EU documentation, there has been a shift in terminology from EI to circular economy. This is perhaps a recognition that the evaluation of the impact on the environment of products and processes has to move beyond the evaluation of the innovation itself to consider the place of that innovation to other systems from a lifecycle perspective. Although it should be noted that the definition of EI given also encompasses the notion of lifecycle.

employees' impact on the environment by encouraging the use of public transport or alternative transport.

In essence, the definition of what is an EI is a rather broad one, with the essential requirement being that the innovation has a positive impact on the environment, leading to a considerable diversity of EI (Carrillo-Hermosilla et al., 2010). The broadness of the definition does however raise some issues, for example an issue often debated in public forums is the "actual" environmental impact of products and processes. Again, using electric cars as an example, the reduction of the environmental impact of using electricity rather than fossil fuel, may be offset by the environmental, and social, impact of mining for minerals required for batteries. For the moment the definition refers to the innovation having less environmental impact compared to relevant alternatives. It is foreseeable that this aspect of the definition could be narrower by measuring the innovation strictly on having a net positive impact on the environment for it to be considered as an EI.[6]

2.2.2. The fundamental difference between EI and non-EI

A question that quickly arises is whether EIs can be distinguished from other innovations, thereby necessitating a particular theory and policy that differs from those for general innovation or non-EI. The EI literature often utilises theoretical frameworks from innovation research, adapting them with the acknowledgement that EI and general innovation are fundamentally distinct. A considerable number of research works can be traced back to a seminal paper (Rennings, 2000) that expounded on the essential differences between EI and non-EI. These differences are summarised below.

1. Eco-innovation has the characteristic of double externality

EI produces positive spillovers, such as knowledge externalities during the innovation (and R&D) phase, and positive environmental externalities in the adoption and diffusion phase (Horbach et al., 2013; Rennings, 2000). These positive

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[6] An even stricter reading could be that the innovation has no negative impact on the environment, however, such a situation in practical terms could be difficult to achieve.

spillovers, which benefit society and other firms, cannot be fully internalised by the EI firm, which may lead to a lack of incentive for firms to invest in EI. Furthermore, EI is a long-term endeavour with the associated high costs of R&D, in addition to the research and establishment of new markets. Other firms benefit from a reduction of environmental damage as a whole and can copy first movers in EI without contributing to the cost (Arranz et al., 2019). This leads to a double market failure because the private return for a firm engaged in EI is less than the positive benefit from its activities (Horbach et al., 2013). This is referred to as the double externality problem and leads to the next difference.

2. Eco-innovation has the characteristic of a regulatory push/pull effect

Similar to other innovations, EI is also influenced by the usual technology-push and market-pull factors; however, given the market distortion caused by the double extremality problem, EI needs specific regulatory support. Without this support, firms may not be willing to invest in EI, even with its environmental benefits. An example of this is electric car adoption in Norway, where the transition was largely driven by a variety of policy instruments (Deuten et al., 2020). Numerous studies have empirically shown the importance of regulation and policy in driving EI (De Marchi, 2012; Horbach, 2008; Rennings, 2000), highlighting the role of coordination between innovation and environmental policy (Rennings, 2000).

3. Eco-innovation generates a 'win-win' outcome

EI allows for the compatibility of improvement in both competitiveness and sustainability (Cainelli et al., 2012; Ghisetti & Quatraro, 2017). A number of studies have shown that engaging in EI is not detrimental to a firm's competitiveness and in fact improves competitiveness on several fronts (Arranz et al., 2020; Hermundsdottir & Aspelund, 2021; Reyes-Santiago et al., 2019).[7] This follows from

[7] For a thorough discussion of how EI can improve a firm's competitiveness, please refer to article 3 of this thesis.

the idea that innovation is a desired goal for a firm and that EI takes this a step further by imposing that innovation must have a positive effect on the environment.

4. Environmental consciousness

Traditional market-pull and technology-push factors are relevant for EI, like other innovations. However, for EI, market-pull factors are also influenced by the environmental consciousness of both consumers and firms (Horbach, 2019). The willingness of consumers to pay more for EI products depends on their awareness of its benefits, which may be both direct and indirect. This highlights the importance of the consumer's environmental consciousness as a driving factor for EI compared with general innovation, which may be more motivated by other considerations.

5. Broad knowledge base

The EI literature has highlighted that EI differs from general innovation in that the resources required at the firm level often extend beyond a firm's existing resource base. This broader knowledge base pertains to almost all facets of innovation, such as design, user involvement, product and service and governance dimensions (Carrillo-Hermosilla et al., 2010). This underlines the relevance of availability of new resources, both internal and external, as well as new organisational structures to adapt to the generation, acquirement and utilisation of those new resources (Horbach, 2008; Marin et al., 2015). Horbach et al. (2013), for example, showed that EI requires more external sources of knowledge and information than other types of innovation.

2.3. Drivers of EI

Rennings (2000) established a framework for studying EI on which many studies since then have been based. This framework approaches the study of EI from the perspective of three main key drivers: regulation, market demand and technology push, as illustrated in Figure 2. These key drivers have been assessed individually using a number of theoretical backgrounds or, more rarely, together using multidimensional theoretical frameworks (Cuerva et al., 2014). This is emphasised by the separation of these drivers and levels in Figure 2.

In the following section, an overview of seminal studies for both regulatory and market drivers of EI is provided. Technology push is more comprehensively addressed in Chapter 2.4 because this is the perspective adopted in the present thesis.

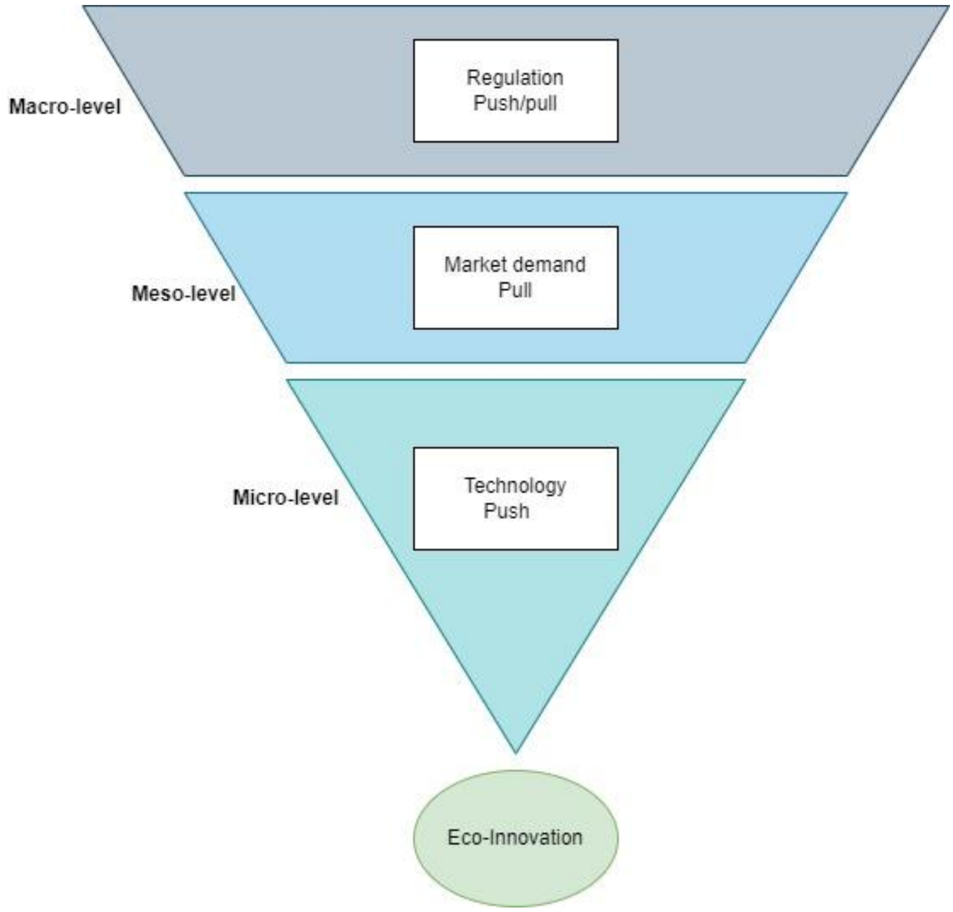

Figure 2: Framework for the study of the drivers of EI. Own elaboration based on Rennings (2000), Díaz-García et al. (2015), and Cuerva et al. (2014).

2.3.1. Macro level: Regulation push/pull

At the macro level, under regulation are factors such as existing environmental law, expected regulation, occupational health and safety standards (Rennings, 2000), technological innovation systems, innovation and industrial/sectoral policy (Díaz-García et al., 2015) and fiscal incentives and subsidies (Triguero et al., 2018). Using a variety of theories, such as neoclassical economics, institutional theory and evolutionary economics theory, numerous studies have underlined the importance such instruments play in triggering EI (Hazarika & Zhang, 2019). A resounding number of these studies found that EIs are more policy driven than non-EIs (e.g. Horbach, 2008; Horbach et al., 2012) while also suggesting that they may be less market driven than other types of innovations (Del Río, Carrillo-Hermosilla, et al., 2015). Some studies have found that a threefold increase in engaging with EI was driven by firms complying with regulatory standards (Sanni, 2018). There is general agreement that these findings confirm the famous Porter hypothesis arguing 'properly designed environmental standards can trigger innovation that may partially or more than fully offset the costs of complying with them' (Porter & van der Linde, 1995, p. 98). The strong version of this hypothesis emphasises the possibility of meeting both economic and environmental goals without compromising either.

It should, however, be noted that, although there is agreement about the general role regulation and policy play in triggering EI, specific types of EI may be affected differently by different types of policy intervention. For example, environmental technology in many instances is more market driven than end-of-pipe technologies, which are more driven by regulation (Horbach et al., 2012).

2.3.2. Meso level: Market pull

Despite the importance of regulation for driving EI, EI has long been considered an interactive process in which other factors also play a role (Del Río, Peñasco, & Romero-Jordán, 2015). Although there is a consensus on the role of regulation in activating EI, agreement of the relevance of drivers at the meso level is perhaps not so clear cut. At the meso level are market demand aspects, such as customer demand, market segments and other stakeholders (Díaz-García et al., 2015), firm reputation, market share, competition and new markets (Rennings, 2000) and corporate social responsibility (Díaz-García et al., 2015). It should be noted that, although some researchers have also included collaborators and information networks at this level external to the firm (Hazarika & Zhang, 2019), the present thesis adopts the approach that knowledge as a resource is difficult to classify as either internal or external to the firm, hence addressing these aspects under technology push and firm resources. The literature that has focused on the meso level has also adopted a variety of theoretical approaches, from ecological modernisation theory to organisational integration theory to social networking theory (Hazarika & Zhang, 2019).

Over the years, there has been an interesting development in studies focusing on the meso level, especially on the role that customer demand plays in driving EI. Initially, there was an argument that demand-side drivers were fairly weak for eco-friendly products because of expense (Rehfeld et al., 2007). Horbach et al. (2012) pointed out that, although consumers can also drive innovations, this is an argument that does not seem supported by empirical evidence. However, there is empirical evidence that customer benefits play a key role in EI as soon as a product delivers added value to the customer, which impacts their demand for such products (Kammerer, 2009). This dictates the willingness of customers to pay for a premium, depending on what the EI product is and how it is presented. In many ways, this framing also applies to process EI where a lot of the mechanisms are in effect hidden from sight. Unless firms specifically advertise them as customer benefits; that is, customers may not directly benefit, but their purchase of a product produced by EI means benefits them generally by the reduced impact on the environment. There is growing evidence of the impact that increased consumption of eco-products and awareness of the value added from the utilisation of eco-processes has had on EI (Munodawafa & Johl, 2019; Ricci et al., 2018).

2.4. Micro level: Technology push

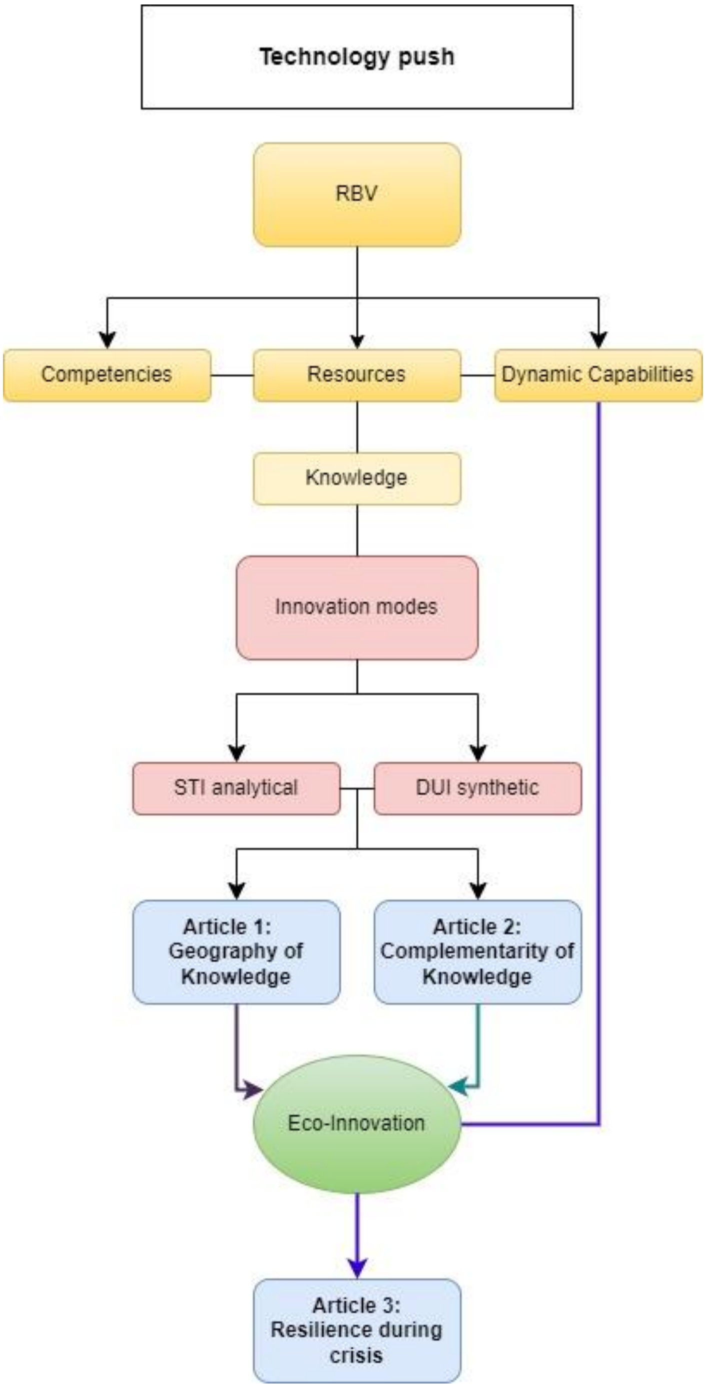

Figure 3: Theoretical positioning of articles.

Figure 3 focuses on the technology push section introduced in Figure 2 and gives an overview of the theoretical framework in which the articles in the present thesis are positioned. The final arrows in the figure are colour coded to further illustrate the path each article takes to or through EI. The individual elements of this framework are elaborate on in the following section.

Firm resources such as physical, human and financial trigger technology push (Cuerva et al., 2014; Horbach, 2019; Triguero et al., 2018). Although there has been a general consensus in the literature about the positive role that regulation plays and the increasing relevance of market pull in driving EI (Demirel & Kesidou, 2019), consensus on the role of firm-specific factors remains elusive (Díaz-García et al., 2015). A lack of a defined theoretical framework in which to analyse these firm-specific factors in a systemic way has contributed to this lack of consensus (Del Río et al., 2016; Kiefer et al., 2019).[8] Improving a firm's technological capabilities, which has been shown to trigger EI (Horbach et al., 2012), very much depends on a firm's resources (Hazarika & Zhang, 2019). Some of the factors at the micro level related to technology push are product quality, energy and material efficiency (Rennings, 2000), cost efficiency, firm competencies, values of owner/manager (Díaz-García et al., 2015), absorptive capacity, managerial vision and resource availability (Hazarika & Zhang, 2019). Although a variety of theoretical approaches have been utilised to study EI at the micro level, one of the most commonly adopted is the RBV of the firm, which has dominated the EI literature since 2001 (Hazarika & Zhang, 2019).

2.5. The resource-based view of the firm

RBV sought to explain why some firms can establish a persistent competitive advantage, often through innovation, here arguing that it depends on its valuable, inimitable and non-substitutable resources and capabilities (Barney, 1991). This theory posits that firms are efficient and profit-driven organisations, led by decision makers limited by bounded rationality and operating in markets that are reasonably predictable and moving towards equilibrium (Hazarika & Zhang, 2019).

[8] Hazarika and Zhang (2019) highlighted this discussion in the literature and proposed an approach to integrate these various theoretical streams of literature. As interesting as the discussion is, for this particular thesis, from a practical perspective engaging in such a discussion is purely academic. We build on established theory, namely RBV which suffices for our purposes.

RBV can be better understood by the utilisation of three main concepts: resources, competences and dynamic capabilities (RCC) (Carrillo-Hermosilla et al., 2019).

- Resources include firm-specific assets that are either tangible, like machinery and equipment, or intangible, like organisational culture or knowledge.
- Competences result from repeated activities usually underpinned by firm processes and routines.
- Dynamic capabilities are the ability of the firm to purposefully create, align and modify its resource base to positively address changes in its business environment.

The usefulness of this theoretical approach for EI lies in its ability to encompass various tangible and intangible assets of the firm, hence allowing the evaluation of their impact on enhancing a firm's environmental and financial performance (Hazarika & Zhang, 2019). Despite this, RBV has also come under some criticism, which is addressed under the discussion in section 3.3. Although some researchers have elaborated specifically on various tangible and intangible RCCs that a firm can exploit for innovation (see Carrillo-Hermosilla et al., 2019 for an overview), the present thesis specifically focuses on the resource of knowledge. Initially, RBV was primarily concerned with the internal factors of a firm; however, the importance of external factors has also been recognised (Teece et al., 1997) to such an extent that it is not possible to classify a factor as specifically internal or external because they are often related (Katkalo et al., 2010). This aspect of RBV captures the resources firms often acquire beyond their firm boundaries, such as knowledge acquired through collaborations and networks, which firms can either add or combine with their existing knowledge base.

Knowledge is an essential resource for the processes of innovation (Holsapple & Wu, 2011). Knowledge has also been shown to be a crucial antecedent of EI (Cuerva et al., 2014; Horbach et al., 2012). To understand knowledge as a resource, the innovation literature offers certain distinctive perspectives. Knowledge can be understood as stocks and flows (Carrillo-Hermosilla et al., 2019). Stock is a firm's existing knowledge base (resource) and how it is applied to innovation processes in a firm (competency). Flows are the processes of acquiring new knowledge either from external sources or through internal knowledge-creating mechanisms, such as internal R&D or education of employees or through the purchase and use of new machinery. These perspectives are further formalised in organisational literature, which distinguishes between exploration, retention and exploitation activities. These perspectives also encompass such concepts as open innovation and absorptive capacity. Open innovation describes a firm's acquisition of new knowledge through collaboration with various external partners, and absorptive capacity describes a firm's ability to incorporate that new knowledge with its existing knowledge base.

As the importance of knowledge to a firm's innovation activity has become widespread, a particular strand of innovation literature—innovation mode—has promoted the idea that these internal and external knowledge-acquisition mechanisms generate a particular form of knowledge. Furthermore, these different forms of knowledge are imbued with certain peculiarities in terms of geography and complementarity that influence the type of innovation activity a firm engages in and their effectiveness in such activities.

2.6. Innovation modes

The literature on innovation modes describes the tension between two archetypical modes in which firms carry out their learning and innovation activities (Jensen et al., 2007). This stream of the literature distinguishes between two different innovation modes: the STI and DUI innovation modes. The STI innovation mode depends on analytical knowledge, whereas the DUI innovation mode depends on synthetic knowledge. These two modes of learning and innovation are present in most sectors, with their intensity depending on sector characteristics and firm strategy (Jensen et al., 2007). Following the literature on innovation modes, the focus is primarily on the knowledge required for each mode, where this knowledge is acquired from and whether these different forms of knowledge are complementary.

2.6.1. Analytical and synthetic knowledge

For a firm, knowledge can be seen as the critical input in production and primary source of value (Grant, 1996). Knowledge is normally discussed in innovation studies using a two-sided dichotomy of closely related terms, this thesis adopts the terms analytical and synthetic. This dichotomy has also been expressed as explicit versus implicit knowledge or codified versus tacit knowledge in the literature.

Formal processes such as R&D produce analytical knowledge that can be written down and interpreted by others who have the required the understanding of the specific language in which that knowledge is expressed.[9] This prior understanding is crucial because analytical knowledge may often be partially written down and requires some prior knowledge to provide context. Therefore, the true value of analytical knowledge is only realised when one has the resources—usually highly qualified employees—that can interpret and apply that knowledge. It is assumed that, because this form of knowledge is written down, it can be transferred easily across geographic distance. The processes that generate and transfer this form of knowledge are also referred to as know-what or know-why mechanisms (Jensen et al., 2007).

On the other hand, synthetic knowledge is generated through regular, typically face-to-face interactions, through observation and practice, such as the instruction of new employees by more experienced ones. The transfer of synthetic knowledge is slow, costly and uncertain (Grant, 1996), hence requiring a certain element of trust. It is skill and people intensive, hence it is difficult to replicate and socially complex (Hart, 1995). This can restrict the transfer of this form of knowledge within a regional context where close social relationships can facilitate its transfer. The processes that generate and transfer this form of knowledge are referred to as know-how and know-who mechanisms (Jensen et al., 2007).

In addition to the analytical and synthetic form of knowledge, a third form of knowledge, which is not addressed in this thesis, is often discussed regarding innovation modes. This third form of knowledge is referred to as symbolic knowledge or the symbolic mode. This mode is the one often employed in creative industries where interactions lead to the creation of meaning, images and symbols

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[9] This aspect of interpretation for analytical knowledge has been acknowledged as also containing elements of synthetic interactions.

with aesthetic cultural attributes (Martin & Rypestøl, 2018; Ocampo-Corrales et al., 2020).

2.6.2. Sources of knowledge

Internal to the firm

From its original conception by Jensen et al. (2007), it has been accepted that analytical knowledge is generated internal in the firm through R&D, either R&D carried out by the firm itself or R&D purchased from external sources (Fitjar & Rodríguez-Pose, 2013; Jensen et al., 2007; Parrilli & Radicic, 2021). This allows the quantitative measure of analytical knowledge through the amount of a firm's monetary investment in these activities.

Unlike analytical knowledge, the measurement of synthetic knowledge poses a challenge because of its tacit nature, which is often difficult to measure quantitatively. Nonetheless, the literature has proposed some quantifiable proxies. For instance, firm investment in the education of employees (Alhusen et al., 2021; Cainelli et al., 2015) and the acquisition and utilization of machinery, equipment and software (Demirel & Kesidou, 2011; Horbach et al., 2012) have all been used to measure synthetic knowledge. Additionally, investment in other downstream functions, such as marketing, has also been adopted as a measure of internal firm synthetic knowledge (Marzucchi & Montresor, 2017).

External to the firm

Although participating in conferences, scientific or industry, as well as accessing knowledge through secondary sources, such as scientific or industry publications, have also been considered sources of knowledge, firms acquire external knowledge primarily through collaboration with external partners.

For a firm, external analytical knowledge is developed in collaboration with universities and other research institutions (Alhusen et al., 2021; Johnson et al., 2002). These collaboration partners are considered as contributing to a firm's analytical knowledge base through collaborative R&D projects. On the other hand, external synthetic knowledge is usually acquired through collaboration with partners, such as suppliers, customers, other firms and even competitors.

Whereas internal knowledge is usually measured in monetary investments, external knowledge has normally been expressed in the degree to which a firm collaborates with different external partners (González-Pernía et al., 2015; Marzucchi & Montresor, 2017; Parrilli & Heras, 2016). For example, engaging in collaboration can be represented by a binary variable where 1 represents engaging in collaboration, regardless of how many collaboration partners there are. It can also be expressed as breadth of collaboration, where relevant collaboration partners are summed, which captures the number of collaborative partners. Additionally, it can be expresses as depth of collaboration, indicated by how important collaboration partners are to the firm. These measures are usually dictated by how the survey is designed, with the CIS being the most prominent.

2.6.3. Geography of knowledge

Given that each of these forms of knowledge differs fundamentally in how they are generated and transferred, this distinction naturally links this approach to the spatial nature of knowledge acquirement and transfer and geography of innovation literature (Fitjar & Rodríguez-Pose, 2013; Isaksen & Trippl, 2017; Tsouri, 2017).[10] This stream of the literature recognises that innovation is a territorially and spatially differentiated phenomenon (Doloreux et al., 2023). This is important because the distinctive characteristics of especially regions can also have a dimensional impact on the development of green industries (Bækkelund, 2022; Fløysand et al., 2022). The geography of innovation literature, including literature centred around innovation systems, argues that the transfer of synthetic knowledge, given its tacit, implicit nature and that it requires regular interaction, is more likely regionally restricted (Asheim et al., 2019). In contrast, analytical knowledge can overcome geographic borders, leading to firms naturally seeking to optimise their knowledge-acquiring efforts by seeking out partners, often international, who represent global

[10] Geography is only one factor—although it may also have overlaps with others—of a number of factors such as cognitive and social that influence interactions between specifically firms and their collaboration partners. These factors are normally studied under the concept of proximity.

nodes of excellence (Fitjar & Rodríguez-Pose, 2013). This is often done in preference to local analytical collaboration partners.

It is important to mention that geography is only one dimension of the concept of proximity, which also includes cognitive, organisational, institutional and social proximity (Boschma, 2005). These dimensions may influence the interaction between firms and their collaboration partners. Although these dimensions can overlap or substitute for each other (Hansen, 2015; Menzel, 2015), this thesis restricts itself to the dimension of geography related to the location of the firm in regards to the geography of its collaboration partners or where knowledge is acquired from. As to the role of geographic characteristics in that process, this thesis recommends further research.

2.6.4. Complementarity of different forms of knowledge for EI

As first proposed by Jensen et al. (2007), the literature on innovation modes has been extended beyond its focus on regional specificities of knowledge transfer to the specific knowledge requirements for the two modes and how that knowledge is acquired and complements each other. This is especially relevant because Jensen et al. (2007) argued that, although firms can innovate through the use of STI or DUI innovation modes, the optimal strategy was a combination of the two. In general, this claim has been enthusiastically embraced by the innovation literature (Doloreux et al., 2023; Haus-Reve et al., 2019), as well as EI literature (Sanni & Verdolini, 2022). This assumption of combination has been studied in the literature as the complementarity of the two forms of knowledge. This approach analyses whether the increase in acquiring one form of knowledge is correlated with the increase in acquiring the other form of knowledge. The existence of such a relationship indicates that the two forms of knowledge are complementary. The existence of the opposite relationship, in that the increase in the acquirement of one form correlates with the decrease in the other, indicates that the two forms of knowledge are substitutes for each other. Despite the widespread acceptance of complementarity between analytical and synthetic knowledge in innovation mode literature, more recently, empirical evidence has emerged indicating that this enthusiasm has perhaps been premature (Carrillo-Carrillo & Alcalde-Heras, 2020; Haus-Reve et al., 2019; Marzucchi & Montresor, 2017). It has now begun to emerge that rather than being complementary, analytical and synthetic knowledge may have a substitutive relationship.

2.7. EI as a dynamic capability

As useful as RBV has been in studying the impact of a firm's resources on its innovation activity, this theoretical approach has also faced some criticism. The most prominent of these criticisms is that this approach does not consider in a meaningful way how a firm's resources are aligned to enhance innovation. The dynamic capabilities perspective evolved from the RBV to consider not just what a firm's resources are, but also how those resources are utilised for efficiency and effectiveness (Del Río, Carrillo-Hermosilla, et al., 2015; Hazarika & Zhang, 2019).

DC refers to the capabilities of a firm to integrate, build and reconfigure internal and external resources and competencies to innovate in an ever-changing environment. Some studies have suggested that engaging in successful EI instils a higher degree of DC (Arranz et al., 2020; Hermundsdottir & Aspelund, 2021; Reyes-Santiago et al., 2019). This suggestion is based on the proposition that, to achieve successful EI, firms must align their resources, of which knowledge is the primary one, in a particular configuration. By aligning strategy with EI to address changing consumer demand and environmental regulation, as well as the constant threat of environmental degradation, requires a certain flexibility and adaptability that characterises EI firms (Munodawafa & Johl, 2019). This has sometimes been referred to as dynamic eco-capacity or green adaptive ability (Pham et al., 2019). The adoption of EI leads to changes at the firm level; these changes are mostly related to human resources and physical infrastructure, but 'if sufficiently pervasive, such adoption may also significantly affect the organisation and the structure of the firm' (Del Río, Carrillo-Hermosilla, et al., 2015, p. 280). EI is closely linked to DC; however, this concept and its complex relationship seem to be underexplored (Pham et al., 2019). Given that EI is considered a firm's ability to address changes in its environment, questions remain regarding what the role of such capabilities play when that business environment changes in drastic fashion, such as during a pandemic. The investigation of these issues is needed for DC which is a concept that remains very much under development (Loureiro et al., 2021).

3. Chapter 3: Methodological considerations

3.1. Context

To paint a more vivid picture of Norway as a context for this study, this section presents some descriptive information concerning EI firms and their locations in different economic regions in the country.[11] This information is based on the results of the Norwegian CIS 2020 the latest results utilized in this thesis. It should be noted that EI in this instance are either product/service EI and/or process EI.

Norway is seen as a country in the midst of "wicked policy paradox" (Kattel et al., 2021, p. 4). On the one hand, it recognizes the need for a transition to more sustainable industries, which on many levels seems to have to potential to carry out. On the other hand, the main driver of growth and technological innovation in its economy, the petroleum industry, is facing a decline which threatens to accelerate over the coming years. Whereas on the surface it would seem a simple solution, encourage the transition to sustainability while at the same time phasing out the petroleum industry, as often the case in reality the solution is never as simple as it sounds. There are indications that these two approaches have become misaligned where policy related to the environment and policy related to the petroleum industry have begun to develop independently of each other (Bang & Lahn, 2020). Such an approach could send a very mixed message to industry and firms about the direction Norway is heading. While undoubtedly the issues at the national, and regional policy level have influence, attention is turned to the firm level which is the focus of this thesis.

In the following figures and tables, EI firms are located within the 85 economic regions of Norway.[12] Economic regions is a regional division standard developed by Statistics Norway which corresponds to the regional level that the EU has defined as NUTS 4-division (Moe & Bloch, 2021, p. 73). Figure 6 also provides information on

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[11] The maps provided in this section were created with the assistance of Karl-Gunnar Severinsen, a fellow PhD.

[12] It should be noted that respondents to the CIS are assumed to be located at the headquarters of multi-divisional firms. Operational activities of such firms may occur in other regional locations.

population density of each economic region as of 2020 provided by Statistics Norway, which may indicate some notion of regional characteristics as related to innovation systems, social responsibility (Fløysand & Jakobsen, 2011) and innovation performance (Aarstad et al., 2016b) which may also have some relevance for EI (Aarstad & Jakobsen, 2020).

As figure 4, 5, and 6 indicate, there does seem to be some correlation between the number of EI firms, total firms and high population density. However, the accompanying Table 1 tells a slightly different story. The weighted average of percentage of EI firms in each region weighted against population density is 40%. While the populous economic regions in Norway such as Oslo, Bergen, Trondheim do not stray particularly far from this weighted average, it's also interesting to note that those economic regions that are well above this average seem to be amongst some of the least populous economic regions, Sør-Troms, Sunndal/Surnadal, Hallingdal.[13] Although a detailed study of the role that regional characteristics, such as population density, play in EI at the firm level was not a focus of this study (refer to subsection 5.1 of this thesis), there are indications that in Norway at least, being located in densely populated regions has a significant negative effect on firm's green strategies (Aarstad & Jakobsen, 2020).

[13] Although it is also observed that regions with low population density are also well represented in those economic regions which are well below this weighted average.

Figure 4: Number of EI firms

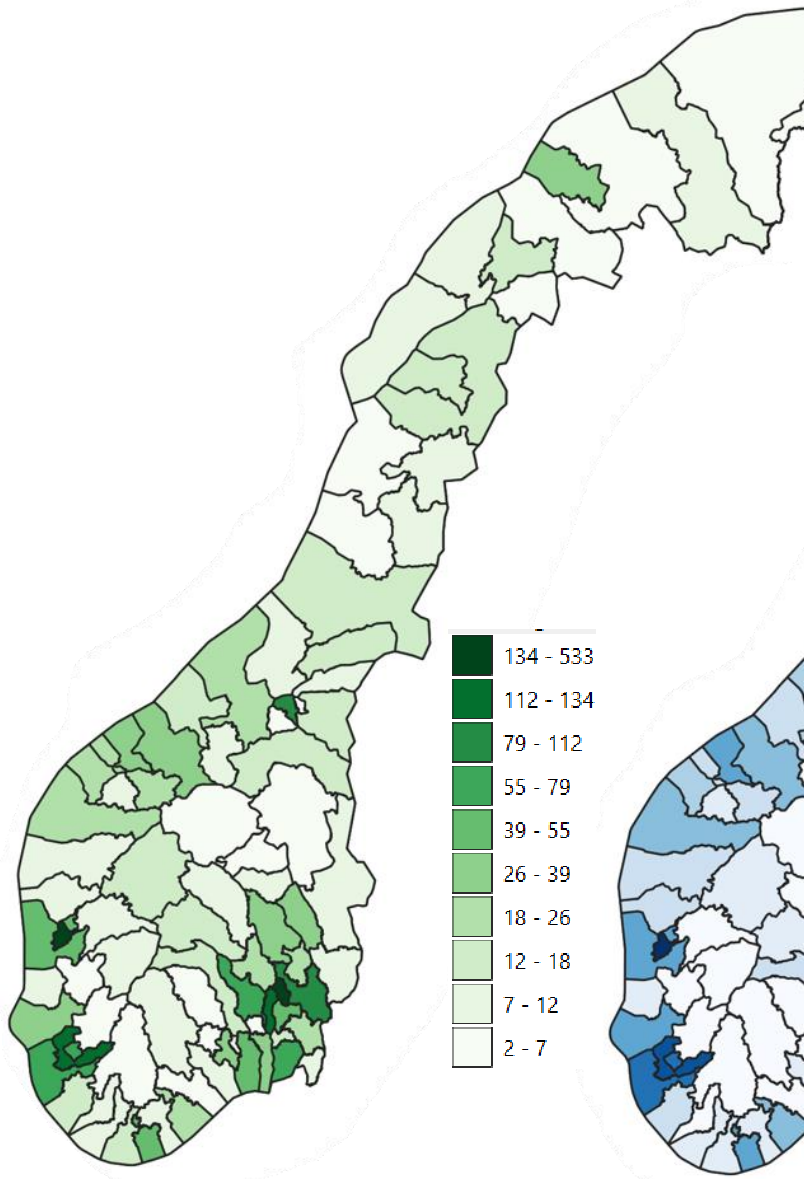

Figure 5: Total firms

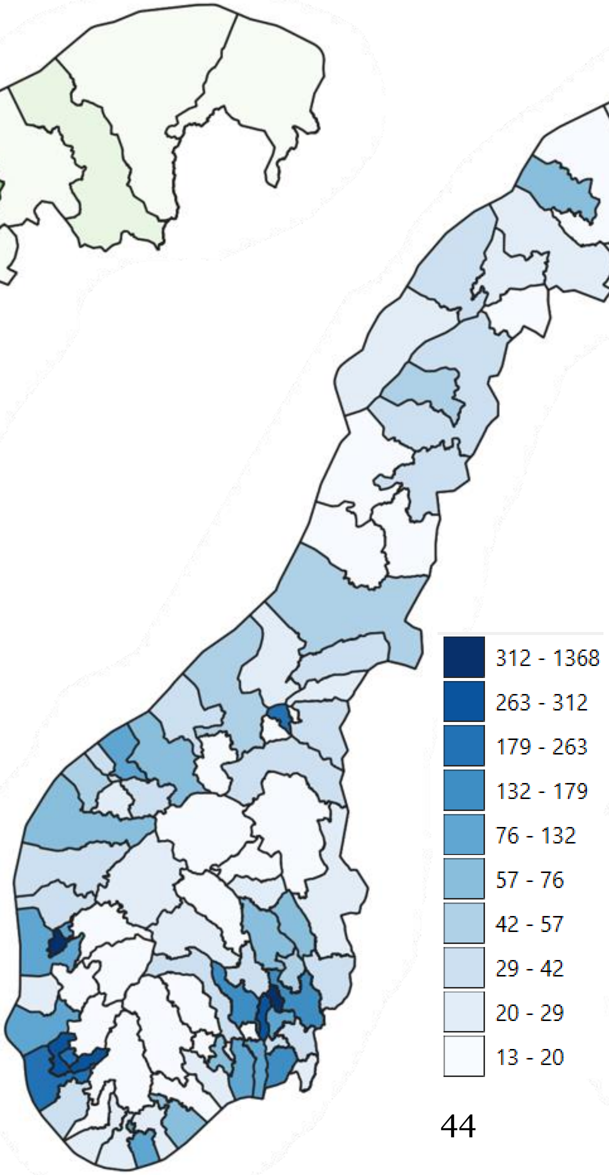

Figure 6: Population density

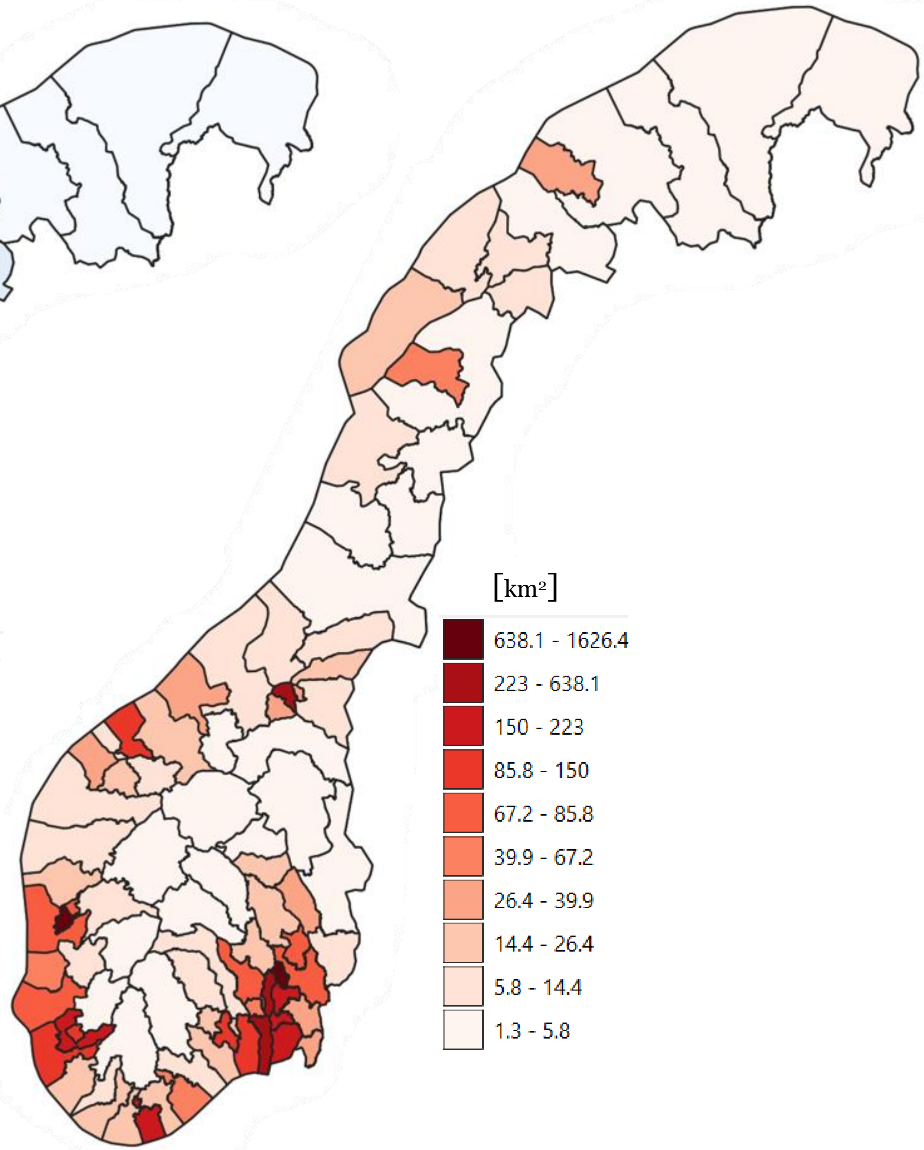

Table 1: Descriptive data for firm locations in economic regions

Economic regions	EI firms	Other firms	Total firms	%EI firms	Pop. Density [km²]
Oslo	533	835	1,368	39	1626.39
Bergen	134	178	312	43	638.06
Asker/Bærum	123	184	307	40	401.61
Stavanger/Sandnes	112	151	263	43	185.91
Trondheim	103	150	253	41	413.24
Lillestrøm	79	86	165	48	82.97
Drammen	76	95	171	44	72.48
Jæren	63	116	179	35	85.82
Fredrikstad/Sarsborg	55	77	132	42	178.21
Kristiansand	51	68	119	43	183.14
Follo	43	58	101	43	187.07
Midthordland	43	51	94	46	72.53
Sandefjord/Larvik	39	70	109	36	93.58
Søre Sunnmøre	35	66	101	35	109.10
Tønsberg/Horten	34	64	98	35	223.02
Porsgrunn/Skien	34	40	74	46	103.82
Hamar	33	41	74	45	38.51
Gjøvik	32	31	63	51	23.68
Tromsø	32	41	73	44	31.12
Haugaland	26	50	76	34	75.05
Molde	26	40	66	39	15.70
Orkland/øyregionen	23	28	51	45	8.35
Sore Sunnmøre	22	31	53	42	37.88
Ullensaker/Eidsvoll	22	28	50	44	67.19
Nordfjord og Kinn	22	41	63	35	9.54
Arendal	21	36	57	37	66.01
Ålesund omland	20	21	41	49	13.45
Indre Østfold	19	19	38	50	36.93
Hønefoss	18	18	36	50	22.24
Dalane	16	20	36	44	15.19
Kristiansund	16	19	35	46	26.41
Bodø	16	34	50	32	39.94
Konsberg	16	14	30	53	8.59
Moss	15	25	40	38	150.04
Trøndelag sør	15	20	35	43	2.96
Steinkjer	15	17	32	47	7.50
Namdal	15	27	42	36	3.15
Hallingdal	14	9	23	61	3.80
Værnes	14	18	32	44	7.04
Sør-Troms	14	8	22	64	12.57
Salten	13	18	31	42	3.08
Indre Sogn	13	11	24	54	3.50
Mandal	12	11	23	52	26.07

Economic regions	EI firms	Other firms	Tot. firms	%EI firms	Pop. Density [km²]]
Ørsta/Volda	11	10	21	52	14.36
Sunndal/Surnadal	11	7	18	61	4.37
Mo i Rana	11	21	32	34	5.57
Nordhordland	11	18	29	38	16.98
Levanger/Verdasøra	11	17	28	39	17.48
Lofoten	10	16	26	38	20.90
Halden	10	17	27	37	37.27
Stord	10	17	27	37	54.22
Mosjøen	9	8	17	53	2.62
Vesterålen	9	23	32	28	11.07
Kongsvinger	9	21	30	30	12.61
Elverum	9	11	20	45	4.91
Grenland	9	16	25	36	17.44
Kristiansand omland	9	16	25	36	23.40
Lyngdal/Farsund	9	12	21	43	16.95
Sunnfjord/Ytre Sogn	9	26	35	26	8.18
Fosen	9	15	24	38	8.33
Lillehammer	8	14	22	36	17.87
Flekkefjord	8	11	19	42	10.97
Valdres	7	12	19	37	3.53
Vest-Telemark	7	9	16	44	2.04
Indre Hardanger	7	11	18	39	2.75
Voss	7	12	19	37	7.53
Vest-Finnmark	7	12	19	37	1.85
Brønnøysund	6	9	15	40	4.24
Ofoten	6	11	17	35	6.75
Midt-Gudbrandsdal	6	8	14	43	4.37
Midt-Telemark	6	11	17	35	19.44
Trondheim forstad	6	12	18	33	38.13
Indre Ryfylke	5	8	13	38	3.61
Tynset	5	13	18	28	1.52
Holmestrand	5	12	17	29	59.98
Øst-Telemark	5	10	15	33	5.81
Østregionen	5	10	15	33	9.28
Sunnhordland Aust	5	13	18	28	10.11
Midt-Troms	5	17	22	23	3.66
Sandnessjøen	4	11	15	27	8.89
Nord-Troms	4	11	15	27	2.03
Øst-Finnmark	4	15	19	21	1.93
NordGundbrandsdal	3	11	14	21	1.92
Setesdal of Sirdal	3	11	14	21	1.55
Midt-Finnmark	2	12	14	14	1.31
Totals	2379	3522	5901		

3.2. Datasets and econometric modelling

The present thesis utilises a number of different datasets. The first is from the results of a survey in 2018 of 800 firms based on the west coast of Norway and a random selection of 401 firms located at various other locations around the country. This survey, although it was purpose built to gauge a variety of innovation behaviour, very closely followed the standard CIS and carried out by Ipsos, a professional market research and consulting firm. The survey data were merged with data from Dun and Bradstreet, which provided data on firm size in number of employees, year of establishment, geographical location, and the industry (NACE code) in which each firm was operating. The second was an unbalanced panel dataset generated from the results of the Norwegian CIS from 2008 to 2016. The items used to generate the dependent variable for EI only appeared from 2008 and then consistently until 2016. The structure of the CIS for these relevant years did not allow for differentiation between product/service EI and process EI. Therefore, EI is operationalised as any innovation activity that conforms to the definition of EI. This is discussed in article 1. Unfortunately, in 2018 (because the CIS is carried biannually in Norway), these or any items related to environmental innovation were absent. In 2020, the format of the Norwegian CIS again substantially changed, where a more detailed approach was adopted to capture firm behaviour regarding environmental impact. The third dataset was constructed from the results of the Norwegian CIS carried out in 2020. Lagged variables from the previous waves could not be included because of variable construction consistency. In addition, the changed format of the 2020 CIS allowed us to formulate the dependent variable as product/service EI and process EI.

The methods and types of questions used in the CIS survey are described in the Organisation for Economic Co-operation and Developments (OECD) Oslo Manual (OECD & Communities, 2005; OECD et al., 1997). The CIS has been carried out in Norway for over 20 years and is mandatory for all firms (with a few exceptions) and follows very closely the standard CIS, which is carried out in a number of European countries as managed by EUROSTAT. Given its relative consistency across European countries, the CIS has been widely used for innovation and EI quantitative studies.

In analysing these datasets, a variety of econometric modelling methods were applied. These methods were generally dictated by the nature of the datasets and model fit. On some occasions, alternative models to test for robustness were also applied, but the final models were those considered the most appropriate. For more details, please refer to the methods section of each article.

Utilising innovation surveys in capturing different types of EI, such as product, process and organisational, as well as including a wide range of controls, is an advantage. Despite the wide use of the CIS or CIS-based surveys, the availability of panel data is surprisingly rare (Horbach, 2019). This point is important because the lack of panel data does not allow the analysis of the impact of certain firm activities that often take time to present themselves in meaningful results. This is especially relevant for EI, given that it is often a long-term endeavour. Endogeneity is a persistent issue in such one-point-in-time data. Although this issue was addressed to some degree in article 2 by utilizing a panel data set, consistency in items in the CIS across different waves, which allowed for a more dynamic analysis, remains an issue. In addition, there are issues with a more complete analysis of the complexity of EI and its drivers, especially in an ecosystems approach, because the data from surveys may not allow for firms to fully express the nuance in the activities and challenges, they face in EI.

3.2.1. Biases

The results from econometric modelling can often by influenced by biases. While efforts were made to control or minimize this influence it is nevertheless wise to interpret the results from this thesis with awareness of the possible existence of these biases. Below biases which are particularly relevant for the modelling and datasets utilized in this thesis are outlined.

Non-response bias, also known as participation biases, is an issue often highlighted as common in survey responses (Groves, 2006). This issue arises when only certain types of firms are more likely to respond to a survey, or specific survey questions, than others leading to a distortion of results. Specifically related to the CIS which is an innovation survey, often it is only innovative firms that are assumed to be more likely to respond. The fact that the Norwegian CIS is mandatory for all firms where they are required to fill out every section, lessens this bias considerably, although it does not eliminate it. It should also be noted that although the CIS is often considered comprehensive for Norway, it is primarily focused on firms with 50 or more employees, with a random selection of firms that have between 5 and 49 employees. This necessarily means that it is weighted accordingly towards larger firms. Furthermore, as the first article was based on another survey, this issue of non-response bias exists to a greater extent in that dataset.

Common method bias is a phenomenon which is observed when respondents are required to respond to a survey using self-reported measures (Podsakoff et al., 2003). Utilizing common measurement techniques, like using multiple-item scales in a single survey to evaluate different constructs, can lead to deceptive outcomes that are linked to the measurement tools rather than the constructs being studied. For example, when respondents are asked to share their views or impressions on several constructs in the same survey, false correlations among the measured items might occur due to elements such as response patterns, the desire to be socially acceptable, and priming effects. These elements bring about biases that are separate from the authentic correlations among the constructs under assessment.

Social desirability is the phenomenon where a respondent desires to project that they meet some standard of desirability which has very obvious effects on how a respondent may choose to answer questions. This can mean for example that they want to be perceived as more concerned with environment than they in fact practice and respond to a survey accordingly by overreporting EI measures.

The effect of these biases can result in difficulty in the interpretation of results, the significance of association between the independent variables and the dependent variable may not be as strong as the results may show, or that in the extreme it may mean that the sign of significance may even be the opposite.

A method to mitigate the effects of common method bias is through use of multiple measurement strategies, which to some degree reduces the risk that respondents consistently exhibit bias or response patterns. A common method to detect the existence of this issue is through the use Harman’s one factor test (Baumgartner &

Weijters, 2021) which resulted in a low score in Article 3 indicating that this was not an issue in that dataset.

The datasets utilized in this thesis were dependent on surveys carried out by professional services including SSB. Many of the biases that can exist in survey results can be minimized through the use of survey construction strategies. During the analysis process, efforts were made to reduce the possibility of bias that exist in the datasets, these include running alternative models, as well as alternative constructions of dependent variables or applying tests to detect the presence of bias in the analysis to increase the validity of the reported results. However, bias remain a persistent issue in quantitative research.

3.2.2. Causality

In this section elaborates on the issue of causality which while related to the previous subsection, warrants a separate discussion on its implications on the results and conclusions of this thesis.

While it has become common in the literature to use the word “drivers” which implies a causal relationship occurring in a particular direction, there are issues. Causality is a persistent issue in statistical modelling, an issue so persistent that often to avoid the difficult implications of it, alternative noncommittal wording has been used such as “association” or “relationship”.

The three classic conditions to establish a measure of the effect of a cause are (Kenny, 1979):

1. Temporal relationship — X must precede Y

2. Non-spurious relationship — X and Y must be reliably correlated beyond chance

3. No alternate causes — The relationship between X and Y must not be explainable by other factors.

Accounting for each of these conditions in econometric models are challenging even with a rigorous approach. Condition 1 for example does not always guarantee causation even if X is a temporal antecedent of Y. Lagged X variables, as in article 2, while often assumed as a possible mitigation of this issue, also doesn't necessarily suffice. The second condition is one that is often assumed to be the easiest to satisfy especially with the application of correct modelling approach and sophisticated modelling programs. The third condition in general can be addressed with the inclusion of adequate control variables. Although such an approach does address the issue, alternative explanations for the relationship between X and Y may in fact be hidden and difficult to undercover. While some of the methods that have been suggested to establish causality and mitigate some of the effects of such as discussed in literature (e.g.Antonakis et al., 2010), it is acknowledge that the results of the analysis in this thesis must be interpreted with the possibility that these issues may still be present.

4. Chapter 4: Main results and discussion

In the following chapter a summary of the results and discussion related to each of the three articles of the thesis are presented.

4.1. Article 1: Regional and international inter-organizational STI and DUI collaborations as carriers for eco-innovation

To address the first research question of the present thesis, the first article investigated which geographic dimension was relevant for acquiring different forms of knowledge for EI. The literature on innovation modes has correlated a particular innovation mode with a specific form of knowledge on which that mode is dependent, often using the innovation mode and form of knowledge interchangeably. This is evident in the discussions and in the formulation of the hypotheses below. However, the mechanisms for each innovation mode obviously go beyond simply the knowledge on which it depends. In line with a number of works in innovation modes (Doloreux et al., 2020; Fitjar & Rodríguez-Pose, 2013; Marzucchi & Montresor, 2017; Parrilli & Alcalde Heras, 2016), the analysis is limited to the specific dimension of knowledge regarding each innovation mode.

It should also be noted that the focus of the present article was not to investigate whether analytical and synthetic knowledge collaboration was conducive to EI: the literature generally agrees that it is. The results from article 2 of the present thesis also confirmed this. Article 1 sought to investigate the geographic nature of such collaborations when expressed as a dichotomy between regional and international collaboration.

To answer the first research question, the current article proposed the hypotheses outlined in Table 2.

It should be noted that the present article did not propose a specific hypothesis related to international synthetic collaboration (international DUI) and EI. Instead, given the lack of prior literature and theoretical basis, the assumption taken by the geography of innovation literature and assume that synthetic knowledge collaborations are normally a regional phenomenon was followed (Doloreux et al., 2020; Fitjar & Rodríguez-Pose, 2013). Product EI and process EI are differentiated because these two types of EI have very distinctive characteristics (Cuerva et al., 2014; Hojnik & Ruzzier, 2016) that may require very specific drivers (Abdullah et al., 2016).

Table 2: Summary of results from logistical regression with cluster (Industry)

	Results in comparison to	
	NI	non EI
H1(a): Regional DUI interorganisational collaboration is positively associated with product EI	ns	**
H1(b): Regional DUI interorganisational collaboration is positively associated with process EI	*	*
H2(a): Regional STI interorganisational collaboration is positively associated with product EI	**	ns
H2(b): Regional STI interorganisational collaboration is positively associated with process EI	**	ns
H3(a): International STI interorganisational collaboration is positively associated with product EI	ns	ns
H3(b): International STI interorganisational collaboration is positively associated with process EI	ns	ns
International DUI interorganisational collaboration is positively associated with product EI	**	ns
International DUI interorganisational collaboration is positively associated with process EI	ns	**

*P < 0.1; **P < 0.05; ***P < 0.01. ns (not significant).

Table 2 summarises the results on the effects of collaboration at the regional and international levels on product and process EI. EI is firstly compared to no innovation (NI) and secondly to non-EI (innovation that does not have a positive impact on the environment). It should be noted that, although the comparison between EI and NI gives some interesting contrast, from the perspective of the literature suggesting that EI is fundamentally different from non-EI, the more important comparison is between EI and non-EI. Therefore, it is, this comparison that perhaps gives the most useful insights into the geography of collaboration or knowledge acquirement for EI.

When comparing EI with non-EI, synthetic knowledge from regional collaboration is more important for both product EI and process EI. In addition, synthetic knowledge from international collaboration is important only for process EI. When comparing EI to NI, synthetic knowledge from regional collaboration is more relevant for product EI, while synthetic knowledge from international collaboration is more important for process EI. These results provide a complex picture of the geography of collaboration. For example, the fact that international synthetic collaboration is more relevant for process EI but not product EI when comparing EI and non-EI could indicate how complex process EI often is (Abdullah et al., 2016; Kawai et al., 2018). This complexity may result in EI firms also engaging in international synthetic collaboration to complement regional synthetic knowledge collaboration. However, in contrast to this reasoning when comparing EI with NI, it is product EI where international synthetic collaboration is more important. Despite this contrast, some general conclusions regarding synthetic knowledge collaboration are forwarded. For EI in Norway, synthetic knowledge interactions are not regionally restricted. Despite the proposition that such knowledge requires face-to-face trust-based interactions usually found within a regionally context, it seems these interactions can also extend well beyond regional borders.

The EI literature has pointed to the importance of analytical knowledge for EI (Marzucchi & Montresor, 2017; Ocampo-Corrales et al., 2020); however, where that knowledge is acquired from geographically can provide some interesting insights. When comparing EI to non-EI, neither regional nor international analytical knowledge collaboration is more relevant for EI. When comparing EI to NI, regional analytical collaboration is more relevant for both product EI and process EI.

Although this finding somewhat supports the emphasis on local analytical knowledge for EI, it does not completely confirm it. Although there is evidence that regional analytical collaboration is more important for EI than for NI, there is no evidence to support the assumption that regional analytical collaboration is more relevant for EI than non-EI. This finding contradicts the prior literature suggesting a positive relationship between regional analytical collaboration and EI (Cainelli et al., 2012; Galliano et al., 2019; Horbach, 2014). Again, the importance of comparing EI and non-EI is emphasised. This finding could be interpreted in several ways, one of which is that, following the literature on EI, regional analytical knowledge collaboration remains an untapped resource for EI compared with non-EI in Norway. In addition, according to the literature, this form of knowledge is not impeded by geographic distance; therefore, international analytical knowledge collaboration remains an unexploited option for EI firms in Norway. The importance of encouraging analytical knowledge—especially from distant places—and the STI innovation mode is that doing so often leads to more radical innovations that break path-dependent trajectories (Asheim et al., 2019). The DUI innovation mode, which depends on synthetic knowledge, more likely results in incremental improvements (Alhusen & Bennat, 2020). One would assume that this proposition from the innovation mode literature may also apply to EI. As important as incremental EI is to address very pressing environmental issues, radical EI should be a more prominent goal for Norwegian firms.

As standard with regression modelling, the effects of certain variables that may affect the results of the model were controlled for. These control variables acknowledge that the specificities of these variables may influence the knowledge sourcing behaviour of firms as related to the dependent variables. These controls include amongst others whether the firm had a majority owner located overseas, firm age, firm size, as well as whether the firm was located on the west coast of

Norway.[14] Running the models with a cluster of Industry is also done to acknowledge such specificities of industries.

4.2. Article 2: Does combining analytical and synthetic knowledge benefit eco-innovation? Evidence from Norway

To answer the second research question, the current article investigated whether combining different forms of knowledge—namely analytical and synthetic knowledge—was advantageous for EI. Although the primary focus of the present article was studying knowledge complementarity, it is common practice in the literature to first establish whether the individual components of the interactions, in this case the individual forms of knowledge, have a positive association with EI (H1 to H4). For instance, if a positive confirmation for H1 and H2 are shown and a positive interaction effect between them (H5(a)) is found, a conclusion that they are complementary in that their combination has a multiplicative effect on EI can be drawn. If, however, we find a negative interaction effect, we can conclude that they are substitutes in that their combination is not advantageous to EI. Finally, if we find no interaction effect, we can conclude that the two forms of knowledge have an additive effect.

It should also be noted that EI is constructed as a general variable if the firm is engaged in any type of activity that conforms to the definition of EI. Unfortunately, the structure of the CIS carried out in Norway for the relevant years did not allow for the operationalism of product/service EI and process EI variables.

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[14] For a discussion of the why these specific controls were included and their possible effects on the model as well as the results, please refer to the control variable section of each specific article. It should be noted that the exclusion of a control variable which may have some influence on the model may also be subject to availability of data.

Table 3: Summary of results from multi-level regressions with yearly observations for firms estimated at a lower-level unit, and industry estimated at a higher-level unit

	Results
H1: Firms that collaborate with external analytical knowledge partners are more likely to eco-innovate than firms that do not collaborate with analytical knowledge partners.	***
H2: Firms that collaborate with external synthetic knowledge partners are more likely to eco-innovate than firms that do not collaborate with synthetic knowledge partners.	***
H3: Firms that invest in internal analytical knowledge sources through R&D are more likely to eco-innovate than firms that do not.	***
H4: Firms that invest in internal synthetic knowledge sources are more likely to eco-innovate than firms that do not.	***
H5(a) The combination of external analytical knowledge and external synthetic knowledge positively affects EI.	negative, ns
H5(b) The combination of external analytical knowledge and internal synthetic knowledge positively affects EI.	negative, ns
H5(c) The combination of external synthetic knowledge and internal analytical knowledge positively affects EI.	negative*
H5(d) The combination of internal analytical knowledge and internal synthetic knowledge positively affects EI.	negative***

* p < .05; ** p < .01; *** p< .001. ns (not significant).

The relevance of different forms of knowledge for EI has been confirmed from the results of article 2, as shown in Table 3. However, the main focus of the article was to investigate whether combining the two different forms of knowledge was beneficial for EI. The combination of synthetic knowledge from external collaborations and internally generated analytical knowledge, especially the combination of internally generated analytical knowledge and internally generated synthetic knowledge, proved to be significantly negative. In fact, the results showed that combining knowledge was not beneficial for EI and that there was generally a substitutive effect between analytical and synthetic knowledge.

Average marginal effects analysis was also applied to address issues related to the interpretation of interaction effects in non-linear logit models alone. These issues are generally attributed to skewness in logit distribution leading to the interaction effects being possibly affected by the variance of the other variables in the model. This necessitates the closer inspection of results through the use of some alternatives. Like others (Acebo et al., 2021; Haus-Reve et al., 2019) we opted for the application of marginal effects analysis, which lent support for the results shown in Table 3. Article 2 elaborates more on this issue as well as presenting the resulting figures from that analysis.

These results seem to go against the acceptance in innovation and EI literature that combining knowledge is the optimal approach. However, like earlier studies that revealed results that contradict the positive effects of knowledge combination (Haus-Reve et al., 2019; Marzucchi & Montresor, 2017), the beneficial effect of knowledge combination are not entirely discounted. Instead there is an acknowledgement that firms may be experiencing difficulties in managing the combination of two very different forms of knowledge. These issues, which have been identified in core innovation concepts such as absorptive capacity, can often be ignored in efforts to generate EI through popular notions of combining different forms of knowledge. Combining different knowledge resources is a worthwhile goal for EI; however, caution is urged for policymakers and firm managers who may be considering the knowledge combination approach to driving EI. Policies that encourage firms to combine different forms of knowledge from different sources may not be successful if they do not include measures to manage the absorption of that knowledge if it is different from the firm's traditional knowledge base. This will be of great relevance for firms in Norway that have traditionally depended on synthetic knowledge and who are hoping to complement this with analytical knowledge to encourage EI.

For this article, the multilevel logistics modelling was carried out with yearly observations for firms estimated at a lower-level unit, and industry estimated at a higher-level unit. Such an approach goes some way in acknowledging industry specificities and their possible effects in the models. In addition, firm size, whether the firm's main market was international, as well as whether the firm was located on the west coast of Norway, were controlled for.

4.3. Article 3: How Eco innovative firms are affected by and responded to an unexpected external shock of the COVID-19 pandemic

To address the final research question, the third article investigated the resilience of EI to an unexpected external shock: COVID-19. The argument is that successfully introducing either product/service EI or process EI was an indication that a firm had developed a distinct form of DC. This DC should allow it to be more positively affected, less negatively affected and introduce more innovations in other aspects of their business as a direct result of the pandemic. This DC is the result of successful EI transforming certain aspects of a firm, such as more flexible and responsive leadership, increased organisational flexibility, more creativity, more responsiveness to consumer demand and possessing a risk-taking characteristic, to name a few.

Whether a firm was positively or negatively affected by COVID-19 was a dependent variable constructed using principal factor analysis; the details are discussed in the article itself. The dependent variable of the number of innovations introduced was constructed from the section of the CIS where the respondents were asked to indicate in which other aspects of their operations, they introduced innovations as a direct response to the pandemic. Other aspects of their business include, for example, delivery, distribution and organisational procedures. These dependent variables were modelled as ordered logit estimators. There is considerable discussion about possible issues related to the violation of assumptions which must be satisfied for this approach to be appropriate. These assumptions include for example the ordinality of dependent variable and the proportional odds assumption. While the dependent variables in this case seemed to satisfy the former assumption, there are issues regarding the latter. To mitigate these issues additional modelling was applied including generalized ordered logit models as well as models where the proportional odds assumption was not imposed. This additional modelling seemed to support the results provided in Table 4.

To answer the third research question, article 3 proposed six hypotheses, which are outlined in Table 4. Table 4 shows that, for firms that introduced a product/service EI in 2020, they were both positively affected and weakly negatively affected by the pandemic. Although on the surface these seem contradictory, it is conceivable that firms may feel that some aspects of their operations may have been positively affected while others may have been negatively affected. Those firms that introduced process EI, however, were not significantly more negatively affected than other firms; however, they were significantly more positively affected by the pandemic than other firms.[15] These results provide evidence that EI firms, whether they were product/service EI or process EI, were quite resilient in the face of an unexpected external shock. It seems that the organisational and structural changes that firms make to facilitate the successful introduction and implementation of EI products/services and processes also allowed them to be positively affected by the pandemic.

[15] The models also controlled for non-product/service EI and non-process EI. Although the former proved to be borderline negatively affected by the pandemic, neither showed any significant effects otherwise.

Table 4: Summary of results from ordered logistics regression with cluster (Industry)

	Results
H1: Firms that introduced product/service EI were more positively affected by COVID-19 than firms that did not introduce product/service EI.	***
H2: Firms that introduced process EI were more positively affected by COVID-19 than firms that did not introduce process EI.	***
H3: Firms that introduced product/service EI were less negatively affected by COVID-19 than firms that did not introduce product/service EI.	negative *
H4: Firms that introduced process EI were less negatively affected by COVID-19 than firms that did not introduce process EI.	ns
H5: Firms that introduced product/service EI also introduced more innovations as a direct response to the impact of COVID-19 than other firms.	***
H6: Firms that have introduced process EI also introduced more innovations as a direct response to the impact of COVID-19 than other firms.	***

* $p < .05$; ** $p < .01$; *** $p < .001$. ns (not significant).

As encouraging as these results are regarding the conceptualisation of EI as a DC, perhaps the more important results are related to the introduction of innovations in other aspects of a firm's operations as a direct result of COVID-19. DC is primarily conceived of as a firm's ability to repurpose its resources to respond to changes in its external environment. In this respect, the results clearly show that EI firms, both product/service and process, introduced significantly more innovations as a direct result of the pandemic than other firms. This lends credibility to the proposition that engaging in EI instils in those firms a DC that makes them not only more resilient, but also more responsive to changes in their environment. This DC is evident in EI firm's ability to respond to changes related to ongoing—and increasingly urgent—environmental issues; it now also seems that this DC is beneficial during times of unexpected shocks. These results inform the concept of DC by providing evidence that DC attributed to EI goes beyond the capability to reorganise or adapt firm resources to changes in a firm's environment: it also facilitates resilience an innovation during extreme and unexpected changes in that environment. For both policymakers and firm managers alike, the results provide encouraging evidence of the beneficial nature of engaging and successfully executing an EI strategy.

Running the regression models with a cluster of industry acknowledges that industry specificities may have some effects in the models. For the modelling in this article variables for firm size, whether the firm received external financial support, and whether the firm's main market was within Norway were controlled for. These controls, amongst others, were included to recognize that these may have some influence in the models as related to the dependent variables. The article discusses what that influence may be as well as the results for the control variables.

5. Conclusions

The results of the present thesis provide important insights not only into the drivers of EI in Norway at the firm level, but also into what the implications of engaging in EI are.

Regarding the drivers of EI and implications for firms, first, it was shown that both regional and international synthetic knowledge collaboration are important for EI when compared with non-EI. In addition, analytical knowledge collaboration is noticeably lacking for EI in Norway compared with non-EI. These findings provide important nuance to the discussion in the literature about the nature of knowledge collaboration and geography. Whereas the literature suggests that synthetic knowledge is primarily a regional phenomenon, these findings suggest that such collaboration may not be regionally restricted. This evidence suggests that other dimensions of proximity, for example, cognitive, may facilitate this interaction. There was also the suggestion that technology may play a role in allowing the interaction between firms and their synthetic collaboration partners, despite geographic distance. This factor may be relevant given globalisation, where customers and suppliers are located well beyond a firm's region.

Furthermore, although the EI literature has emphasised the importance of regional analytical collaboration for EI when compared with non-EI, little evidence of this was uncovered. The results also showed little evidence that international analytical collaboration is more important for EI, despite the proposition that knowledge from such interactions is important for innovation. In Norway, it seems that EI, when compared with non-EI, is driven more by synthetic knowledge acquired through collaboration with distant partners.

Second, both analytical and synthetic knowledge, regardless of whether they are acquired externally or generated internally, are important for EI. However, although combining these forms of knowledge may very well be the optimal approach, as the literature has argued, the findings in this thesis urge caution. Combining two very different forms of knowledge comes with challenges, which, if not overcome, can prove detrimental to EI efforts.

Regarding the implications of engaging in EI at the firm level in Norway, the results clearly show that engaging in such activities—either product/service EI or process EI—benefited firms during a period of external shock, that is, during the COVID-19 pandemic. Not only were firms that engaged in EI more positively affected, they also responded more by introducing innovations in other aspects of their business. The literature has often relied on different measures of DC, arguably the most common of which is to gauge DC by how much a firm invested in R&D (Loureiro et al., 2021). As insightful as this research has been, an argument is proposed that the structural and organisational changes firms require to engage in successful EI represent a legitimate expression of DC. In effect, DC can be conceptualised beyond those measures currently employed by the literature. Although conceptualizing DC by encompassing dimensions of sustainability as a measure has been suggested in earlier research (Pham et al., 2019; Wu et al., 2016), this thesis extends that argument with specific focus on successful product/service and process EI strategies. In addition, it also provides evidence that for firms engaged in successful EI, this DC to reorganise firm resources to respond to changes in their environment is also beneficial for resilience during times of unexpected external shock such as the COVID-19 pandemic.

5.1. Limitations and suggestions for future research

It is worthy to note that each of the articles elaborate more specifically on future research avenues, as dictated by the peculiarities of data or lack thereof, and those will not be repeated here. Although providing some insights into the drivers of EI and how engaging in EI may influence structural and organisational changes that might instil a higher degree of DC, the present thesis also leads to some unexplored research avenues. It has been suggested that innovation modes and their impact on specific types of innovation are context specific (Doloreux et al., 2020; Parrilli & Alcalde Heras, 2016), and the present thesis has specifically focused on Norwegian firms. Despite the fact that some of the results regarding geographical sources of knowledge and the combination of different knowledge forms, seem to show some consistency with other countries, it is premature to make any definitive generalisations. Norway has certain peculiarities regarding how firms innovate and its general resilience to the effects of the COVID-19 pandemic, which may have influenced those results. Therefore, similar studies are recommended to be carried out in other contexts.

Although the results from the present thesis have revealed some insights into the geography of knowledge acquirement for EI, as mentioned before there may be other dimensions of proximity that also play a role in these collaborations. With the assumption that EI is indeed a knowledge-intensive activity, the study of the other dimensions of proximity (Boschma, 2005), and how they influence knowledge acquirement are required.

In addition, it is appreciated that the operationalising of quantitative variables that rely on register data may not sufficiently capture the complex mechanisms involved in generating different forms of knowledge and how firms combine that knowledge. There have been recent works that have suggested more complex frameworks to capture this nuance in knowledge and innovation modes (Alhusen et al., 2021), and any future research should take these into account. Along similar lines, the combination of different forms of knowledge is a complex process, and the findings from the present thesis should promote a more detailed study. Perhaps to address this issue, a different approach should be adopted: the use of qualitative methods to explore in detail the mechanisms that are at play within the firm regarding knowledge acquisition and complementarity. This may provide a nuance that may not have been captured in this study. The danger in not fully considering the complexity of how firms innovate is that the innovation mode approach, as it is currently being framed, may provide overly simplified solutions to a complex problem both for policy makers and firm managers. Simply utilizing more of one innovation mode over the other may not lead to any measurable improvement in EI without careful management of the processes involved. These processes remain a fruitful field for further research.

Although the issue of firm ownership was accounted for to some degree in Article 1 by including a control for firms with a majority overseas owner, this issue remains underexplored in EI literature. This issue is very closely related to the effects on EI of firms being independently owned or part of a multi-divisional company. While there have been arguments that independent firms are more innovative due to an assumed higher flexibility, others have found the opposite effect (Aarstad & Jakobsen, 2020).

Moving beyond the boundaries of the firm level which is the focus of this thesis, innovation modes is an approach that originated in the discussion of innovation systems and how the innovation behaviour of firms may be dictated by economic, institutional and social background as it relates to regional specificities (Jensen et al., 2007; Parrilli et al., 2020). In more recent years some strands of the literature on innovation modes has diverged away from the studying these aspects of innovation modes to focus specifically on knowledge. It is this strand of literature that this thesis, and the few studies that have applied the innovation mode approach to EI have adopted. While such an approach provides insights in the knowledge acquirement and generation mechanisms at the firm level, it perhaps neglects that the firm is not an isolated system. There are other factors which influence the knowledge flow and combination in a firm, such as industry characteristics, as well as the flow of employees, and educational institutions which may play a role in the transformation of a firm's routines and knowledge bases, these factors are often dictated by regional characteristics (Herstad & Brekke, 2012; Herstad et al., 2015). Reconnecting the study of innovation modes to important discussions related to the spatial dimensions of knowledge sourcing is important for EI research as "both regional specificities and the nature of the innovation matter" (Parrilli et al., 2020, p. 1).

Development of the literature on DC is ongoing; although this thesis adds its voice to those that argue for EI to be legitimately considered as an expression of DC, more research is required. This thesis, for example, could not include the economic impact of the pandemic for EI firms which is also an important aspect of DC (Aarstad et al., 2021). Although the findings from the EI literature about the nature of EI very much conform to the concept of DC, more detailed analysis needs to be carried out, both quantitatively and qualitatively, at the firm level to study exactly how engaging in EI changes firm organisation and structure. These approaches can reveal insights into the nature of EI and help with the practical implementation of EI strategies at the firm level. Finally, the CIS in 2020 only captured the immediate effects of COVID-

19; follow-up studies on the continued resilience of EI firms, especially their recovery, to the effects of the pandemic would provide valuable insights.

Finally, although the effects of differing industry characteristics are somewhat accounted for through various modelling approaches, the issue of industry both in regard to knowledge as well as to dynamic capabilities as related to EI is not explicitly addressed. An overreaching goal of this thesis was to initiate the conversation about the possibility of generalizing the results of earlier studies that have focussed on specific industries (e.g. Doloreux et al., 2020; Marzucchi & Montresor, 2017). However, it should be acknowledged that there remain avenues for future research in this respect, such as the impact of industry lifecycles on EI, and urge future research to pursue such avenues.

5.2. Policy recommendations

In each of the three articles, policy recommendations are included specifically based on the results of each article. However, this section takes an overview perspective, considering the possible implications for policy of the thesis as a whole. First, as a direct result, policies that prioritise knowledge acquirement are essential for the continued success of EI at the firm level. A specific focus on policies that encourage external interactions with analytical knowledge providers, both at the regional and international levels, should be encouraged. In addition, internal knowledge-generating activities should also be encouraged because they are important drivers of EI. However, a note of caution is sounded for the implementation of policies encouraging the acquisition of knowledge without addressing how this knowledge may complement a firm's existing knowledge base. There are indications that combining knowledge, which is a widely accepted tenet in innovation studies and the EI literature, is not without challenges. Second—and connected to the first point—policies that generally facilitate firms engaging in EI are urged. The results clearly show that engaging in these activities significantly contributes to both resilience and responsiveness during times of unexpected shock. This is especially relevant because the occurrence of such events is predicted to become more frequent.

Finally, some thoughts on policy recommendations that move beyond the direct results of the present thesis are offered. The EI literature has highlighted the emerging benefits of engaging in EI, a win-win situation that benefits both firms and society. Unfortunately, this knowledge may not be sufficient to achieve a rapid transition that will have a meaningful impact in averting a looming environmental disaster. Policy instruments such as regulation and incentives will be required to have an even larger role in promoting EI at the firm level (Veugelers, 2012). Given the required level of change, the conversation naturally leads to considering such policy instruments in motivating more radical coordinated system changes across the macro, meso and micro levels. This requires that these policy instruments are designed well from the beginning, reiterating the basis for Porter's hypothesis that these well-designed policies have the potential to more than offset the cost in achieving environmental goals for firms. Some studies have shown that the current approach of system optimisation, where firms meet the minimum to satisfy policy requirements or market demands (Cai & Li, 2018; Chu et al., 2018), has led to a situation of incremental EI that does very little to change the existing infrastructure (Hazarika & Zhang, 2019). With this perspective in mind, policy efforts that are focused specifically at the firm level are required, for example, as outlined in the individual articles; however, their impact will be limited if they are not considered as part of a more ambitious multilevel policy mix approach (Díaz-García et al., 2015; Veugelers, 2012).

5.3. Concluding remarks

As the threat of environmental disaster continues and scale of response required moves beyond the scope of any one individual firm, what is required is a response that is coordinated across all levels. As insightful as focused research into EI has been, there is growing recognition that a complete sustainability transition approach is needed (Truffer & Coenen, 2012). At its simplest, at the firm level, some have called for adopting a natural resource-based view (NRBV), which studies EI by taking into account the constraints imposed by the natural environment (Hart, 1995). This approach is consistent with calls to move EI even further from a cost-benefit analysis based on technological progress towards an eco-centric approach that places the natural environment at the centre. Current theoretical approaches based on neoclassical assumptions have unintendedly resulted in a focus on incremental improvements while reducing the probability of long-term system shifts (Hazarika & Zhang, 2019). The key to achieving such a coordinated policy approach may lie in EI research adopting theoretical approaches, such as evolutionary theory or multilevel perspectives (Hazarika & Zhang, 2019), which take into account the interrelatedness of the macro, meso and micro levels. In addition, as mentioned in the future research section, this widening of perspective will naturally also encompass such issues as innovation systems within regions or national borders. These theoretical approaches will help identify key stakeholders whose engagement at different stages of policy design will be required. These interventions have been shown to be extremely effective in the development and adoption of EI when they are designed with a long-term and encompassing perspective (Veugelers, 2012).

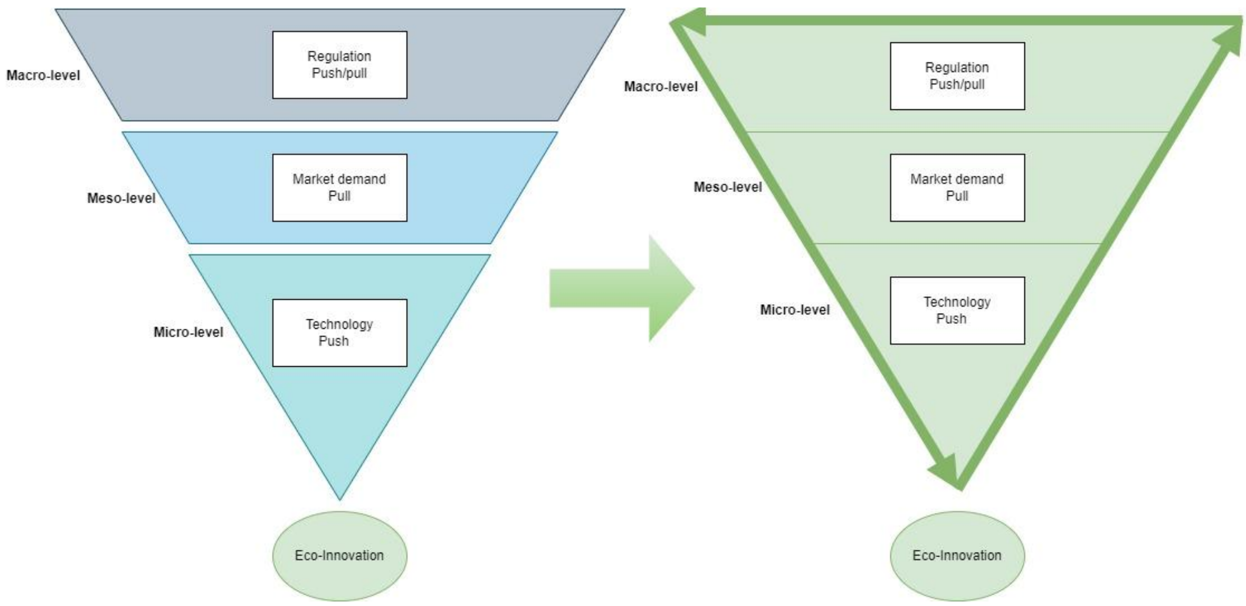

Figure 7: A new direction for EI research. Own elaboration.

Figure 7 illustrates this transition from static approaches, which are embedded at each individual level (as illustrated by Figure 2 previously), to adopting a research approach that reflects the interrelatedness of the different levels. Taking this approach to the study of EI rather than focusing on specific static drivers may be required to push the current focus of the literature towards approaches that can trigger more radical EI. Even within the firm, the changes required are system changes rather than simply increasing efficiency of the individual components, which often seem to be the focus of the drivers of EI research.

In this thesis, there is a keen awareness of the lack in addressing exactly how these different subsystems affect each other, especially how macro-level measures influenced micro-level factors. The importance of complex targeted policy approaches in influencing the direction of EI development cannot be understated (Jakobsen et al., 2022). Researchers must acknowledge that more comprehensive measures are required to address our impact on the environment. This calls for a focus on measures that fundamentally change our approach to EI, even at the firm level—beyond simply making incremental improvements to products and processes—to a complete system shift. Only when such a system shift occurs will we be able to address the possibility of changing the path we are currently on.

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Regional and international inter-organizational STI and DUI collaborations as carriers for eco-innovation

Faraimo J. Vai

ABSTRACT
This paper investigates regional and international inter-organizational doing, using and interacting (DUI) and science, technology and innovation (STI) collaborations as carriers for eco-innovation. Contextually, it studies a sample of Norwegian firms primarily based on the west coast of the country. Overall, the econometric analysis shows mixed results for regional and international inter-organizational collaborations. Results were significant for both regional DUI and STI inter-organizational collaborations. In addition, international DUI was also relevant; however, international STI inter-organizational collaborations consistently showed no effects. These latter findings challenge the notion that DUI collaborations are restricted to regional boundaries, whereas STI collaborations can overcome them.

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eco-innovation; collaboration; regional; international; knowledge; STI; DUI

INTRODUCTION

Eco-innovation (EI) has, in recent years, received an understandable amount of attention from practitioners, academics and policymakers as the world faces a race against the clock to transition to a more sustainable future. Consequently, academic research into what drives EI has flourished, especially in the last two decades. A popular definition for EI adopted by researchers, as we do here, is given by Kemp and Pearson (2008, p. 7), who define EI as:

> The production, assimilation or exploitation of a product, production process, service or management or business method that is novel to the organisation (developing or adopting it) and which results, throughout its life cycle, in a reduction of environmental risk, pollution and other negative impacts of resources use (including energy use) compared with relevant alternatives.

In its latter part, the definition differentiates EI from non-EI in that EI positively impacts the environment, which can either be an explicit goal or a side effect (Horbach et al., 2012).

In most recent review articles of the literature on the drivers of EI, several antecedents were identified as being particularly relevant. Firms that were more environmentally concerned (Zubeltzu-Jaka et al., 2018), through long-term-based EI orientation and management,

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dynamic green absorptive and adaptive capacity (Pham et al., 2019), were highlighted. In addition, more traditionally accepted antecedents such as environmental regulation, company size and research and development (R&D) activities (Bitencourt et al., 2020) were more likely to lead to an EI outcome. Common amongst these findings was the role of external information sources (Bitencourt et al., 2020) through collaborative networks (Zubeltzu-Jaka et al., 2018) with appropriate partners (Pham et al., 2019).

The beneficial role of external knowledge sources through collaboration has been well documented for innovation in general; however, these findings prove difficult to transfer to EI (Kobarg et al., 2020) because the concept of EI is fundamentally different from non-EI. EI is often characterized by relatively new technologies and a systemic nature due to the high complexity of environmental challenges (del Río et al., 2016; Horbach, 2008). The required organizational and technological competencies must often be drawn from sources beyond the firm's boundaries (Ben Arfi et al., 2018; Cainelli et al., 2015). Generally, research has shown that inter-organizational collaboration patterns differ concerning EI and non-EI (i.e., 'regular' innovation). Also, inter-organizational collaboration is more crucial for EI to be successful than non-EI (Fabrizi et al., 2018; Ghisetti et al., 2015), which lends weight to the multidimensionality and systemic nature of EI.

Recently, researchers have moved away from the relevance of inter-organizational collaboration per se as a driver for EI generally to consider more nuanced aspects such as how the breadth or depth of collaboration partners may impact the emergence of different types of EI typologies, such as product- and process-EI (González-Moreno et al., 2019; Kobarg et al., 2020; Marzucchi & Montresor, 2017). In particular, Marzucchi and Montresor (2017) considered how different types of collaboration partners inherently reflect specific 'types of knowledge' or 'innovation modes', science, technology and innovation (STI) exchanging analytical knowledge, or doing, using and interacting (DUI) exchanging synthetic knowledge. This collaboration partner distinction was made by Fitjar and Rodríguez-Pose (2013); however, Marzucchi and Montresor (2017) did not consider the important aspect of geographical proximity as was inherent in the original framing. This is especially relevant given that 'firms obtain knowledge from different sources, by use of different knowledge linkages, and from different geographical levels' (Isaksen & Trippl, 2017, p. 126).

Since then, researchers have begun to make inroads into the issue of geography of inter-organizational collaboration and EI. Arranz et al. (2019), without elaborating on some important issues, such as which type of inter-organizational collaboration partner is relevant for which particular type of EI, suggested that the density of companies in a region positively impacts EI as it facilitates learning, dissemination of knowledge and collaboration. Ocampo-Corrales et al. (2021) focused on renewable energy by evaluating the importance of scientific and technological knowledge flowing from distant and non-distant places. This analysis was based on non-patent literature citations from patent data, and not on collaboration partners nor did they consider DUI knowledge. Galliano et al. (2019) provide some important insights into the question of geographical proximity, knowledge sources and EI, specifically in five agro-ecological projects in peripheral areas, and highlight the importance of institutional actors at the regional level. However, as to which geographical location of collaboration partner is important for which type of innovation output, EI included, the empirical evidence remains unclear and is probably context specific (Doloreux et al., 2020). Local and global collaboration interactions exhibit advantages and limitations. Which of these linkages are most important is 'not a straightforward issue but instead a topic that should be analysed and tested empirically in several geographical contexts' (Parrilli & Alcalde Heras, 2016, p. 749).

Building on these works, and prompted by the latter, this paper explores the geography (international versus regional) of DUI and STI inter-organizational collaborations as potential carriers for product- and process-EI in Norway. Norway as a country is capable of generating comparatively higher innovation and economic output than others based on a given amount of R&D expenditure (González-Pernía et al., 2015; Parrilli & Alcalde Heras, 2016). Norwegian firms have generally invested less in intra-mural R&D and instead tended to pursue collaborative innovation strategies with external partners more than other European countries (Fagerberg et al., 2009). Innovation tends to rely more on DUI than on STI inter-organizational collaborations (Parrilli & Alcalde Heras, 2016), partially explained by its reliance on resource-based industries (Fagerberg et al., 2009).[1] The literature provides little evidence on how DUI and STI collaborations are related to product- and process-EI in such a context. This absence is problematic because many countries and regions find themselves in this similar situation (Parrilli & Alcalde Heras, 2016). In response to this research gap, we contribute by analysing the extent to which DUI and STI inter-organizational collaborations are associated with EI in a sample of 1201 Norwegian firms.

We contribute to the ongoing conversation about the relevance of geography to STI and DUI modes in general, and product- and process-EI in particular. We also contribute to the better understanding of which specific type of collaboration is relevant for the emergence of specific EI dimensions. In addition we contribute to the discussion of the fundamental difference between EI and non-EI and apply an approach similar to Horbach (2008). That is, we compare (1) enterprises with EIs with enterprises having no innovation at all; and (2) enterprises with EIs with enterprises having 'regular' or 'general' innovations not considered as particularly eco-friendly (i.e., non-EIs). Our motive for this approach is to gain a more nuanced understanding of potential carriers of the very concept of EIs.

The remainder of the paper is structured as follows. The next section considers theoretical aspects and introduces a few hypotheses. The third section outlines our methodology and empirical application. The fourth section reports the results of our analysis and discussion. The fifth section concludes.

THEORY AND HYPOTHESES

Modes of innovation

The concepts of modes of innovation were introduced by Lundvall and Johnson (1994), and the seminal paper by Jensen et al. (2007) explicitly defined the science and technology-based innovation mode (STI) and the learning-by-doing and interactions mode (DUI), which encompass both internal and external knowledge sourcing activities. The first of the modes is centred around high R&D investments as well as knowledge centres such universities and research institutions, and knowledge brokers who participate in the diffusion of knowledge. These sources of knowledge are seen as generators of codified and explicit or analytical knowledge that can be used to generate innovations by firms (Fitjar & Rodríguez-Pose, 2013). It is a type of knowledge that is typically associated with high-technology industries, pharmaceuticals, biotechnology and nanotechnology (Parrilli & Alcalde Heras, 2016). However, by acquiring this knowledge and understanding that it may also involve the transmission of tacit knowledge, there is always an element of learning-by-doing even when codified knowledge is transmitted and applied (Doloreux et al., 2020).

In contrast, the second innovation mode focuses on the relevance of informal relationships and mutual learning between firm employees and their local social ties (Doloreux et al., 2020). This is often expressed as know-how and know-who collaborative interactions. These interactions lead to the generation of a synthetic or tacit type of knowledge (Asheim & Coenen, 2005; Lundvall & Johnson, 1994) based on trust with less likelihood for codification. DUI-type knowledge is used for innovation typically seen in engineering based industries (Parrilli & Alcalde Heras, 2016).[2]

Fitjar and Rodríguez-Pose (2013), in a much-cited paper, classified the interactions with different external partners into STI collaborations and DUI collaborations. Collaborations with universities, research institutions and consultants are STI, and DUI collaborations are with suppliers, customers and competitors. Marzucchi and Montresor (2017), in the context of EI, labelled these as STEI and DUIEI collaboration. By adopting this perspective, 'EI is looked at through the lens of "innovation modes" where firms' innovative behaviours are systematized into a manageable and interpretable set of typologies of innovation practices, strategies, and performances' (Caravella & Crespi, 2020, p. 183).

Some researchers have addressed the complementarity between these two modes of innovation (Alhusen & Bennat, 2021; Parrilli & Alcalde Heras, 2016) finding evidence that a combination of the two modes seems to yield positive innovation outcomes. However, others have found that the two modes are substitutes for each other (Haus-Reve et al., 2019) and are difficult to combine (Marzucchi & Montresor, 2017). The latter confirms perhaps that while firms combine analytical and synthetic knowledge, in most cases they draw primarily on one of them (Asheim et al., 2019; Hansen, 2015; Menzel, 2015).[3]

Product-EI, process-EI and innovation modes

While the aforementioned multidimensionality of EI also extends to other types of innovation, such as business model or management innovation, 'a focus on technological innovation implies the differentiation between product- and process-EI' (Kobarg et al., 2020, p. 5). While the general innovation literature has found differences between product and process innovations, the EI literature has recognized that both product- and process-EI are different types of multidimensional constructs of EI and that both are dependent on complex and new technologies (Kobarg et al., 2020). Arguments have been presented that, generally, EI by its nature (and more specifically renewable energy) is an innovation that depends on analytical knowledge (Ocampo-Corrales et al., 2021). Some have argued that product-EI is dependent on synthetic knowledge, whereas process-EI is dependent on analytical knowledge (Marzucchi & Montresor, 2017). Empirical findings suggest that synthetic knowledge partners are more relevant than analytical ones for certain types of EIs over non-EIs (Kobarg et al., 2020; Marzucchi & Montresor, 2017). However, the majority of the relevant literature seem to be in consensus that the complexity of EI expressed in both typologies promotes the requirement of both types of knowledge (González-Moreno et al., 2019; Kobarg et al., 2020; Triguero et al., 2013). This perhaps is also a reflection that some form of DUI knowledge may be generated along with STI, and that DUI may be required to interpret STI knowledge (Doloreux et al., 2020; Parrilli & Alcalde Heras, 2016). We argue that despite any possible differences between product- and process-EI in terms of goals, strategies, processes and organizational aspects, both typologies of EI require multiple dimensions of knowledge; synthetic and analytical, DUI and STI.

The need for new environmental solutions that embrace the whole spectrum of elements in the technological system motivates the former of these results. The complexity of the knowledge that green innovations require, and its degree of scientific codification, have been argued to explain the latter.

(Ben Arfi et al., 2018, p. 213)

Geography of inter-organizational collaboration and innovation

In addition to classifying collaboration partners as STI or DUI, Fitjar and Rodríguez-Pose (2013) explored the geographical dimension, 'STI and DUI-mode interaction are often conducted at different geographical scales and may significantly affect the capacity of firms to produce different types of innovation' (p. 129). They explored this under the proposition that the codified nature of STI facilitates its flow irrespective of geographical borders, generally leading to firms seeking out 'global nodes of excellence' (p. 131). In contrast, the tacit and social interaction nature of DUI may restrict its diffusion to a local geographical dimension. Despite enthusiasm in the literature since the publication of the seminal paper by Jensen et al. (2007) on DUI and STI innovation modes, there are not many quantitative studies of how collaborations that reflect innovation modes are associated with different types of innovation, nor of the geography of these associations (Doloreux et al., 2020). The studies that have addressed this issue, however, led Parrilli and Radicic (2021) to suggest that these innovation modes are typically anchored to their innovation systems that are characterized by a peculiar culture and style of producing innovation, emphasizing earlier propositions by Parrilli and Alcalde Heras (2016) and Doloreux et al. (2020).

Regional DUI inter-organizational collaboration and EI

A long line of geography of innovation literature, including literature centred around innovation systems, argues that DUI given its tacit, implicit nature, requiring regular interaction is more likely local (Asheim et al., 2019). Even more recent contextual-based analysis of the geographical dimension of the two types of knowledge (Doloreux et al., 2020) as well as the EI literature itself (Marzucchi & Montresor, 2017) suggest the same. However, Fitjar and Rodríguez-Pose (2013) found that local DUI matters only slightly, whereas global DUI linkages are the most important for product or process innovation. Parrilli and Alcalde Heras (2016) confirmed this importance of global DUI for technological, non-technological and radical innovation, while finding no significance of local DUI.

For EI, the case for international DUI collaboration has yet to be empirically documented. Within the regional context, however, there have been indications that DUI collaborations with suppliers (Cainelli et al., 2012) are important, and that EI is largely reliant on local resources and networks and regional interactions (Arranz et al., 2019; Cainelli et al., 2012). Galliano et al. (2019) emphasized the reliance of EI on strong personal relationships built over time and on productive activities that already exist locally using local technologies and know-how. These local networks presumably will have a better understanding of the product and processes involved in local industries through interaction and experience (Asheim et al., 2019) allowing them to identify and offer better environmentally focused solutions. In addition, geographical proximity is beneficial for DUI inter-organizational collaboration because it makes industrial cooperation within the region more efficient (Fitjar & Rodríguez-Pose, 2013). If we then follow geography of innovation works that suggest DUI is more likely a regional or local phenomena, and that EI is more dependent on DUI than non-EI (Kobarg et al., 2020; Marzucchi & Montresor, 2017), our first hypothesis is:

Hypothesis 1: Regional DUI inter-organizational collaborations are positively associated with (a) product- and (b) process-EI.

In the absence of prior literature or evidence of EI international DUI inter-organizational collaboration, and despite the emergent empirical literature documenting the relevance of this for non-EI, we hesitate to put forward a hypothesis accordingly. We instead choose to follow the assumption taken by geography of innovation studies that DUI collaboration is primarily a regional phenomenon, like others before us (Doloreux et al., 2015, 2020; Fitjar & Rodríguez-Pose, 2013).

Regional and international STI inter-organization collaboration and EI

The widely accepted assumption from the years of geography of innovation literature is that firms usually source their innovations from their immediate vicinity as the region is the area where geographical and institutional (and often also social) proximity is present (Martin & Rypestøl, 2018; Ocampo-Corrales et al., 2021).[4] This exploitation of local knowledge sources instead of investment in internal R&D for innovation partially explains the success of countries such as Norway and Denmark and various other European regions (Asheim & Gertler, 2005;

Edquist, 2005). Keller and Yeaple (2013) also stated that the more knowledge intensive a process, which EI undoubtedly is, the less likely its knowledge will diffuse in space, and knowledge spillovers is primarily a local phenomenon (Isaksen & Trippl, 2017). Boschma (2005), in a discussion of dimensions of proximity, also states that short spatial distance may even be just as relevant for codified knowledge as it may have a component of tacit knowledge (Asheim et al., 2019). Parrilli and Alcalde Heras (2016) show that local STI connections are most closely related to innovation, and that a higher proportion of firms engage in local STI interactions rather than in transregional ones.

For EI, the literature has pointed to the important role of local universities and research institutions as determinant for EI over non-EI (Cainelli et al., 2012; Galliano et al., 2019; Horbach, 2014). Others have pointed to how regions facilitate learning, dissemination of knowledge and collaboration (Arranz et al., 2019). Rather than reaching for international collaboration partners, firms may restrict themselves to regional inter-organizational collaborations where other forms of proximity, which may also include cognitive, are inherent. Regional STI partners may be more aware of products and processes in local industries and how analytical knowledge provided by research can solve relevant environmental issues. These regional university–industry networks are important for STI (Asheim et al., 2019). We argue that in the search for collaborations to gain knowledge to solve specific complex problems (such as, for instance, EI), firms will form STI inter-organizational networks at the regional level.

Hypothesis 2: Regional STI inter-organizational collaborations are positively associated with (a) product- and (b) process-EI.

However, empirical works have documented the impact of extra-regional knowledge sources on the innovative performance of firms (Fitjar et al., 2016; Fitjar & Rodríguez-Pose, 2020). It is generally accepted that the codifiable nature of STI can facilitate its frictionless transfer regardless of geographical distance, meaning that interacting with regionally based STI partners may not lead to any added value, making global nodes of excellence much more attractive for innovative firms (Fitjar & Rodríguez-Pose, 2013). From the EI literature it has been suggested that the more important aspect of proximity here, perhaps, is not only geographical but also cognitive proximity (Ocampo-Corrales et al., 2021). Searching for sources of knowledge to develop EI, firms will usually begin this search with sources that are at a certain cognitive distance (González-Moreno et al., 2019); cognitive proximity may help overcome any friction imposed by geography. Some empirical findings on the dependence of EI, over non-EI, on STI knowledge from distant places have been positive (Galliano et al., 2019; Ocampo-Corrales et al., 2021). Additionally it has been suggested that seeking knowledge from distant places may help established industries break out of path-dependent trajectories (Asheim et al., 2019), which may be required for firms to transition into EI.

We additionally argue that firms will use all channels available in the search for STI knowledge, and because it is codifiable, geography will be less relevant.

Hypothesis 3: International STI inter-organizational collaborations are positively associated with (a) product- and (b) process-EI.

METHOD AND DATA

Empirical context

The data set used for this research was the result of a survey taken in 2018 that was carried out by telephone interviews of chief executive officers (CEOs) in the first months of 2018. The candidate firms were randomly selected from Statistics Norway, the statistics bureau of Norway. Firms having at least five employees and operating in most industries, except for the real estate and the public sector, were targeted for the survey. The response rate of those firms that were contacted was 34.8% and was consistent across firm size, firm location and industry classes.

Ipsos, a professional market research and consulting firm, carried out the survey interviews and the coding of the raw data. The raw data were merged with register data on firm size (number of employees), geographical location, year of establishment and the industry (NACE) code provided by Dun and Bradstreet.

The resulting data set contained 1201 firms, 800 firms in the counties of Rogaland, Hordaland, and Sogn and Fjordane on the west coast of Norway, and 401 firms from other parts of Norway.

Dependent variables

Data concerning firms' product or process innovations were assessed by applying operational definitions following the *Oslo Manual* (Bloch, 2007; OECD & Communities, 2005). The respondents were asked as follows concerning the concept of product innovation: 'Has your firm during the last three years introduced a new or substantially improved product or service?' Those firms that responded 'yes' were coded 1 as having a product innovation, and those that responded 'no', 'do not know' or did not respond at all were coded 0 as not having a product innovation.

In addition, process innovation was defined and assessed by the following phrase and question: 'Process innovation implies to start using new or substantially improved technology or methods of production, delivery, and distribution. Has your firm during the last three years introduced a new or substantially improved process innovation?' Those firms that responded 'yes' were coded 1 as having a process innovation, and those who responded 'no', 'do not know' or did not respond at all were coded 0 as not having process innovation.

A follow-up question was asked to those respondents who answered 'yes' to the first question concerning product innovation: 'Do you consider these new or substantially improved products and services to be especially environmentally friendly?' Another follow-up question was also posed in reference to process innovation: 'Do you consider these new or substantially improved processes to be especially environmentally friendly?' Those firms that responded 'yes' were coded as having either a product- or process-EI innovation, respectively (those who responded 'no', 'do not know' or did not respond at all were coded as not having either a product- or process-EI innovation, respectively). Product- or process-EI innovation, respectively, were coded as 1, and 0 otherwise. Table 1 shows these classifications and the share of firms surveyed in the context of product and process innovations, respectively.

Independent variables

To assess firms' inter-organizational collaboration, we adopted operational definitions similar to those used by the Community Innovation Survey (CIS). The respondents were asked: 'Has your firm during the last three years had collaboration with other firms or institutions concerning the development or improvements of products and processes?' Respondents who answered 'yes' were coded as 1, and those that answered 'no', 'do not know' or did not respond at all were coded as 0. Those that answered 'yes' were then asked to identify their collaboration partners

Table 1. Innovations developed in the last three years.

Innovation type	Number of firms	% of total firms sampled
Product-EI	494	41.13%
Non-EI product	274	22.81%
No product innovation	433	36.05%
Process-EI	331	27.56%
Non-EI process	197	16.40%
No process innovation	673	56.04%

and where they were located with the following question: 'Which type of collaboration partner has your firm had and where are these geographically located?' Partner type options were suppliers, customers, competitors, universities/technical colleges/research institutes and consultants.

Suppliers, customers and competitors were classified as DUI. Universities/technical colleges/research institutes, and consultants were classified as STI. Locations options were local/regional (regional), other places in Norway (national) or overseas (international), or 'not relevant'. Inter-organizational collaboration for each type, DUI or STI at each geographical dimension was coded as a summation or breadth of collaboration reported. For DUI collaborations this meant a possible value of 0, 1, 2 or 3 (one for each collaboration partner) for each geographical dimension. For STI this meant a possible value of 0, 1 or 2 for each geographical dimension.[5]

Variables for regional and international collaborations are related to our three hypotheses; however, we feel it appropriate to also include variables related to national collaboration. We include variables for national DUI and national STI collaboration since we otherwise cannot be sure that the regional effect, or the international effect for that matter, are genuine carriers. If national collaboration is omitted, we can falsely conclude that regional collaboration has an effect while it is national collaboration that genuinely has an effect. By including national collaboration as a variable, we clarify this issue and illustrate the genuine effects of regional and international collaboration. We include the variable for international DUI inter-organizational collaboration for similar reasons to clarify the genuine effects of our relevant independent variables as expressed in the hypotheses. Table 2 provides descriptive statistics on geography of collaboration for each innovation output.

Table 3 informs about how our control variables are related to each innovation output and hence also descriptive statistics on each of our subsamples of firms for each model.

Control variables

We include a dummy variable to control for enterprises located in the counties of Rogaland, Hordaland and Sogn og Fjordane on the west coast (coded 1, and 0 otherwise). The reason is that the sampling procedure was different for enterprises located in these counties versus the rest of the country. In the three counties representing the west coast of Norway, we sampled 800 enterprises, and in the rest of the country, we sampled 401 enterprises. As there are less enterprises in Western Norway than in the rest of the country, sampling a relatively large share of enterprises in Western Norway and a relatively small share of enterprises in the rest of the country may induce unobserved variation between these two groups of enterprises stemming from different sampling procedures.

Whether a firm is independent was assessed with the following question: 'Is your firm part of a larger corporation?' Those responding 'no' were coded 1 as an independent firm. Those responding 'yes, as a mother company' or 'yes, as a daughter company' were coded as 0. All firms responded to one of the three alternatives. We also control for age measured in number of years since establishment, and firm size measured in number of employees. In the survey, the following questions were also included: 'Has your firm over the last three years developed in any of the following ways?' Responding 'yes' to 'Having had growth in employees' was coded 1, and responding 'no' or not responding at all was coded 0, which we control for under the label 'Growth in employees'. We expect growth in employees, which we also consider as a proxy for overall growth in a firm, to positively affect product- and process-EI in that firms who are assumed to be experiencing growth can direct more resources, at the very least employees to activities outside their normal day-to-day operations. In addition, we include a control for the major owner of the firm being located overseas (Fitjar & Rodríguez-Pose, 2013), coded as a dummy and formulated from the following question: 'Where is the majority owner located?

Table 2. Geography of collaboration for each innovation type.

	Innovation type	Reported ≥ 1 collaboration	Mean	SD	Minimum	Maximum
Regional DUI	Product-EI	329	1.318	1.133	0	3
	Non-EI product	127	1.022	1.126	0	3
	No product innovation	104	0.822	1.142	0	3
	Process-EI	172	1.375	1.141	0	3
	Non-EI process	107	1.173	1.125	0	3
	No process innovation	217	0.893	1.137	0	3
National DUI	Product-EI	265	0.901	0.995	0	3
	Non-EI product	127	0.737	0.936	0	3
	No product innovation	104	0.418	0.832	0	3
	Process-EI	172	0.867	1.006	0	3
	Non-EI process	107	0.909	0.985	0	3
	No process innovation	217	0.538	0.881	0	3
International DUI	Product-EI	207	0.664	0.919	0	3
	Non-EI product	82	0.449	0.789	0	3
	No product innovation	65	0.222	0.595	0	3
	Process-EI	125	0.625	0.937	0	3
	Non-EI process	65	0.497	0.806	0	3
	No process innovation	184	0.360	0.723	0	3
Regional STI	Product-EI	242	0.656	0.748	0	2
	Non-EI product	102	0.489	0.697	0	2
	No product innovation	111	0.337	0.621	0	2
	Process-EI	172	0.710	0.767	0	2
	Non-EI process	83	0.569	0.737	0	2
	No process innovation	200	0.382	0.637	0	2
National STI	Product-EI	152	0.381	0.618	0	2
	Non-product-EI	60	0.259	0.523	0	2
	No product innovation	56	0.166	0.462	0	2
	Process-EI	100	0.387	0.638	0	2
	Non-EI process	60	0.355	0.576	0	2
	No process innovation	108	0.382	0.637	0	2
International STI	Product-EI	66	0.162	0.439	0	2
	Non-EI product	22	0.088	0.308	0	2
	No product innovation	18	0.046	0.231	0	2
	Process-EI	45	0.160	0.428	0	2
	Non-EI process	23	0.127	0.363	0	2
	No process innovation	38	0.068	0.296	0	2

Table 3. Control variables related to each innovation output.

Innovation type	Independent variables	Mean	SD	Minimum	Maximum
Product-EI	Major own int.	0.164	0.489	0	1
	Independent	0.686	0.464	0	1
	Age	18.670	15.798	1	165
	Size-employees	38.482	157.072	5	3098
	Growth	0.605	0.490	0	1
	West Coast	0.686	0.464	0	1
Non-EI product	Major own int.	0.128	0.334	0	1
	Independent	0.726	0.447	0	1
	Age	19.022	19.158	1	172
	Size-employees	30.595	56.018	5	464
	Growth	0.566	0.497	0	1
	West Coast	0.631	0.483	0	1
No product innovation.	Major own int.	0.092	0.290	0	1
	Independent	0.770	0.422	0	1
	Age	21.358	18.400	1	178
	Size-employees	30.607	42.076	5	431
	Growth	0.434	0.496	0	1
	West Coast	0.667	0.472	0	1
Process-EI	Major own int.	0.130	0.337	0	1
	Independent	0.665	0.473	0	1
	Age	18.858	16.485	1	176
	Size-employees	37.804	91.876	5	1321
	Growth	0.595	0.492	0	1
	West Coast	0.619	0.486	0	1
Non-EI process	Major own int.	0.188	0.392	0	1
	Independent	0.695	0.461	0	1
	Age	21.990	22.534	1	178
	Size-employees	31.848	48.912	5	464
	Growth	0.558	0.498	0	1
	West Coast	0.680	0.468	0	1
No process innovation	Major own int.	0.113	0.367	0	1
	Independent	0.764	0.425	0	1
	Age	19.478	16.402	1	165
	Size-employees	32.480	125.243	5	3098
	Growth	0.498	0.500	0	1
	West Coast	0.686	0.464	0	1

Alternatives offered were local/regional (regional), other places in Norway (national) or overseas (international), or do not know. Those who responded ‘overseas’ were coded as 1, while those who indicated one of other three alternatives were coded as 0. This control was included under the premise that firms who had a majority international owner may be more likely to use international links and networks for the collaborations in their owner’s country of location.

RESULTS AND DISCUSSION

In addressing the research question, we fit regression models by using robust logistical regression with cluster (industry) robust standard errors, which correct for potential industry effects in terms of autocorrelation (industries are distinguished by using two-digit NACE codes). Robust logistical regression also corrects for potential heteroscedasticity in the data.[6]

We run a total of four separate models: model 1A compares firms with product-EI (coded 1) with those that have no product innovation at all (coded 0); model 1B compares firms with process-EI (coded 1) with those that have no process innovation at all (coded 0); model 2A compares firms with product-EI (coded 1) with those that have product innovation, but they are not EI (coded 0); and model 2B compares firms with process-EI (coded 1) with those that have process innovation, but they are not EI (coded 0). For each model, we include measures of maximum and average variance inflation factors (VIFs), which indicate that multicollinearity is not a problem in our data.

Model 1A

Hypothesis 1a is not confirmed. Regional DUI inter-organizational collaboration is not positively associated with product-EI when compared with no product innovation. However, Hypothesis 2a is confirmed. Regional STI inter-organizational collaboration is positively associated with product-EI. For example, Table 4, model 1A, reports 32% higher odds of occurrence in product-EI for firms with regional STI inter-organizational collaborations (cf. an odds ratio of 1.323, which we report in brackets).[7] Hypothesis 3a is not confirmed, which is surprising given the relative ease STI knowledge is assumed to diffuse across spatial distance and to the attraction international nodes of excellence would have for innovating firms (Fitjar & Rodríguez-Pose, 2013).

International DUI inter-organizational collaboration is significant with 57% higher odds of occurrence of product-EI. This is surprising given the focus of the literature on the importance of regions for DUI. In a more practical consideration, it is perhaps an indication that DUI partners often lie well outside regional borders, and that mechanisms, especially technological, may allow the transfer of tacit knowledge across geographical borders.

The negative significance of independent firms for product-EI is perhaps not surprising given the assumed lack of resources independent firms have compared with those who are part of a corporate group drawing from shared resources. In addition, the significance of growth in employees is understandable, with the assumption that large firms can allocate more resources to the exploration of activities outside their normal operations, which may include product-EI.

Model 1B

Hypothesis 1b shows $p < 0.1$ significance, and Hypothesis 2b is confirmed with 43% higher odds of occurrence for process-EI. Hypothesis 3b is not confirmed: international STI inter-organizational collaboration is not positively associated with process-EI. Again, the negative significance for our control variable of independent firm is noted. In addition, the negative significance of a firm located on the west coast for process-EI, which may be an indication that firms located on the west coast are not transitioning to process-EI. If one is to consider the nature of industry in this region, which is heavy resource based, transitioning to more environmentally friendly processes may involve considerable capital investment.

Model 2A

Hypothesis 1a is confirmed. Regional DUI inter-organizational collaboration has a positive relationship with product-EI when compared with non-EI product. The odds ratio suggests a 16% higher odds of occurrence. Hypotheses 2a and 3a are rejected. Neither regional STI nor international STI inter-organizational collaboration are positively associated with product-EI. There are no significant effects from any of our control variables.

Model 2B

Hypothesis 1b only shows a $p < 0.1$ level of significance, and both Hypotheses 2b and 3b are rejected. International DUI inter-organizational collaboration is significantly associated

Table 4. Results of logistic regressions.

	EI compared with no innovation (at all)		EI compared with non-EI	
	1A: Product-EI	1B: Process-EI	2A: Product-EI	2B: Process-EI
Inter-organization collaboration				
DUI region	0.131 (0.089)	0.178 (0.095)*	0.149 (0.070)**	0.142 (0.086)*
		[1.195]	[1.161]	[1.153]
STI region	0.281 (0.138)**	0.356 (0.145)**	0.125 (0.118)	0.123 (0.133)
	[1.325]	[1.428]		
STI international	0.300 (0.217)	0.209 (0.212)	0.211 (0.187)	0.090 (0.237)
DUI international	0.451(0.193)**	0.160 (0.111)	0.179 (0.124)	0.228 (0.109)**
	[1.570]			[1.257]
DUI national	0.185(0.108)*	0.049 (0.090)	−0.092 (0.143)	−0.243 (0.091)***
STI national	0.134(0.159)	0.192 (0.140)	0.208 (0.183)	0.080 (0.127)
Control variables				
Majority owner Inter	0.360(0.307)	−0.185(0.223)	0.171 (0.210)	−0.642 (0.299)**
				[0.784]
Independent firm	−0.419 (0.164)**	−0.551 (0.181)***	−0.128 (0.180)	−0.322 (0.290)
	[0.658]	[0.576]		
FirmAge	−0.006 (0.004)	0.000 (0.004)	0.000 (0.004)	−0.009(0.004)**
				[0.992]
FirmSize	0.000 (0.000)	0.000 (0.001)	0.000 (0.001)	0.002 (0.001)
Growth in employees	0.587 (0.142)***	0.249 (0.145)*	0.129 (0.129)	0.102 (0.237)
	[0.587]	[1.283]		
West Coast	0.022 (0.132)	−0.399 (0.133)***	0.224 (0.178)	−0.341 (0.170)**
		[0.671]		[0.711]
Constant	−0.434 (0.228)*	−0.740 (0.229)***	0.061 (0.241)	0.901 (0.478)*
Wald χ^2	156.477***	80.442***	51.472***	49.309***
Log pseudo-likelihood	−568.820	−591.336	−486.682	−336.824
Industries included	54	55	53	50
Maximum/average VIF	1.817/1.317	1.717/1.296	1.671/1.264	1.714/1.292
Observations	927	1004	768	528

Note: Coefficients are given with the robust standard errors adjusted for industry effects in parentheses. Reported are odds ratios below significant regressors in brackets. VIF, variance inflation factor.
*$p < 0.1$; **$p < 0.05$; ***$p < 0.01$.

with process-EI when compared with non-EI process innovation. Given the arguments presented in the hypothesis development about the possible regional restriction of DUI knowledge, this is surprising. A perplexing result is the negative significance of national DUI inter-organizational collaboration ($p < 0.01$). It is a finding contrary to the general assumption that collaboration in general is positively associated with EI. It seems to underline theoretical frameworks such as local buzz and global pipelines (Aarstad et al., 2016; Bathelt et al., 2004), and the general discussion on geographical dimensions where the regional and international geographical dimensions are usually discussed as the relevant distinction. We also note the negative significant effect of having an international majority owner for process-EI as well as the negative significant effect of firm age and being located on the west coast of Norway.

CONCLUSIONS

Discussion of the findings

In this paper, we have studied DUI and STI inter-organizational collaborations as potential carriers for EI. Empirically, we have studied a sample of 1201 Norwegian firms. As to the relevance of the region for inter-organizational collaboration, the findings are mixed. When comparing EI with no innovation, it is difficult to make a definitive statement about the relevance of regional collaboration. Whereas regional STI collaboration is significantly positively associated with both product- and process-EI, the same cannot be said for DUI collaboration. This finding is especially challenging for the argued regional relevance for the diffusion of DUI knowledge. This is underlined by the significance of international DUI collaboration in model 1A. Additionally it is challenging to the notion that STI collaboration can overcome geographical borders. Despite codified STI knowledge moving frictionless across geographical borders, and the proposition that firms will seek out international nodes of excellence, firms are choosing local sources.

When comparing EI with non-EI, these mixed results persist. For product-EI it is regional DUI inter-organizational collaboration that is significant. This is not surprising and makes sense for firms to build on their existing collaborations at the regional level. For process-EI, it is international DUI inter-organizational collaboration that is significant. Here we add our voice to the growing literature that challenges the assumption that DUI knowledge cannot transcend regional boundaries (Fitjar & Rodríguez-Pose, 2013; Parrilli & Alcalde Heras, 2016). Why the geographical dimension for inter-organizational collaboration differs for product- and process-EI is difficult to interpret, and we hesitate to offer definitive conclusions about the possible differences between these two typologies of EI. There have been suggestions that where knowledge originates, regionally or internationally, differs in its effect on different types of innovation, incremental or radical (Asheim et al., 2019), which may have some relevance here.

The findings that DUI inter-organizational collaboration is positively associated with both product- and process-EI (models 2A and 2B) is interesting given that neither regional nor international STI is positively associated with either. This may indicate that the historic dependence of firms in this context on DUI collaborations has led to a sort of familiarity. Not only in engaging in this type of collaboration, but also using the type of knowledge exchanged in these types of interactions for EI. There are suggestions that DUI knowledge when applied to innovation usually results in incremental improvements (Alhusen & Bennat, 2021), rather than radical innovations which require knowledge, usually STI that come from distant places (Asheim et al., 2019). This could indicate that Norwegian firms are engaging only in incremental EI, making small environmental improvements in both product and processes.

Overall, our findings show that inter-organizational collaboration patterns for EI differ from non-EI with regard to geography, which speaks to the fundamental difference between EI and non-EI. As to the geography of inter-organizational collaboration, the proposition that this is probably context specific (Doloreux et al., 2020; Parrilli & Alcalde Heras, 2016) seems to be supported. As to the relevance of regional versus international inter-organizational collaboration, we do not contradict those who suggest the importance of local networks, and resources for learning and knowledge dissemination for EI (Arranz et al., 2019; Cainelli et al., 2012; Horbach, 2014). We suggest, as have others have Galliano et al., 2019; Ocampo-Corrales et al., 2021), that other geographical dimensions, namely those at a distance, are also relevant for

EI. Finally, we find that the reliance of firms in positive innovation paradox regions such as Norway on DUI collaborations seems to be persistent even in regard to EI.

Policy implications

First, we recommend that policy efforts to facilitate the interaction between industry and knowledge institutions not only continue but also intensify. Our findings reveal that an opportunity for firms to achieve EI remains underutilized, namely STI inter-organizational collaboration, at both the regional and international levels. Policy to facilitate interactions between industry and DUI partners should be encouraged, and these findings show positive results for EI.

Limitations and future research

The inclusion of relevant exogenous variables and the use of a longitudinal research design could address several limitations of our study. Although the inclusion of variables such as firm size, firm age and geographical location provided by register data goes some ways to limiting potential endogeneity problems that arise by relying solely on our survey, these issues cannot be entirely discounted. Future research should include appropriate instrumental variables provided by register data or other sources. The use of longitudinal data could also provide insights into EI's persistency over time, which is not addressed in this study. Related to this is a more dynamic (Balland, 2012) or evolutionary approach used to understand the required knowledge for EI as well as EI itself (Galliano et al., 2019).

An additional limitation is that this study did not address the role collaboration may play in organizational routines and business practices concerning EI. Our data set did not allow us to explore such relationships. Much has also been said about refining product- and process-EI measures to classify them as incremental, radical, end-of-pipe or cleaner technologies to fully understand what specific types of EI are being influenced by which collaboration partners. We believe there is a relevant relationship between the location of collaboration partners and these specific types of EI and urge future research to explore this issue.

Given the persistence of relevance for DUI inter-organizational collaboration, this research raises questions about how firms may combine these external knowledge inputs with internal knowledge across their firm borders, a complex question that has been emphasized by recent research (Marzucchi & Montresor, 2017; Triguero et al., 2018). Haus-Reve et al. (2019) suggested that internal absorptive capacity may play a role in which type of external inter-organizational collaboration a firm may choose and may also affect the geography of that collaboration.

Lastly, given that our analyses were based on a sample of firms in Norway and the discussed peculiarities of Norwegian firms, this may potentially limit the validity of our results for other jurisdictions. However, our results may have more relevant implications for the so called 'positive innovation paradox' regions.

DISCLOSURE STATEMENT

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NOTES

[1] This situation for innovation in Norway, Denmark, and specifically regions such as the Italian industrial districts and the Basque Country has often been referred to as a 'positive innovation paradox'(Asheim & Gertler, 2005; Asheim & Parrilli, 2012; Edquist, 2005). The literature on innovation systems and the so-called 'innovation paradox' is where the debate on STI and DUI modes originates (Parrilli & Alcalde Heras, 2016).

[2] A third knowledge type is often discussed, the so-called symbolic mode, which seems more relevant for creative industries (Martin & Rypestøl, 2018). Symbolic knowledge entails those activities where innovation consists of the creation of meaning, images and symbols with aesthetic and cultural attributes (Ocampo-Corrales et al., 2021).

[3] This paper does not examine all dimensions of STI and DUI innovation: rather, in keeping with Fitjar and Rodríguez-Pose (2013) and others (Doloreux et al., 2020; Marzucchi & Montresor, 2017; Parrilli & Alcalde Heras, 2016), it limits the analysis to some specific dimensions.

[4] Boschma (2005) distinguishes between five proximity dimensions, of which geographical is only one, namely: cognitive, organizational, institutional and social proximity. These dimensions can overlap, but also substitute one another (Hansen, 2015; Menzel, 2015). Hansen (2015) specifically found that social and institutional proximity overlap with geography, but organizational and cognitive can act as substitutes.

[5] In the survey, universities/technical colleges/research institutes was given as a single option. This meant that at every geographical dimension, it was only possible to have a maximum value of 2 for STI, rather than the 3 for DUI collaboration.

[6] The use of a logit model is consistent with previous studies of innovation modes (Fitjar & Rodríguez-Pose, 2013; Haus-Reve et al., 2019; Marzucchi & Montresor, 2017).

[7] This can be interpreted as having one more regional STI inter-organizational partner results in 32% higher odds of occurrence for product-EI (see Szumilas, 2010; and Aarstad et al., 2016, for an interpretation of odds ratio).

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Does combining analytical and synthetic knowledge benefit eco-innovation? Evidence from Norway.

Abstract

Analytical or synthetic knowledge is widely considered beneficial for eco-innovation (EI). For a firm, analytical and synthetic knowledge can be acquired externally through collaboration with various partners or generated internally through R&D and other internal firm activities. However, evidence supporting the assumption that both forms of knowledge are complementary and that 'doing more of all' will benefit EI is unclear. We found that external analytical and synthetic knowledge and internal analytical and synthetic knowledge all positively affect EI, with internal analytical being the most prominent. However, combining analytical and synthetic knowledge may not be beneficial for EI. The interaction between analytical and external synthetic knowledge is generally substitutive. We found a particularly significant substitutive effect between internal analytical and internal synthetic knowledge, as well as between internal analytical and external synthetic knowledge. In short, we found little evidence of complementarity between analytical and synthetic knowledge, regardless of where it is acquired from. These findings advise caution to firm managers and policymakers who are considering strategies to combine different forms of knowledge from different sources to successfully achieve EI goals.

Keywords:
Eco-innovation. Knowledge. Analytical. Synthetic. Complementary. Innovation modes.

1. Introduction

The detrimental impact that industries have had on the environment, such as pollution from production and consumption, has been a global concern for many years. This has motivated researchers to study ways in which firms can reduce this impact through innovation. Although we largely understand what drives innovation overall, not all innovation is necessarily desirable or sustainable for the environment. With this understanding, a distinct branch of innovation studies has focused on what drives sustainable green innovation, which is popularly referred to as eco-innovation (EI). Formally, Kemp and Pearson (2008, p. 7) define EI as:

> The production, assimilation or exploitation of a product, production process, service or management or business method that is novel to the organisation (developing or adopting it) and which results, throughout its life cycle, in a reduction of environmental risk, pollution and other negative impacts of resources use (including energy use) compared to relevant alternatives.[1]

Literature on the driving factors of EI has flourished over the last few decades. More recently, the focus has shifted from considering the integration of regulatory and legislative drivers with other non-institutional drivers towards a more nuanced understanding of how a firm's resources and capabilities may impact EI (Ghisetti et al., 2015; Marzucchi & Montresor, 2017). One of the more prominent resources of a firm is its knowledge. Research has firmly established that knowledge is an important requirement for EI. However, studies

[1] This definition of EI is consistent with many others (see Díaz-García et al. (2015) for a review). The issue of whether or not EI is the intention of the innovation, or if it also includes innovation that results in the reduction of environmental impact has been widely discussed in EI literature. The consensus is that it can be measured using either the intention, or as the result of innovation (Del Río et al., 2016; Díaz-García et al., 2015; Horbach et al., 2012).

on how different forms of knowledge are effectively combined for successful EI are only now emerging.

This research can be framed by addressing the tension between two innovation modes, as described by Jensen et al. (2007). The first is the science, technology, and innovation (STI) mode, which is based on the use of codified or analytical scientific and technical knowledge. This is typically generated through internal research and development (R&D) or external collaborations with knowledge institutions, such as universities and research laboratories (Parrilli & Radicic, 2021). The second innovation mode is the doing, using, and interacting (DUI) mode, which is based on the exchange of mostly tacit and synthetic knowledge (Alhusen & Bennat, 2020). Such exchanges of DUI knowledge occur internally through various interactive activities (Alhusen et al., 2021) and externally through collaboration with partners, such as customers or suppliers (Jensen et al., 2007; Marzucchi & Montresor, 2017).

A key proposition by Jensen et al. (2007) is that, although firms exploit DUI and STI at different intensities, combining both modes yields the best results for innovation. An effective way to gauge the intensity by which firms practice these modes is by measuring knowledge flow (Alhusen et al., 2021). The main focus of this paper, therefore, is to test the proposition by Jensen et al. (2007) about the complementarity between the analytical and synthetic knowledge that innovation modes are based on and its effect on EI. Our research question is as follows: Are firms that combine analytical and synthetic knowledge more eco-innovative than firms that do not?

Since Jensen et al. (2007), general innovation research has promoted this optimal approach of combining both knowledge forms for successful innovation. However, more recent empirical evidence suggests that they may actually substitute for each other, and their combination does not benefit innovation. Marzucchi and Montresor (2017) first addressed this tension in the context of EI. Despite their paper being quite central in the EI literature, few, if any, followed this line of research despite the limitations highlighted in the paper.

We follow this line of literature on innovation modes (Fitjar & Rodríguez-Pose, 2013; Haus-Reve et al., 2019; Parrilli & Alcalde Heras, 2016) and innovation modes in EI in particular (Marzucchi & Montresor, 2017). We first examine effects on EI of analytical and synthetic knowledge generated through either external collaborations or internal firm activity. Second, we examine the complementary or substitutive interaction between analytical and synthetic knowledge and its likelihood of generating EI. We utilize an unbalanced panel dataset of 12,707 firm observations constructed from five waves of the community innovation survey (CIS) which was carried out in Norway covering the years 2008 to 2016.

This paper contributes to the literature in several ways. First, it further extends the discussion on the complementarity of analytical and synthetic knowledge to EI. This core proposition in innovation literature claims that combining different forms of knowledge is beneficial for innovation. Though some aspects of this discussion have previously been applied to EI (Marzucchi & Montresor, 2017), our study contributes with a more complete assessment of the complementarity of analytical and synthetic knowledge. We go beyond the investigation of knowledge complementarity across firm borders to also address knowledge complementarity internally within the firm, as well as externally outside firm borders which has so far been neglected. We utilize a longer panel dataset to address some of the limitations identified by earlier studies. In addition, we apply a marginal effect analysis which goes beyond simply assessing the sign, magnitude, or significance of the interaction term coefficient. This approach is applied to address contradictory results that emerge in the issue of complementarity (Acebo et al., 2021; Haus-Reve et al., 2019). Second, using data from the Norwegian CIS contributes to more precise econometric results. Participation is mandatory, which practically eliminates the risk of non-response bias. Third, we contribute to the debate of whether innovation modes can be verified and systematized across industries and geographic contexts and their effectiveness in generating different innovation types (Alhusen & Bennat, 2020; Parrilli & Radicic, 2021), such as EI (Marzucchi & Montresor, 2017). Whereas previous studies have focussed on singular industries, by utilizing multi-level regression analysis which accounts for industry effects, the results from this study argue that substitution rather than complementarity of different forms of knowledge is indeed consistent regardless of specific industry characteristics.

This paper is organized into five sections. Section 1 is the introduction. Section 2 discusses theory and research on analytical and synthetic knowledge and its relevance to EI. Prior literature arguing for complementary or substitutive interactions between both forms of knowledge for EI is also discussed, and hypotheses are presented. In Section 3, we present our case and data description and outline the method of analysis we employ. In Section 4, we discuss the results of our empirical analysis. In the final section, Section 5, we present our conclusions, recommendations, and suggestions for future research.

2. Theoretical framework and hypotheses

Many studies on EI have highlighted the fundamental differences between EI and general innovation (De Marchi, 2012; Horbach et al., 2013). There are several elements that give rise to these differences (Arranz et al., 2019). For example, EI leads to a ‘win-win’ outcome due to economic and sustainable development compatibility. Further, it originates from environmental problems that require urgent solutions. There is also a lack of incentive for firms to produce EI, as others benefit from it without contributing to the often-high development costs involved. It is also relatively easy for others to copy EI from first movers, which is referred to as the ‘double externality problem’ (De Marchi, 2012). Compared to non-EI, EI is also often motivated by a regulatory push/pull effect. These differences lead to higher degrees of novelty and uncertainty that often require EI firms to go beyond their industrial knowledge base (Cainelli et al., 2015; De Marchi, 2012). Furthermore, the high relevance of collaboration for EI is often attributed to the greater technological diversity and complexity that EI demonstrates at a systemic level (Del Río et al., 2015; Kobarg et al., 2020). Collaboration allows EI firms to access new technology that lies outside their traditional technological trajectory (Ben Arfi et al., 2018; Cainelli et al., 2015). This has encouraged research specifically focussed on the knowledge firms required to generate EI and how various forms of knowledge are combined. The underlying assumption is that the requirements for EI are different from other kinds of innovation (Triguero et al., 2018). Research on the knowledge requirements for EI, such as the present study, is often grounded in the resource-based view (RBV) (Barney, 1991). This approach argues that a firm's innovation performance is largely determined by its valuable, inimitable, and non-substitutable resources or capabilities. Although the principal focus of RBV was initially on the internal factors of a firm, literature has also recognized the importance of external factors. A firm can obtain sustainable competitive advantage based on the way these internal and external resources and capabilities are utilized and configured.

2.1. The role of external analytical and synthetic knowledge on EI

Innovation collaboration literature has already established that external partners provide different forms of knowledge (Alhusen & Bennat, 2020). Similar to earlier literature on innovation modes (Fitjar & Rodríguez-Pose, 2013; Haus-Reve et al., 2019; Vai, 2021), we distinguish between the two sorts of collaborative partnerships: STI, analytical knowledge-generating collaborations, and DUI, synthetic knowledge-generating collaborations.

It is well established that external analytical knowledge for a firm is developed at universities and research institutions (Alhusen et al., 2021; Johnson et al., 2002). Given EI's complexity and technological requirements, it is assumed that analytical knowledge is highly relevant for EI. Collaborations with scientific partners allow greater access to technological competencies, advanced R&D, better infrastructure, and increased human capital to solve EI’s technological complexities (Acebo et al., 2021; Kobarg et al., 2020). Several empirical works have demonstrated the importance of universities as an analytical knowledge source (Cainelli et al., 2012; Galliano et al., 2019; Triguero et al., 2013). Additionally, laboratories and research institutions have also proved to be important sources of analytical knowledge for EI (Marzucchi & Montresor, 2017; Mothe et al., 2018).

External synthetic knowledge is the by-product of informal ‘know-how’ and ‘know-who’ interactions with partners such as customers, suppliers, and competitors where the learning processes are based around ‘using’ and ‘doing’ (Alhusen et al., 2021; Jensen et al., 2007). Several studies suggest that synthetic knowledge is even more important than analytical knowledge for EI (Acebo et al., 2021; Kobarg et al., 2020; Marzucchi & Montresor, 2017), because synthetic knowledge generated by collaborating with customers is required to match customer expectations and ease their adaptation process to EI (Acebo et al., 2021; De Marchi & Grandinetti, 2013; Kobarg et al., 2020). Synthetic knowledge obtained from collaborations with suppliers can further assist with the supply chain issues of obtaining new materials required for EI (Marzucchi & Montresor, 2017). Such collaborations can also lower transaction costs by developing synergies between firms and suppliers, thus facilitating successful EI (Cainelli et al., 2012). Furthermore, synthetic knowledge is exchanged when firms interact with other firms within the same organization or concern (Alhusen & Bennat, 2020). Despite the possibility of adversarial relationships, collaborations with competitors can provide synthetic knowledge to solve common problems (Marzucchi & Montresor, 2017; Vai, 2021). Furthermore, collaboration with consultants is essential for the flow and exchange of synthetic knowledge (Alhusen et al., 2021).

Literature supports the requirement for external analytical and synthetic knowledge for EI (Kobarg et al., 2020; Marzucchi & Montresor, 2017; Vai, 2021). Studies highlighting the importance for EI of different forms of knowledge acquired through collaboration led us to the formulation of our first set of hypotheses:

H1: Firms that collaborate with analytical knowledge partners are more likely to eco-innovate than firms that do not collaborate with analytical knowledge partners.

H2: Firms that collaborate with synthetic knowledge partners are more likely to eco-innovate than firms that do not collaborate with synthetic knowledge partners.

2.2. The role of internal analytical and synthetic knowledge for EI

Analytical knowledge can also be generated internally. Scientific, codified, or analytical knowledge is widely accepted in literature as being a result of investment in internal R&D (Fitjar & Rodríguez-Pose, 2013; Jensen et al., 2007; Parrilli & Radicic, 2021). The importance of this analytical knowledge for EI has been empirically proven (Marzucchi & Montresor, 2017; Mothe et al., 2018). For firms that possess the resources, internal R&D meets the higher knowledge demands of EI. Since it is often at an early stage of development, EI requires more basic research at the technological frontier and often incorporates technologies that are new to the firm (Consoli et al., 2016; Galliano et al., 2019). This is especially relevant for high-tech industries like renewable energy (Ocampo-Corrales et al., 2020).

Synthetic knowledge-generating mechanisms are often difficult to measure due to their tacit nature. However, certain measurable proxies have been suggested in the literature. Internal synthetic knowledge can be generated through employee education, employee interactions, or when employees use new technology (Alhusen et al., 2021). The purchase and use of machinery, equipment, and software can also generate synthetic knowledge for EI (Demirel & Kesidou, 2011; Horbach et al., 2012). Additionally, investment in other internal firm activities, such as the enhancement of knowledge of human capital (Cainelli et al., 2015; Cainelli et al., 2012), and downstream activities such as marketing (Rennings, 2000), have proven to be important for EI. Given its systemic and multidimensional nature, EI requires both internal analytical and synthetic knowledge. Therefore, we hypothesize that:

H3: Firms that invest in internal analytical knowledge sources through R&D are more likely to eco-innovate than firms that do not.

H4: Firms that invest in internal synthetic knowledge sources are more likely to eco-innovate than firms that do not.

2.3. Complementarity of analytical and synthetic knowledge

We now turn to the main focus of our study, which is the interaction between different forms of knowledge. Literature on organizational learning promotes the effectiveness of ambidexterity, or balancing exploration and exploitation activities (O'Reilly & Tushman, 2008; Smith & Tushman, 2005). It argues that innovation is the result of firms enhancing existing, firm-specific routines (exploitation) by combining them with various knowledge resources (exploration). Reliance on current competencies is considered to inhibit innovation as it systematically overlooks better solutions provided by novel combinations of heterogeneous forms of knowledge (Levinthal & March, 1993). A variety of knowledge elements enhance the potential combinations in the innovation process (Laursen, 2012). Reliance solely on one form of knowledge leads to rigidity and lack of creativity, which hinder a firm's ability to develop and commercialize innovative technologies (Leonard-Barton, 1992). This argument is very similar to claims in innovation mode literature about the effectiveness of combining synthetic and analytical knowledge to facilitate the emergence of especially radical innovation (see Alhusen and Bennat (2020) for a review).

EI literature, like innovation mode literature, has promoted complementarity between analytical and synthetic knowledge (Sanni & Verdolini, 2022). The combination seems particularly relevant for EI as firms must often go beyond established knowledge bases to solve the innovative complexities that characterize EI (Del Río et al., 2015; Horbach, 2008). This may require radical, path-breaking changes in a firm's production processes (Kiefer et al., 2017). A few EI studies have tested the relationship between different external collaboration partners. Acebo et al. (2021) reported a partial complementary effect in a combination of supplier, customer, and scientific collaboration partners. Kobarg et al. (2020) also found the same effect in the same three-way combination. This complementary relationship has also been observed between internal R&D and supply chain partners for EI (Albort-Morant et al., 2018). Although this research focuses primarily on individual collaboration partners, it suggests a complementary relationship between analytical and synthetic knowledge for EI, which leads us to our fifth hypotheses:

H5: (a) The combination of external analytical knowledge and external synthetic knowledge positively affects EI.

(b) The combination of external analytical knowledge and internal synthetic knowledge positively affects EI.

(c) The combination of external synthetic knowledge and internal analytical knowledge positively affects EI.

(d) The combination of internal analytical knowledge and internal synthetic knowledge positively affects EI.

2.4. Substitutive interactions between analytical and synthetic knowledge.

Absorptive capacity (AC) attributes a firm's innovation performance to its capacity to absorb and combine new knowledge with its existing learning capacity and knowledge base

(Cohen & Levinthal, 1990). This capacity has often been measured as internal R&D investments, but AC literature also encompasses other measurements, such as organizational routines and the processes by which a firm identifies, processes, and exploits knowledge (Zahra & George, 2000). These routines also include personnel training and innovation cooperation (Murovec & Prodan, 2009). However, Cohen and Levinthal (1990) suggest that AC is a function of prior, related knowledge and requires a degree of overlap between the firm's existing knowledge base and new knowledge. Organizational structure and cognitive distance are some of the barriers that can hinder a firm's ability to combine knowledge. This is especially true when it new knowledge fundamentally differs from the firm's existing knowledge base (Alhusen & Bennat, 2020; Haus-Reve et al., 2019). Such difficulties in effectively combining different forms of knowledge can be exacerbated by employee resistance and limitations in managerial attention (Delgado-Verde et al., 2021). The transaction cost associated with acquiring, interpreting, and combining an unfamiliar form of knowledge is often high.

Despite the widespread acceptance of complementarity between analytical and synthetic knowledge in innovation mode literature, there have recently been some contradictory findings. Haus-Reve et al. (2019) found a substitutive relationship between external analytical and external synthetic knowledge and noted that despite the enthusiasm of innovation modes literature, the central theme of complementarity has rarely, if ever, been empirically tested. Further, other studies have suggested that despite any notions of combining different forms of knowledge or innovation modes, firms often lean on either one or the other (Asheim et al., 2019; Hansen, 2015). Given its complexity, the knowledge required may be equally complex for EI, which makes combining different forms of knowledge even more challenging. In comparing non-EI and EI for manufacturing firms in Spain, Marzucchi and Montresor (2017) discovered that all the interactions between analytical and synthetic knowledge across firm borders had negative effects on EI. Similarly, Mothe et al. (2018) found that interactions between internal R&D and some sources of internal synthetic knowledge, such as purchasing machinery, negatively affected EI. Given that existence of evidence that points in the opposite direction of common views of complementarity, we propose our final hypotheses:

H6: (a) The combination of external analytical knowledge and external synthetic knowledge negatively affects EI.

(b) The combination of external analytical knowledge and internal synthetic knowledge negatively affects EI.

(c) The combination of external synthetic knowledge and internal analytical knowledge negatively affects EI.

(d) The combination of internal analytical knowledge and internal synthetic knowledge negatively affects EI.

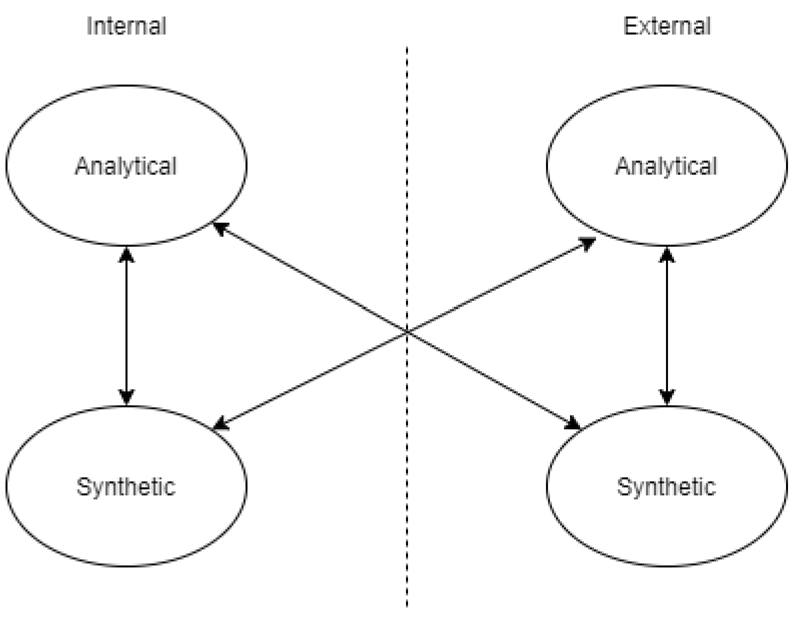

Figure 1: Research model. Each arrow indicates an interaction that will be tested.

For added clarity, Figure 1 illustrates our research approach regarding the interactions we will be testing.[2] Testing interaction effects can reveal the potential *genuine* influence of analytical and synthetic knowledge (Aarstad et al., 2016; Acebo et al., 2021; Haus-Reve et al., 2019). For example, if analytical and synthetic knowledge is positively associated with EI, and we find a positive interaction effect between the two, we can conclude that their combination has a multiplicative or complementary effect. If analytical and synthetic knowledge is positively associated with EI, but we find a negative interaction effect, we can conclude that the two forms of knowledge are substitutes for each other and combining them does not benefit EI. Finally, if analytical and synthetic knowledge have a positive association with EI but no interaction effect, we can conclude that the two have an additive effect.

3. Method, context, and data.

To answer our research question, we constructed an unbalanced panel dataset that includes five biannual survey waves of the Norwegian CIS from 2008 to 2016. Each wave includes data from Norwegian firms with at least 50 employees. For firms that have between five and 49 employees, random strata are included in the survey. Participation in the survey is mandatory and a fine is imposed for non-respondents, which largely eliminates the risk of non-response bias. Since 2006, all firms were required to fill out the entire CIS regardless of whether they engaged in innovation or not. Respondents had to report their external collaborations and investments in internal firm activities. Selection bias from only allowing

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[2] We maintain the dimensions, or external and internal, for the sake of clarity on the exact source of knowledge and across which dimension the tested interaction is occurring. As for the role these dimensions may play in the issue of complementarity, (i.e., is it easier to combine different knowledge forms internally than across firm borders), we advance no expectations and leave the empirical analysis to reveal any particularities in the interaction across dimensions.

innovative firms to fill out the relevant sections of the CIS has been identified as a recurring problem in other countries (Marzucchi & Montresor, 2017).

3.1. Dependent variable

Our dependent variable was constructed from the section of the CIS where respondents were asked to indicate their innovation goals.[3] To measure EI, we followed previous literature (Arranz et al., 2020; Arranz et al., 2019; De Marchi, 2012; Sánchez-Sellero & Bataineh, 2021). We utilized three firm goals that may result in a reduction of environmental risk, pollution and other negative impacts of resource use (including energy) use compared to relevant alternatives.[4] These goals were as follows: (1) Reduction in material and energy cost per produced unit for the development of new products or processes; (2) Reduction in environmental effects for the development of new products and processes; (3) Improvement of employees' health and safety for the development of new products or processes. Respondents were asked to rate the importance of these goals (very important = 3; quite important = 2; little important = 1; not relevant = 0).[5] Responses indicating a 0 or 1 for any of the goals were coded 0, while responses indicating 2 or 3 were coded 1. We then aggregated these values and assigned a 0 to firms with 0 across all three activities and a 1 to the others. We constructed our binary dependent variable following the literature (e.g., Acebo et al., 2021; Marzucchi & Montresor, 2017).

[3] The methods and types of questions used in the CIS are described in the Organization for Economic Co-operation and Developments (OECD) Oslo Manual (OECD & Communities, 2005; OECD et al., 1997).
[4] As per the definition of EI given in the introduction.
[5] The three items are correlated (Cronbach's alpha = .900) and have been part of the standard CIS in Norway since 2010.

3.2. Independent variables

All independent variables were lagged at t_{-2}, as the CIS in Norway is carried out every two years. This restricts our sample to those firms that participated in at least two consecutive surveys.

3.2.1. External knowledge sources

Our external knowledge variables were constructed from the section of the CIS where respondents were asked to indicate their collaboration partners. The external analytical *(Ext_Analytical)* variable was constructed from collaborations with commercial laboratories, R&D firms, universities, technical colleges, and public or private research institutes. Respondents were asked to indicate where these partners were located (locally in Norway, other places in Norway, in the Nordics, other places in Europe, in the USA, in China or India, or in other countries). Summing the responses resulted in a scale of 0 to 21. The external synthetic *(Ext_Synthetic)* variable was constructed using collaborations with other firms in the same concern, suppliers, clients, customers, competitors, and consultants. Respondents were asked to indicate where these partners were located (same as above), and summing the responses resulted in a scale of 0 to 35. Both Ext_Analytical and Ext_Synthetic were standardized by subtracting the mean from each score and dividing it by the standard deviation. The construction of these variables is consistent with previous literature on EI (Marzucchi & Montresor, 2017; Triguero et al., 2018) and aims to capture the breadth of collaboration for each individual firm (Laursen & Salter, 2006).

3.2.2. Internal knowledge sources

To create our internal analytical knowledge (*Int_Analytical)* variable, we summed how much a firm spent on internal R&D and purchasing external R&D services (Marzucchi & Montresor, 2017). To create our internal synthetic *(Int_Synthetic)* variable, we summed how much a firm spent on (1) equipment or software specifically for the development of new products and/or processes, (2) external knowledge to develop new products and/or processes, (3) improving the competence of employees directly related to the development and introduction of new or improved products and/or processes, (4) activities related to the introduction of innovations to the market, (5) design activities related to innovation, and (6) other activities to implement new products and/or processes. The internal synthetic variable was constructed in line with Marzucchi and Montresor (2017) and Triguero et al. (2018). *Int_Analytical* and *Int_ Synthetic* were measured by 1000 NOK divided by the number of employees each year. As firm spending is nominal for each year, we used Statistics Norway's consumer price index to model them to 2016 prices, adding a constant of one, before carrying out a natural logarithmic transformation to avoid dropping any zeros. These values were then mean-centred to further reduce multicollinearity issues when modelling interactions (Cronbach, 1987).

3.2.3. Controls

We control for *firm size*, measured in the logged number of employees, as larger firms have more extensive resources, routines, and capabilities that may benefit EI (Del Río et al., 2016). We also control for firms whose most important market is international. *Market_Int* is a binary variable with a value of 1 if a firm's most important market is international and 0 if its most important market is within Norway. Firms operating in international markets are observed to be more eco-innovative, because they are exposed to international competition and environmental regulations that are more stringent than domestic ones (e.g., Haus-Reve et al., 2019; Marzucchi & Montresor, 2017). We also control for particular regions whose characteristics may influence a firm's EI behaviour (Acebo et al., 2021). We do this with a binary variable of *West Coast.* It has a value of 1 if a firm is located on the west coast of Norway and 0 if it is located in another region of the country. The west coast of Norway is largely dependent on the oil and gas industry. Given the industry's environmental impact, we expect firms located in that region to be more eco-innovative. We also control for industry effects, utilizing a two-digit NACE code, when modelling the regressions. We elaborate upon this below. We also include year dummies in the analysis. Table 1 provides descriptive statistics for our dependent variable, our independent variables, and our control variables.

Table 1 Descriptive statistics

Variable	Mean	N	SD	Min	Max
Dependent					
Eco Innovation	.290	31,502	.453	0	1
Independent					
Ext_Analytical†	.280	31,502	1.155	0	21
Ext_Synthetic†	.637	31,502	2.071	0	35
Int_Analytical*	79.333	31,502	342.224	0	16409.47
Ext_Analytical*	37.402	31,502	824.614	0	119454
Controls					
Firm size*	97.266	31,052	402.769	5	19825
Market_Int	.130	31,052	.337	0	1
West coast	.212	31,052	.408	0	1

*Before log transformation. †Before standardization.

3.3. Modelling

We carry out multi-level mixed-effects random intercept logistics regression for all models (for more information about mixed-effects random intercept regressions, see e.g., Raudenbush & Bryk, 2002; Snijders, 2011). Multi-level modelling has been previously applied to EI study (e.g.Horbach, 2014). In all our models, firm-year observations are nested in firms, and firms are nested in industries. Yearly observations for firms are estimated as a lower-level unit, while the industry is estimated as a higher-level unit. Model 1 includes all our independent variables and Model 2 includes interaction effects between our independent variables. In addition, Model 3 includes only significant interactions from Model 2 to test the robustness of our results.

4. Results and discussion

Table 2 reports the results of our regression analysis.[6] The maximum and average variance inflation factors (VIFs) reported in the table are well within acceptable ranges and do not indicate multicollinearity (cf. O'Brien, 2007).

4.1 Results of Model 1: Main effects

Table 2 shows the results for Model 1 when modelling our main independent variables. We find external analytical knowledge significant at 1.0%, external synthetic knowledge significant at 5.0%, and internal analytical and internal synthetic knowledge both significant at 0.1%. Therefore, hypotheses H1, H2, H3, and H4 are all confirmed. Our findings support previous EI studies that posit that knowledge, regardless of form, is required to solve the complex challenge of EI.

[6] We carried out additional unreported modelling using an ordinal EI dependent variable with no substantial differences in results.

Table 2 Multi-level mixed effects random intercept logistic panel regressions with an independent binary variable of EI at t_0

Variables	**Model 1** *(main effects)*	**Model 2** *(with interactions)*	**Model 3** *(significant interactions)*
FIXED EFFECTS			
Independent variables			
Ext_Analytical. at t_{-2}	.0932 (.0312) **	.1222 (.0393) **	.1101 (.0309) ***
Ext_Synthetic. at t_{-2}	.0747 (.0295) *	.1392 (.0413) ***	.1421 (.0411) ***
Int_Analytical. at t_{-2}	.2128 (.0138) ***	.2200 (.0139) ***	.2219 (.0136) ***
Int_Synthetic. at t_{-2}	.0771 (.0167) ***	.1404 (.0120) ***	.1397 (.0200) ***
Interactions			
Ext_ Analytical. at t_{-2}* Ext_Synthetic. at t_{-2}		-.0002 (.0077)	
Ext_ Analytical. at t_{-2}* Int_Synthetic. at t_{-2}		-.0092 (.0107)	
Ext_Synthetic. at t_{-2} * Int_Analytical. at t_{-2}		-.0218 (.0102) *	-.0232 (.0098) *
Int_Analytical. at t_{-2}* Int_Synthetic. at t_{-2}		-.0324 (.0060) ***	-.0338 (.0057) ***
Controls			
Firm size	.2234 (.0232) ***	.2017 (.0229) ***	.2020 (.0228) ***
Market_Int	.2758 (.0741) ***	.2859 (.0726) ***	.2866 (.0726) ***
West coast	.1815 (.0649) *	.1754 (.0634) **	.1762 (.0634) **
Year dummies included	Yes	Yes	Yes
Constant	-1.2155 (.1462) ***	-1.0463 (.1449) ***	-1.0473 (.1449) ***
RANDOM EFFECTS			
Firm effect	.9536 (.1056)	.8320 (.1003)	.8321 (.1004)
Industry effect	.5905 (.1242)	.5635 (.1186)	.5633 (.1185)
Wald $\chi2$	1070.70 ***	1090.37 ***	1090.00 ***
Log likelihood	-7188.45	-7164.17	-7164.55
Likelihood ratio (LR) $\chi2$	1017.29 ***	1000.67 ***	1001.57 ***
Maximum/average VIF	2.27/1.52	4.69/2.23	4.65/2.04
Number of firms	6,002	6,002	6,002
Min./avg./max. obs.p.ent	1/2.1/4	1/2.1/4	1/2.1/4
Number of industries	66	66	66
Min./avg./max.ent.obs.p.ind.	1/192.5/647	1/192.5/647	1/192.5/647
Number of observations	12,707	12,707	12,707

We report standard errors in parentheses. For fixed effects, we report conservative two-tailed tests of significance. * $p < .05$; ** $p < .01$; *** $p< .001$.

Our results also demonstrate that while both analytical and synthetic knowledge from external and internal sources are important to EI, their importance differs. Internal analytical knowledge is more prominent and has a greater effect on EI. This mirrors the findings of some (e.g. Ocampo-Corrales et al., 2020) and contradicts others (e.g. Marzucchi & Montresor, 2017) who found that external synthetic knowledge had a more prominent role. The prominence of a particular form of knowledge in those studies seemed to be dictated by industry characteristics. High-technology industries were seen to be more dependent on analytical knowledge than, for example, manufacturing or low-technology

food industries. Given that we control for industry effects, our findings can be seen as generalized across all industries.

The results for our control variables are as expected and have significant positive effects on EI.

4.2 Results of Models 2 and 3: With interactions

Table 2 also presents the results for Model 2 when interactions are included. While a negative interaction prevails across all interaction terms, only the interactions between internal analytical and external synthetic and between internal analytical and internal synthetic are significant. Therefore, only hypotheses H6(c) and H6(d) are confirmed. The combination of internal analytical and external synthetic knowledge and the combination of internal analytical and internal synthetic knowledge are seen to have negative effects on EI. Table 2 also reports Model 3, when modelling is carried out only including our significant interactions, and it did not show any great variation in our results. This indicates that our results are robust. Figure 2 summarizes the results of the interactions from Model 3.

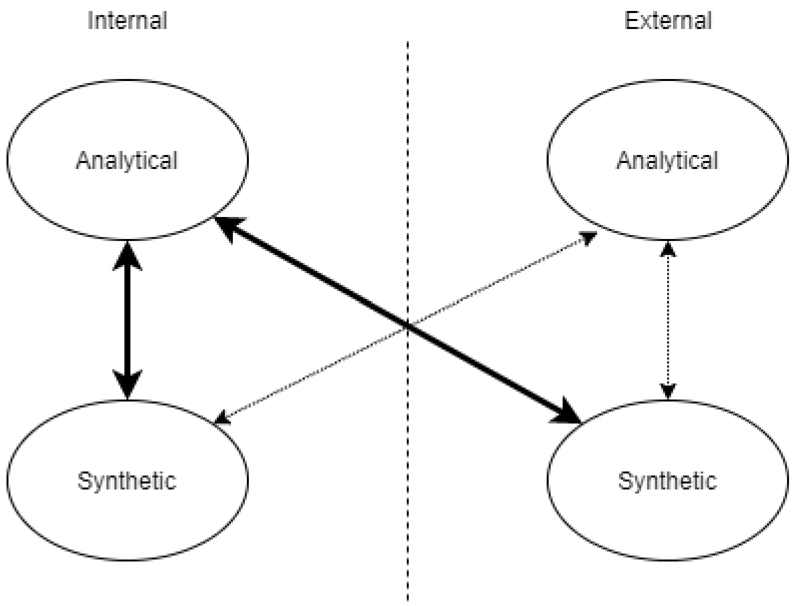

Figure 2: Results of analysis. Bold arrows indicate significant negative interactions, dotted arrows indicate negative non-significant interactions.

To explore these findings in more detail, we turn to the results of average marginal effects analysis. The use of average marginal effects analysis is an alternative to address a possible issue with interpreting marginal effects of interactions in isolation in non-linear logit models (e.g. Cameron and Trivedi, 2005). Another alternative involves the examination of the changes in the odd ratios (e.g. Buis, 2010). This potential issue is attributed to the potential skewness in the tail of the logit distribution. The significance for the marginal effects is therefore affected by the variance of the other variables as it is dependent on the values of the other variables in the model (Haus-Reve et al., 2019). This neccesitates a closer inspection of the interaction effects. Like others who have encountered this issue (Aarstad et al., 2016; Acebo et al., 2021; Haus-Reve et al., 2019), we have adopted the average marginal effects approach. Average marginal effects analysis was only applied to significant interactions from Model 3, which is shown in the appropriate column in Table 2.

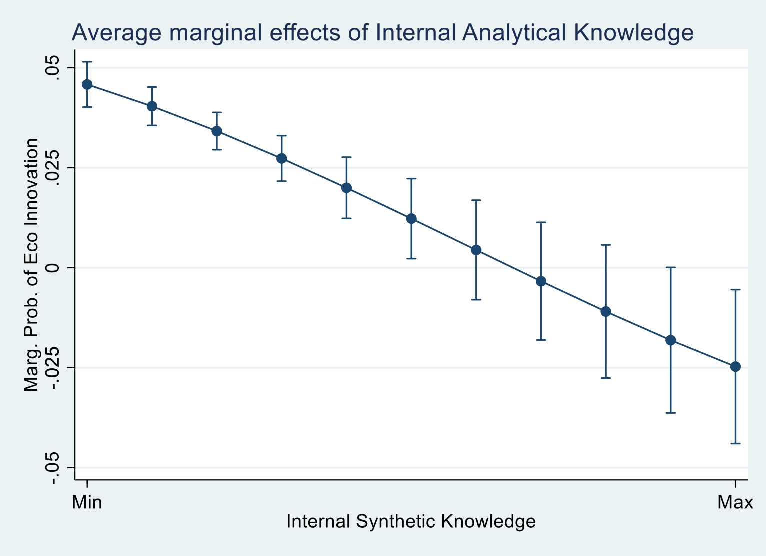

Figure 3: Average marginal effects of internal analytical knowledge as a function of increasing internal synthetic knowledge. 95% confidence intervals are shown. The calculation is based on the estimates in Model 3.

Figure 3 shows that a one-unit increase in internal analytical knowledge increases the probability of EI by approximately four percentage points when internal synthetic knowledge is zero (Min). If the internal synthetic knowledge is at a maximum (Max), a one-unit increase in internal analytical knowledge decreases the probability of EI by about 2.5 percentage points.

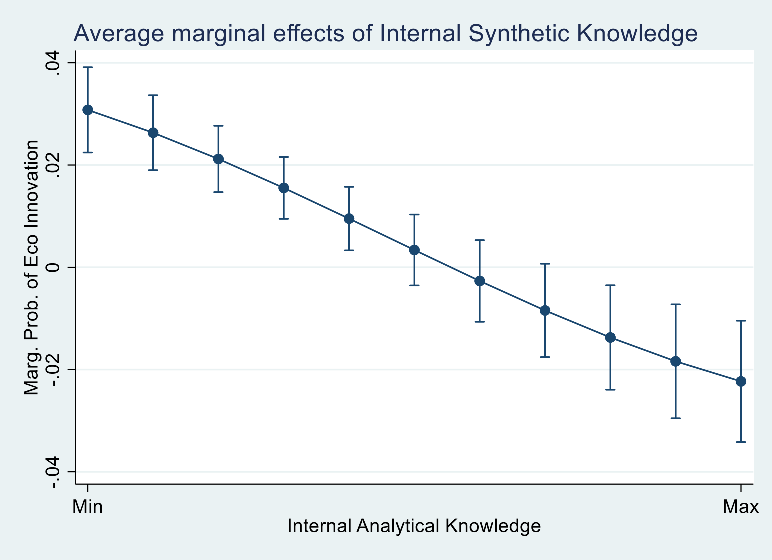

Figure 4: Average marginal effects of internal synthetic knowledge as a function of increasing internal analytical knowledge. 95% confidence intervals are shown. The calculation is based on the estimates in Model 3.

Figure 4 shows the interaction that occurs when internal synthetic knowledge is modelled as a function of internal analytical knowledge and the marginal probability of EI.

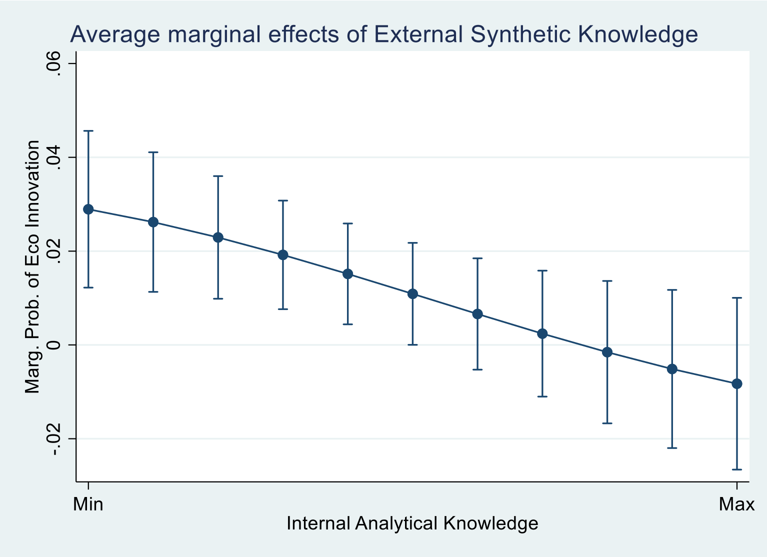

Figure 5: Average marginal effects of external synthetic knowledge as a function of increasing internal analytical knowledge. 95% confidence intervals are shown. The calculation is based on estimates in Model 3.

Figure 5 shows that a one-unit increase in internal synthetic knowledge increases the probability of EI by about three percentage points when internal analytical knowledge is at zero (Min). If internal analytical knowledge is maximum (Max), a one-unit increase in external synthetic knowledge decreases EI probability by about one percentage point.

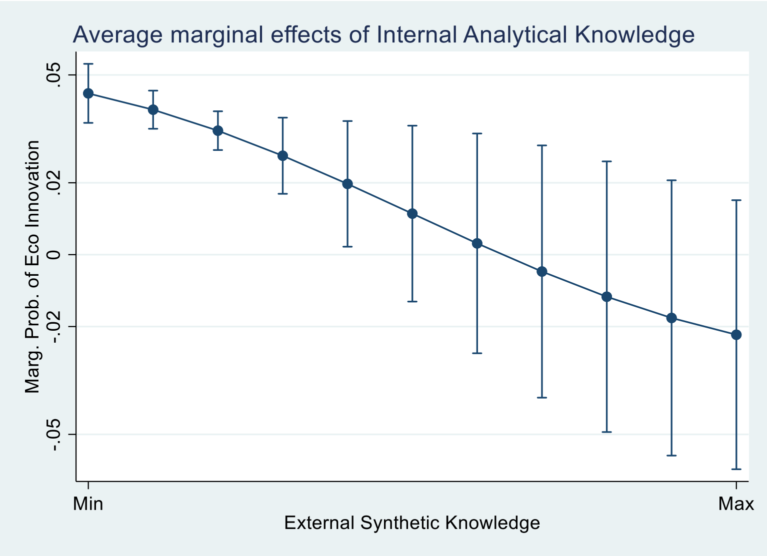

Figure 6: Average marginal effects of internal synthetic knowledge as a function of increasing partners of external synthetic knowledge. 95% confidence intervals are observed. The calculation is based on estimates in Model 3.

Figure 6 shows the interaction when internal analytical knowledge is modelled as a function of external synthetic knowledge. It also illustrates its marginal probability on EI.

As Figure 3–6 illustrate, a negative tendency is observed in the interaction between the two different forms of knowledge. These findings of a negative or substitutive interaction between analytical and synthetic knowledge mirror more recent findings when the interactions between both forms of knowledge are empirically tested (Haus-Reve et al., 2019; Marzucchi & Montresor, 2017). A finding that is contrary to popular notions in non-EI literature (Alhusen & Bennat, 2020) and EI literature (Sanni & Verdolini, 2022) about the complementarity of analytical and synthetic knowledge. A possible explanation may be that combining the two is a process whose complexity is only little understood. Both these forms of knowledge may require separate and distinct management, which makes their complementarity difficult to achieve.

5. Conclusion

Following research that has approached EI drivers through the lens of a firm's resources and capabilities (Cainelli et al., 2015; Ghisetti et al., 2015; Kobarg et al., 2020; Marzucchi & Montresor, 2017), we investigate the impact of knowledge on EI. In particular, we expand upon the findings of Marzucchi and Montresor (2017), who applied a popular notion in innovation mode literature to EI in the manufacturing industry: combining analytical and synthetic knowledge benefits innovation. We first confirm that, given its systemic and complex nature, synthetic and analytical knowledge that is generated internally or externally can lead to successful EI. Internal analytical knowledge is most prominent when comparing the importance of these two forms of knowledge, i.e., the internal STI innovation mode, which is dependent on analytical knowledge, seems to be the most promising path to EI. Furthermore, our general finding is that analytical and synthetic knowledge are not complementary for EI, and that this seems consistent even when accounting for industry effects. Specifically, we find a significant substitutive interaction between internal analytical and internal synthetic, and internal analytical and external synthetic knowledge. These findings suggest combining analytical and synthetic knowledge is not beneficial for EI and combining them can even be counterproductive and lead to a negative probability of EI.

While innovation mode literature has promoted the idea of complementarity, more recent empirical works have suggested that this enthusiasm is perhaps premature (Haus-Reve et al., 2019). EI literature in general also embraces complementarity between knowledge resources, this is despite the fact that there are studies that report mixed results. When framed as the interaction between analytical and synthetic knowledge our findings provide further evidence that knowledge combination remains an issue for EI and contradict the notion that more of all concerning knowledge benefits EI. We reiterate the suggestion that firms face substantial challenges when combining analytical and synthetic knowledge (Alhusen & Bennat, 2020; Haus-Reve et al., 2019; Marzucchi & Montresor, 2017).

Our conclusions urge caution for both policymakers and firm managers. In innovation studies, which EI is a subset, there has been enthusiasm to embrace the notion of diversity of resources to benefit innovation. There have even been suggestions that EI, being fundamentally more complex than non-EI, may further benefit from the combination of heterogeneous resources. However, the results of our analysis show otherwise. Policymakers and firm managers should carefully consider any measures implemented to promote EI through such combinations that do not consider the substantial challenges involved. We do not suggest abandoning complementarity of analytical and synthetic knowledge for EI as this well-established tenet in innovation studies we believe has merit. However, combining analytical and synthetic knowledge may be more complicated in practice. Assisting firms in managing the synergy between analytical and synthetic knowledge could prove to be greatly beneficial. Simply facilitating firms' access to knowledge may not be sufficient, and a more focused approach, which consider their capacity to absorb, exploit, and combine knowledge, may also be required. More specifically, the acquisition of different forms of knowledge may require careful and well-defined management if a firm is to succeed in combining analytical and synthetic knowledge for successful EI.

This study is not free of limitations that present future research avenues. Although we have addressed the issue of the persistence of EI and its possible drivers through time using longitudinal panel data and lagged independent variables, EI is constructed as a general variable. Future research should pursue the same avenues of research using specific types of EI, such as product, process, or organizational EI. An issue also remains regarding what these results mean for radical/incremental EI. The difference between radical and incremental innovation is where the discussion by Jensen et al. (2007) on innovation modes and the combination of analytical and synthetic knowledge originated. Although we confirmed findings from other jurisdictions, opportunities remain to extend this research to other countries. We also acknowledge that, especially for synthetic knowledge, our current measures may not be refined enough to capture the complexity of the process that firms use to generate and incorporate knowledge in their innovation process. We point to the development of more refined measures in innovation mode literature (Alhusen et al., 2021). Analysis based on these measures may reveal a complexity to knowledge combination that could not be revealed by our dataset. This should be incorporated into the research into this issue for EI. Additionally, digitalization's role in driving EI has been of great interest (Costa & Matias, 2020). Given its complexity, we assume that digitalization will only add to the challenges a firm can face when trying to combine its traditional knowledge base with new knowledge. How digitalization will be framed within innovation mode literature and the distinction between analytical and synthetic knowledge may be fruitful avenues for future research. Finally, future research should also consider the role of moderating factors in the interaction between analytical and synthetic knowledge for EI (Sanni & Verdolini, 2022).

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How Eco-innovative firms were affected by and responded to the unexpected external shock of the COVID-19 pandemic

Abstract

The impact of COVID-19 on different types of firm strategies, and how those firms responded to the effects of the pandemic is a subject of great interest for researchers, policymakers and firm managers. This paper studied the effects and response of eco-innovative Norwegian firms to the immediate effects of the pandemic. Given the strategy, structural, and leadership changes required for firms engaged in successful eco-innovation, such firms are assumed to possess a higher degree of dynamic capabilities that not only can mitigate the negative effects of the pandemic, but more importantly allow them to respond innovatively to those effects. Utilizing a dataset from a survey of Norwegian firms in 2020, the results of econometric modelling showed that firms that introduced product/service eco-innovations, or process eco-innovations during COVID-19 were significantly positively affected by the pandemic compared to other firms. In addition, these firms significantly introduced more innovations in other areas of operations as a direct consequence of the pandemic. However, the results also showed that firms that introduced product/service eco-innovations were also more negatively affected by the pandemic. These results confirmed that while the higher degree of dynamic capabilities attributed to firms engaging in eco-innovations can significantly contribute to their ability to be positively affected and respond more innovatively to an unexpected external shock, it does not make them entirely immune to the negative effects.

Keywords:

Eco-innovation, dynamic capabilities, COVID-19, innovation, business strategy

1. Introduction

The unexpected occurrence of the COVID-19 pandemic led to unprecedented consequences for every country in the world. Specifically, for firms the disruption in markets as a result of lockdown restrictions, changing consumer focus, as well as disruptions in supply networks posed questions about firm strategies that might mitigate the effects of such unexpected external shocks. As eco-innovation (EI) becomes increasingly recognized as a long-term organizational strategy for achieving both environmental and economic sustainability (Karimi Takalo et al., 2021), questions about the resilience of such a strategy to unexpected shocks have begun to emerge (Hermundsdottir et al., 2022). Understanding resilience of EI is of great importance for both policy makers and firm managers, as it has implications for the continued adoption of EI at the firm level. The continued adoption of EI is necessary, as the current level of efforts to alleviate the detrimental impact of production and consumption on the environment falls far short of what is required. This is especially relevant as it is predicted that unexpected external shocks such as pandemics will become more frequent occurrences.

Employing a deliberate long-term EI based strategy that results in successful EI requires fundamental changes to the structure, leadership and organization of a firm (Karimi Takalo et al., 2021; Munodawafa & Johl, 2019). Such strategies which align firm resources with EI goals are also considered to instil a higher level of dynamic capabilities (DC) (Arranz et al., 2020). DC refers to the capabilities of a firm to integrate, build and reconfigure internal and external resources and competencies to respond to rapidly changing environments (Teece et al., 1997). Beyond the clear benefits for the environment, such a strategy has also proven to result in better overall economic performance and competitiveness (Díaz-García et al., 2015; Hermundsdottir & Aspelund, 2021; Munodawafa & Johl, 2019; Pham et al., 2019).

Additionally, this deliberate strategy differentiates EI firms from other firms including firms who are engaged in general innovation (Del Río et al., 2015; Horbach, 2008).

Thus, the purpose of this paper is to investigate how firms that have successfully introduced product/service EI and process EI have (1) been affected by and the impact of COVID-19 and (2) responded to that impact. In this paper, COVID-19 is referred to as an 'unexpected external shock' in that it is an unexpected event originating external to the firm, which can also include commodity price fluctuations, natural disasters and international financial crisis (Raddatz, 2007), that dramatically changes a firms operating environment.[1]

Given the recentness of the pandemic and the lack of relevant data, research into the impact of COVID-19 on EI is very much in the preliminary stage. Despite this, important contributions have already been made specifically with focus on the manufacturing industry (Hermundsdottir et al., 2022), aquaculture, hospitality, tourism and culture industries (Aarstad et al., 2022). However, these studies like others (Ding et al., 2021; Huang et al., 2020) were centred on firms that had either a general EI strategy, or firms that emphasized sustainability or had a sustainability focus. A gap however remains regarding how 'specific' types of EI strategy, especially when those strategies are successfully implemented, may alleviate and respond to the impact of COVID-19. So, this paper looks beyond firms with a general EI strategy that may not have fully implemented the required organizational changes required to achieve a higher degree of DC. This paper also elaborates beyond singular industries to formulate generalizations about EI and DC and unexpected external shocks across all industries. This paper is the first provide empirical evidence that a higher degree of DC allows EI firms to respond to an unexpected external shock with more innovations. This contributes to the developing definition of DC by suggesting that it can be extended beyond simply

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[1] The most prominent difference between the COVID-19 pandemic and other external shocks was perhaps the motivation for changing consumer behaviour such as the fear of the unknown and lock-down measures that restricted movement and motivated a shift to online purchasing (Sheth, 2020).

‘respond to rapidly changing environments’ (Teece et al., 1997, p. 516), to also encompass specifically that response to be an ‘innovative’ one. By elaborating on this dimension of sustainability of which there is very little mention in the literature (Loureiro et al., 2021), this paper contributes to the continuing conceptualization of DC. Since there is no universally agreed upon measure of DC (Schilke et al., 2018), this article contributes by arguing that DC can also be measured by successful EI as it more than satisfies the definition of DC. In addition, it contributes to the ongoing discussion on the relationship between EI and other innovations (Arranz et al., 2020), by showing that there is an interrelatedness between EI and other innovations specifically during times of an unexpected external shock.

This article is organized into five sections. Section 2, which follows discusses theory and earlier research into EI that may affect its resilience to an external shock and presents the hypotheses. In Section 3, the data is explained, as well as the construction of variables and analysis method are outlined. In Section 4, the findings are presented and discussed. In Section 5, is the conclusion, limitations of the study and the recommendations for future research paths.

2. Theory and literature

Although there have been many attempts to define EI (for a review, see Díaz-García et al., 2015), this study adopted the definition proposed by Kemp and Pearson (2008, p. 7), where EI is:

> The production, assimilation or exploitation of a product, production process, service or management or business method that is novel to the organisation (developing or adopting it) and which results, throughout its life cycle, in a reduction of environmental risk, pollution and other negative impacts of resource use (including energy use) compared to relevant alternatives.

This definition encapsulates the 'fundamental difference' between EI and non EI (Del Río et al., 2016), that is to say between EI and innovation that does not have a positive impact on the environment. To elaborate, EI are innovations that are often motivated by regulatory push/pull effects (De Marchi, 2012). They lead to a 'win-win' outcome given the compatibility of both sustainable and economic development (Ghisetti & Quatraro, 2017). EI is motivated by environmental problems that require urgent solutions (Arranz et al., 2020). In addition, EI is characterized by the 'double-externality' problem which is the lack of incentive for firms to engage in EI as other firms also benefit without contributing to the often, high costs of development (Rennings, 2000). This lack of incentive is also compounded by the relative ease by which other firms can copy EI from first movers (Arranz et al., 2019).

Given the complexity involved, EI is believed to involve the long-term investment of a firm's resources and focus, and path dependent on previous investments and, routines, and existing resources (Aragón-Correa & Sharma, 2003; Hermundsdottir & Aspelund, 2021). EI is also a result of a 'sequential logic to the implementation of environmental strategies' (Hart, 1995, p. 8) and demonstrates a persistence over time (Arranz et al., 2020). The suggestion is that successful EI is the result of a firm's deliberate long-term strategy of sustainability (Mousavi et al., 2018). Others support this claim by pointing out that the EI process requires the cumulative accumulation of tasks, routines and teams within a firm over time and leads to the development of subsequent EI (Arranz et al., 2020). These firms have implemented specific strategies dictated by a particular emphasis on sustainability, routines and combinations of resources (Munodawafa & Johl, 2019; Pham et al., 2019) and have successfully executed that strategy, as evidenced by the introduction of product/service EI and process EI.

2.1. Product/service EI and process EI

As one study into the specific dimensions of EI have stated, ‘a focus on technological innovation implies the differentiation between product/service EI and process EI’ (Kobarg et al., 2020, p. 5). Others have pointed out that in the implementation of firm strategies, such as a formal environmental management system, using a unitary measure of EI might mask the specific impact of such strategies on product/service EI and process EI (Kawai et al., 2018). Others have argued that product/service EI and process EI differ in terms of technical aspects, criteria and types of practices and that drivers and barriers are specific to each type of EI (Abdullah et al., 2016). Marzucchi and Montresor (2017) also noted that firms require unique strategies depending on which dimension of EI they target, with each requiring a different mobilisation of strategic and organisational resources (Kawai et al., 2018). In general, most studies have highlighted that the primary focus of product/service EI is on improving the firm’s image and securing and increasing existing markets (Cuerva et al., 2014), whereas process EI is focused more on internal firm processes that facilitate the efficient use of resources and minimize pollution (Hojnik & Ruzzier, 2016; Kawai et al., 2018).

2.2. EI during a crisis

Although a number of studies have assessed the impact of prior crises on non EI (Babina et al., 2020), studies on the impact of crises on EI are rare. However, this may be unsurprising given the nascent nature of the EI literature. The few studies that do exist have focused mainly on the impact of financial crises, finding a positive relationship between corporate environmentalism and innovative activities (Kim, 2015) and the resilience of firms with EI goals (Alos-Simo et al., 2020b). Despite these positive findings regarding the resilience of EI to an external shock, the uniqueness of COVID-19 has undoubtedly impacted firms in unprecedented ways. EI firms are generally more focused on long-term trajectory, which promotes questions about the resilience of such a strategy compared to one that is more aligned with short-term stability goals. These questions are especially relevant given previous research that has found that EI often involves a higher degree of uncertainty, complexity and investment costs (García-Sánchez et al., 2020), with return on investment rarely occurring in the short term (Rezende et al., 2019). Firm focus on corporate social responsibility, which incorporates economic, environmental, and social dimensions, was also found to protect firms from stock price volatility and aid in a quick recovery from the pandemic (Ding et al., 2021). Additionally, others have tested organizational resilience and the effects of COVID-19 and found that corporate social responsibility positively influenced organizational resilience to the effects of the pandemic (Huang et al., 2020). While there are findings contrary to the aforementioned, even those contrary studies suggested the results could be different for firms that had a particularly strong focus on EI (Hermundsdottir et al., 2022).

2.3. Higher degree of DC through EI and resilience during COVID-19

The fundamental organizational and structural changes that a firm experiences by the comprehensive adoption of EI (Del Río et al., 2015) highlight the relationship between EI and a higher degree of DC (Arranz et al., 2020; Hermundsdottir & Aspelund, 2021). This naturally follows from the RBV approach to studying firm level drivers of EI as DC is one of the main concepts utilized in RBV (Carrillo-Hermosilla et al., 2019). Specifically Mousavi et al. (2018) found that the DC elements of sensing, seizing and reconfiguring played a prominent role in innovation for sustainability, which incorporates ecological and social concerns alongside economic ones. In short, sensing capabilities allows a firm to assess changes in market demands, technological developments, business trends and the impact of their activities on the environment. Seizing capabilities enables firms to build and improve competencies and deploy resources to target market acceptance. Reconfiguring capabilities expresses a firm’s flexibility to respond to challenges by adjusting and changing previous innovation processes to accommodate the development of innovation for sustainability. This finding is supported by others when focused specifically on EI (Wu et al., 2016).[2] Pham et al. (2019) elaborated on this relationship considerably, referring to it as dynamic eco-capacity or the green adaptive ability of an organization to reconfigure its resources into new combinations of operational capabilities. This dynamic eco-capacity is generated by a firm engaging in a variety of activities related to EI such as R&D, external knowledge integration, and green knowledge sharing.

Engaging in EI has also been shown to transform the strategic leadership of a firm, making them more innovative, open-minded, more motivating, and flexible and adaptive to economic and social challenges which contribute to a higher degree of DC (Bucea-Manea-Țoniş et al., 2021). This leads to EI firms having increased organizational flexibility (Chu et al., 2019), creativity (Pham et al., 2019) and ability to deploy resources to protect their competitiveness in dynamic environments (Hermundsdottir & Aspelund, 2021), especially when responding to external stakeholder demand (Tariq et al., 2017). In addition, successful EI can contribute to a firm attaining a sustainable competitive advantage by improving its market position and attracting customers (Karimi Takalo et al., 2021). Furthermore, EI has also been shown to contribute to the financial performance of a firm (Chu et al., 2019; Díaz-García et al., 2015) especially for those that engage in high-intensity EI (Aguilera-Caracuel & Ortiz-de-Mandojana, 2013). Others have also pointed out that engaging in EI also requires a firm to possess a risk taking characteristic, especially during times of uncertainty (Chu et al., 2018). ‘Amongst all, the existing literature claims that eco-innovation has emerged as one of the utmost dynamic innovations for firm sustainability’ (Toha et al., 2020, p. 2). Finally, EI is often a strategy that has a long-term horizon, it may well be that such a strategy is more resilient to short-term disruptions. This paper argues that the DC which can be attributed to firms that have successfully introduced product/service EI or process EI allows them to

[2] EI excludes the social dimension and focuses on the ecological and economic dimensions of sustainability.

express certain dimensions of resilience against the effects of a pandemic such as COVD-19. Specifically, such firms will be more positively affected, less negatively affected and more innovative as a direct result of the pandemic.

Therefore, it is expected that EI firms would be more positively affected by the impact of COVID-19, as they may be more confident in their ability to withstand the sudden impact of the pandemic. Additionally, both product/service EI and process EI firms, may be more confident in their capacity to adapt, regardless of the specific disruptions to their EI strategy caused by the pandemic. With the perspective that the introduction of product/service EI and process EI is an expression of a firm's DC, the first two hypotheses are proposed:

H1: Firms that introduced product/service EI were more positively affected by COVID-19 than firms that did not introduce product/service EI.

H2: Firms that introduced process EI were more positively affected by COVID-19 than firms that did not introduce process EI.

The most noticeable negative impact of the pandemic that firms may have initially experienced is the disruption of consumer buying behaviour. Evidence suggests that the pandemic lockdowns shifted consumer focus from ongoing and long-term concerns, which EI addresses, to more immediate concerns and uncertainty (Smirnov & Hsieh, 2022). Thus, one might initially assume that this may have negatively affected consumer buying decisions for product/service EI. Additionally, consumers often perceive product/service EI to be more expensive (Rehfeld et al., 2007), which may can influence consumer decisions in turbulent times, at least in the short term. However, the pandemic's comprehensive impact on the market can also be assumed to have affected all products and services, and, relatively speaking, product/service EI firms may not have been more negatively affected than other firms. Despite an immediate disruption which may change consumer focus, a higher degree of

DC can make product/service EI firms more optimistic about their ability to adapt. On the basis of the above discussion, it is expected that firms that introduced product/service EI may have experienced a certain resilience against the negative effects of the pandemic. Therefore, the third hypothesis is proposed as:

H3: Firms that introduced product/service EI were less negatively affected by COVID-19 than firms that did not introduce product/service EI.

Given that process EI is primarily directed at the reduction of a firm's material and energy costs, it is argued that this type of EI will be even less affected by initial disruptions as these measures will be more embedded in a firm's operational capabilities, at least in the short term. Undoubtedly, over the long term, supply-chain disruptions will eventually have an impact on all facets of a firm's operations. Therefore, the fourth hypothesis is proposed as:

H4: Firms that introduced process EI were less negatively affected by COVID-19 than firms that did not introduce process EI.

These first four hypotheses are proposed with the understanding that firms may be both positively and negatively impacted by the pandemic. It is conceivable that the pandemic may have had an adverse effect on certain aspects of a firm's business, while at the same time having a favourable effect on others.

Hermundsdottir et al. (2022) found that firms with an existing general EI strategy seemed to have been more active in responding to COVID-19 with either a green strategic response or a general strategic response. This ability to respond to changes in its external environment by adapting organizational structure and reorganizing resources is consistent with the concept of DC. Arranz et al. (2020) demonstrated that EI is interrelated with other innovations, both simultaneously and sequentially. In essence, firms that eco-innovate develop a habit to innovate generally. Therefore, the positive influence of EI on firm ambidexterity to mobilize their strategic and organizational resources more efficiently (Alos-Simo et al., 2020a; Kawai et al., 2018) coupled with EI firms being more innovative generally will lead to such firms responding more innovatively to the pandemic. On this basis the final two hypotheses are:

H5: Firms that introduced product/service EI also introduced more innovations as a direct response to the impact of COVID-19 than other firms did.

H6: Firms that have introduced process EI also introduced more innovations as a direct response to the impact of COVID-19 than other firms did.

3. Methods

The empirical analysis was carried out on a dataset from the 2020 wave of the Community Innovation Survey (CIS), a biannual survey conducted by Statistics Norway. Participation in the survey is mandatory, which minimizes the issue of non-response bias. In addition, all respondents are required to fill out every section of the survey regardless of their innovation status, which also minimizes selection bias which may result from allowing only innovative firms to fill out the whole survey. The survey participants included firms with 50 or more employees, as well as a random stratum of firms with fewer than 50 employees. These firms represent most industries and all regions of Norway.

3.1. Dependent variables

The two dependent variables *positively affected by COVID-19* (Model 1), and *negatively affected by COVID-19* (Model 2), were constructed from five items from the 2020 CIS that gauged how firms were negatively or positively affected by COVID-19. These items and the results of applying principal factor analysis are reported in Table 1 (translated from Norwegian). For each of these five items, respondents indicated how they were affected: to no extent (coded as 1), to a little extent (coded as 2), to some extent (coded as 3) or to a great extent (coded as 4). As reported in Table 1, the application of principal component factor analysis with orthogonal varimax rotation identified two factors with an eigenvalue of 1.60, explaining 69.0% of the variance (the eigenvalue for three factors was .673) and showed satisfactory convergent and divergent validity. Reliability was satisfactory, as indicated by the Cronbach's alpha score. *Positively affected by COVID-19* was measured by taking the mean of the score of the first three items in bold in Table 1, while *negatively affected by COVID-19* was measured by taking the mean of the score of the last two items in bold in Table 1 (Acock, 2008).

Table 1. Principal component factor analysis with orthogonal varimax rotation (N = 5,924)

Factors 1 and 2, respectively	Positively affected by COVID-19	Negatively affected by COVID-19
Did the enterprise strengthen its position compared to its competitors due to the situation concerning COVID-19?	**.835**	-.015
Has the enterprise had commercial gains due to the situation concerning COVID-19?	**.764**	-.317
Has the enterprise become more efficient due to the situation concerning COVID-19?	**.688**	.289
Has the enterprise experienced economic consequences due to the situation concerning COVID-19 that will affect the enterprise negatively in the long term?	-.042	**.880**
Did the enterprise lose its competitive edge due to the situation concerning COVID-19?	-.029	**.858**
Cronbach's alpha for items in bold	*.643*	*.731*

The third dependent variable, *innovative response* (Model 3), was constructed as the sum of all innovations introduced as a direct result of COVID-19.[3] Respondents were asked to indicate whether they introduced a variety of different innovations in seven different areas of operation as a direct result of COVID-19, and their responses were coded as 1 if they indicated that they had and 0 if they indicated that they had not. These areas of operation were: (1) product or service; (2) delivery, distribution or logistics; (3) information processing

[3] Note that this section specifically asked respondents if they had introduced any innovations as a *direct result* of COVID-19 and is separate from the sections of the CIS in which respondents were asked to indicate if they had introduced an innovation during the relevant period.

or communication; (4) accounting or other administrative purposes; (5) organizational procedures or organization of external relationships; (6) distribution of responsibility, decision-making or processing of human resources; (7) marketing, presentation, packaging, product placement or after-sales service. Summing these items resulted in a score of 0 if no innovations were introduced as a direct result of COVID-19 or a maximum of 7 if innovations were introduced in all these operational areas.

3.2. Independent variables

The independent variables were constructed from the section of the CIS in which respondents were asked to indicate in what area they had introduced an innovation with a positive environmental effect. *Product/service EI* was coded as 1 if a respondent indicated that they introduced an EI related to a product and/or service and was coded zero otherwise. *Process EI* was coded as 1 if a respondent indicated that they introduced an EI related to process and 0 if they had not.

3.3. Control variables

Firm size was modelled as the log-transformed number of employees in 2020. *Non-product/service EI* is a binary variable that was coded as 1 if the firm had introduced a new or significantly improved product innovation in the period and/or introduced a new or significantly improved service innovation and had received a zero for product EI. The variable was coded as 0 if the firm did not meet all these conditions. That is, if the firm introduced a product or service innovation, that did not have a positive impact on the environment. *Non-process EI* is a binary variable that was coded as 1 if the firm had introduced a new or significantly improved processes or methods of product or service production in the period, including development methods and/or innovation in delivery, distribution or logistics, and had received a zero for process EI. [4] The variable was coded as 0 if the firm did not meet all of these conditions. That is, if the firm introduced a process innovation, that did not have a positive impact on the environment. *External financial support* is a binary variable that was coded 1 if the firm received some form of public financial support during the period, whether from national authorities, government-run institutions, or EU authorities or EU institutions. This variable was coded as 0 if the firm had not received such financial support or if the value was missing. *R&D investment* was constructed from the sum in Norwegian kroners the firm invested in its own R&D and the purchase of R&D services from others. This was then divided by the number of employees; missing values were coded 0, and then the log was taken after adding 1 to avoid dropping the zero. *External collaboration* is a binary variable that was coded as 1 if the firm either collaborated with other enterprises or organizations on R&D during the period or the firm collaborated with other enterprises or organizations on other innovation activities during the period. This variable was coded 0 otherwise or if the value was missing. *Productivity* was constructed as firm turnover during the period divided by the number of employees; this was then logged after adding 1 to avoid dropping the zero. Finally, *Norwegian market* is a binary variable coded as 1 if the firm's most important market was located within Norway and 0 if its most important market was outside Norwegian borders. Table 2 summarizes descriptive statistics for all variables.

[4] The definition of process innovation was suggested by Reichstein and Salter (2006) which includes innovation in distribution and transport.

Table 2. Descriptive statistics

Variable	Mean	Number	SD	Min.	Max.
Dependent variables					
Positively affected	2.118	5,920	.648	1	4
Negatively affected	2.102	5,920	.782	1	4
Innovative response	.697	5,920	.986	0	7
Independent variables					
Product/service EI	.243	5,920	.429	0	1
Process EI	.205	5,920	.404	0	1
Control variables					
Firm size*	96.948	5,920	348.268	5	18,415
Non-product/service EI	.010	5,920	.101	0	1
Non-process EI	.005	5,920	.069	0	1
Financial support	.318	5,920	.466	0	1
R&D investment*	6,086.348	5,920	47,331.21	0	2,184,002
External collaboration	.393	5,920	.488	0	1
Productivity*	4,011.607	5,920	2.228	0	3,599,048
Norwegian market	.343	5,920	.473	0	1

*Before log transformation. EI: Eco-innovation

3.4. Modelling

To test the hypotheses, hierarchical ordered logit regressions was used. To warrant the use of ordered logit regressions, a number of assumptions have to be satisfied. All three of our dependent variables as they were constructed seemed to satisfy the ordinality of dependent variable assumption. This assumption dictates that the order of the categories in which the dependent variable is measured is meaningful, but the distance between these measures are not assumed to be equal. Another of these of these assumptions is the proportional odds assumption which dictates that the relationship between the independent variables and the cumulative odds of being in a category less than or equal to a particular category versus being in a higher category is constant across all levels of the ordinal dependent variable. Given the consequences of violation of these assumptions, such as loss of information, invalid statistical inferences as well as misleading conclusions, alternative unreported models were also applied using a linear regression.[5] These alternative models did not result in any significant changes to our statistical conclusions.

A total of three analyses were run, Model 1 analysed whether EI firms were positively affected by COVID-19, Model 2 analysed whether EI firms were negatively affected by COVID-19, and Model 3 analysed whether EI firms introduced more innovations in other areas of their operation as a response to COVID-19. For each of the main models a total of three nested models (a-c) were run. In order to test H1-H6 a basic regression model which takes the following form was used:

Dependent variable = constant + β_1(product/service EI) + β_2(process EI) + β_3(firm size) + β_4(non-product/service EI) + β_5(non-process EI) + β_6(financial support) + β_7(R&D investment) + β_8(external collaboration) + β_9(most important market) + u(industry)

Dependent variable takes on the appropriate value of each particular dependent variable for each model, as outlined above, and u(industry) is the random effect for a firm belonging to a particular industry. In running hierarchical regressions, firstly the control variables (β_4 - β_9) were introduced as the first block, and then the independent variables (β_1 and β_2) were added as two subsequent blocks (Acock, 2008). The results for all models are reported in Table 3. Table 3 also reports the maximum and average Variance Inflation Factor (VIF) for each model, which is well within acceptable ranges and indicate that there are no significant issues with multicollinearity (cf. O'Brien, 2007). In addition, common method variance was tested using Harman's one factor test and all values are well within acceptable range and are reported in Table 3.

[5] In addition, generalized ordered logit models were applied as an alternative (Williams, 2016), this approach gave very similar results. Regression models where the relevance of the ordering of the dependent variable and the proportional-odds assumption were not imposed were also applied. These did not show any significant changes to our statistical conclusions for all three models.

4. Results and discussion

Table 3, model 1(a) reports the associations between the control variables and being positively affected by COVID-19. Model 1(b) introduced product/service EI and it had a significant effect on being positively affected by COVID-19. Model 1(c) introduced process EI, and it also had a significant effect on being on being positively affected by COVID-19. Therefore, firms that had introduced product/service EI or process EI were significantly positively affected by COVID-19 and means that both H1 and H2 gained empirical support. Furthermore, Model 1 also shows positive significance for firm size. This supports suggestions that larger firms, which are often resource rich, are able to mediate dramatic changes in their external circumstances confirming previous findings (Noone et al., 2022). Firms that had their most important market in Norway were also positively affected by the pandemic, which may be due to the fact that Norway was relatively less affected by the pandemic than other countries (Hermundsdottir et al., 2022).

Model 2(a) reports the association between the control variables and being negatively affected by COVID-19. Model 2(b) introduced product/service EI and it had a significant

Table 3. Results of hierarchical ordered logistics regression

	Model 1 *Positively affected*			Model 2 *Negatively affected*			Model 3 *Innovative response*		
	1(a)	1(b)	1(c)	2(a)	2(b)	2(c)	3(a)	3(b)	3(c)
Independent variables									
Process EI			0.341***			0.002			1.090***
			(0.059)			(0.069)			(0.102)
Product/service EI		0.388***	0.417***		0.124*	0.124*		0.916***	1.030***
		(0.067)	(0.072)		(0.057)	(0.057)		(0.074)	(0.100)
Control variables									
Firm size (log)	0.105***	0.095***	0.088**	-0.092**	-0.095***	-0.095**	0.114**	0.093*	0.065
	(0.027)	(0.027)	(0.027)	(0.028)	(0.028)	(0.029)	(0.036)	(0.038)	(0.037)
Non-product/service EI	0.376*	0.374*	0.241	0.451**	0.445**	0.444*	0.504**	0.481*	0.117
	(0.187)	(0.182)	(0.188)	(0.169)	(0.171)	(0.178)	(0.193)	(0.194)	(0.211)
Non-process EI	-0.096	-0.331	-0.256	-0.291	-0.365	-0.364	0.034	-0.494	-0.263
	(0.311)	(0.328)	(0.325)	(0.204)	(0.202)	(0.204)	(0.269)	(0.275)	(0.280)
Financial support	0.045	0.025	0.019	0.560***	0.554***	0.554***	0.356***	0.304***	0.307***
	(0.083)	(0.083)	(0.082)	(0.091)	(0.092)	(0.092)	(0.072)	(0.079)	(0.083)
R&D investment (log)	0.004	-0.008	-0.006	-0.050*	-0.054*	-0.054*	0.322***	0.298***	0.309***
	(0.021)	(0.022)	(0.022)	(0.024)	(0.023)	(0.023)	(0.035)	(0.037)	(0.036)
External collaboration	0.204**	0.136*	0.087	0.004	-0.019	-0.02	1.435***	1.308***	1.196***
	(0.068)	(0.065)	(0.064)	(0.072)	(0.071)	(0.067)	(0.128)	(0.126)	(0.109)
Productivity	0.032	0.030	0.028	-0.009	-0.010	0.017	-0.010	-0.016	-0.024
	(0.027)	(0.026)	(0.026)	(0.027)	(0.027)	(0.072)	(0.017)	(0.016)	(0.018)
Norwegian market	0.234**	0.212**	0.219**	0.024	0.017	0.017	0.314***	0.257***	0.289***
	(0.074)	(0.073)	(0.073)	(0.071)	(0.072)	(0.072)	(0.059)	(0.056)	(0.062)
Wald $\chi 2$	116.15***	33.45***	33.87***	90.32***	4.77*	0.00	1280.52***	152.16***	113.66***
Degrees of freedom	8	1	1	8	1	1	8	1	1

No. of industries	62	62	62	62	62	62	62	62	62
Maximum/average VIF			1.52/1.16			1.52/1.16			1.48/1.15
Harman's 1-factor test[a]			0.189			0.198			0.244
Observations	5,920	5,920	5,920	5,920	5,920	5,920	5,920	5,920	5,920

Note: Coefficients are given with the robust standard errors adjusted for industry effects in parentheses.

* p < .05; ** p < .01; *** p < .001.

[a]Includes indicators measuring all concepts except for firm size and the industry in which the firm operate (as they are measured by using register data and not self-reporting perceptual data).

EI: Eco-innovation. VIF: Variance inflation factor. (log): log transformed.

effect on being negatively affected by COVID-19. That is, firms that had introduced product/service EI were significantly negatively affected by COVID-19 compared to other firms (although the effect was borderline significant). So H3 did not gain empirical support as the hypothesis proposed that firms that had introduced product/service EI would be less negatively affected. Some studies have found that manufacturing firms were more negatively influenced by COVID-19 (Hermundsdottir et al., 2022), suggesting that uncertainties in market sentiment and unique supply chains may have made EI firms particularly vulnerable. During times of crisis, consumers tend to focus on practical and regularly purchased products to mitigate uncertainty (Loxton et al., 2020; Smirnov & Hsieh, 2022). This may have resulted in consumers choosing not to purchase EI products and services which were newly introduced into the market. In contrast there are others who found that certain consumer segments actually increased their purchases of environmentally sustainable products during the pandemic (Peluso et al., 2021).

While the results for Model 1(b) and Model 2 (b) may seem contradictory, in that firms that introduced product/service EI were both positively and negatively affected by COVID-19, it is quite conceivable for a firm to perceive that they had been positively affected in certain aspects of their business while being negatively affected in others. Product/service EI firms, for example, may have perceived that consumers behaviour changed during the pandemic; however, their confidence in their DC may have encouraged them to feel that they could nevertheless cope.

Model 2(c) introduced process EI, which did not have a significant effect on being negatively affected by COVID-19. That is firms that introduced process EI were not less negatively affected than other firms. Therefore, in addition, H4 did not gain empirical support. Earlier studies have shown that the vulnerability of being dependent on global supply chains seems to be inherent in all firms, not just those engaged in EI during the pandemic (Ding et al., 2021). Firm size was significant with a negative coefficient implying that the larger the firm, the less negatively affected it was by the pandemic. Firms that received external financial support were negatively affected by the pandemic, as evidenced by the significance of the control variable for financial support.

Model 3(a) reports the association between the control variables and innovative response. Model 3(b) introduced product/service EI which showed a significant effect on innovative response. Model 3(c) introduced process EI and it also had a significant effect on innovative response. These results confirm both H5 and H6 in that firms that had introduced product/service EI or process EI also introduced more innovations in other aspects of their business then other firms. Several other studies have highlighted that firms focus on sustainability seems to play a role in mitigating the effects of COVID-19 through a corporate social responsibility strategy. These firms experienced a smaller fall in their stock price (Ding et al., 2021), suffered fewer losses and recovered more quickly from the pandemic (Huang et al., 2020).This is particularly interesting given that firms that have product/service and process innovations that were not environmentally friendly were controlled for, and neither of these were significant. On the other hand, in a study of the aquaculture, hospitality, tourism and culture industries, Aarstad et al. (2022) found that being strongly impacted by COVID-19 did not always initiate a corresponding response, even for firms that emphasized sustainability. This perhaps highlights the difference between firms that *emphasized sustainability* and firms studied in this case who have successfully introduced EI. The assumption being that the latter have a higher degree of DC from making the required organizational and leadership changes to overcome the numerous challenges associated with EI such as the high risk of failure, higher cost for R&D and integrating different types of knowledge (Karimi Takalo et al., 2021; Marzucchi & Montresor, 2017).

As far as control variables are concerned, firms that received external financial support were also more innovative as a response to the pandemic. An explanation for this could be that this financial support was allocated to innovations in other areas of operation to mitigate the impact of COVID-19. Investment in R&D, which is considered important for innovation, also seems beneficial for innovation as a response to COVID-19. This is also true for firms with external collaborations. Firms that had a their most important market in Norway were more innovative as a direct result of COVID-19.

5. Conclusion

A firm's ability to respond to a changing external environment has often been attributed to its DC to repurpose its resources to respond appropriately. This often implies that such firms are not only more efficient in reacting to mediate the negative effects of those changes but are also more proactive in responding to their advantage. Firms that engage in implementing a successful EI strategy are often referred to as having a higher degree of DC. This is attributed to their ability to implement a long-term strategy that incorporates a diversification of their traditional knowledge base from both internal and external sources and, more importantly, their ability to reorganize firm resources to respond to unexpected events. While EI research has largely confirmed that such assumed DC does indeed contribute to EI firms being more resilient, innovative and proactive during times of relative stability, what remains unclear is how these EI firms fare during times of extremely unstable market conditions and disruptions. The COVID-19 pandemic afforded the opportunity to answer this question. Using the introduction of product/service EI and process EI as evidence that a firm had successfully implemented an EI strategy, this paper studied whether such firms were more or less affected by the pandemic and, additionally, whether they were more innovative as a direct result of COVID-19.

What is particularly encouraging for EI is that those firms with product/service EI, or process EI were significantly more positively affected than other firms, even when controlling for non EI firms. In addition, EI firms were also more innovative, as demonstrated by their introduction of different types of innovations as a direct result of the pandemic. This, in many ways, speaks to the optimism associated with EI activities being able to respond positively to both ongoing and unexpected crises. In addition, it contributes more support to the notion that firms that engage in EI, especially process EI, may indeed possess a higher degree of DC, which provide an advantage even in times of unexpected shocks. These findings contribute to a more nuanced discussion on the concept and definition of DC especially how it relates to EI and unexpected external shocks. On a more practical level, for both policy makers and firm managers alike, it suggests that a long-term focus on mitigating the ongoing environmental emergency by producing product/service EI, and process EI indeed makes firms relatively resilient to unexpected shocks and more positively proactive to them. Despite this, the findings contain a note of caution for firms that plan to introduce innovative products or services, EI or otherwise, to the marketplace during times of crisis as there is evidence that consumers may have preferred more familiar products and services.

This study is not without limitations. First and foremost, it is contextual. Norway seems to have been less vulnerable to global disruptions, both economically and otherwise, during the COVID-19 pandemic (Hermundsdottir et al., 2022). The expectation of substantial financial aid packages, especially for the oil and gas industry, the largest industry in Norway, may also have contributed to mitigating the negative effects of the pandemic. Some evidence of this was present in this study, where firms with their most important market within Norway being more positively affected and innovative during the pandemic. This may limit the application of the results to other countries. Unfortunately, the dataset consisted of one wave of the

Norwegian CIS, which does not allow for lagged variables.[6] Despite the argument that firms with successful EI is the result of a long-term firm commitment, as the literature suggests, it is highly recommended that this is confirmed through a longitudinal study. This is also especially relevant regarding effect of the pandemic on other key performance indicators during and after the pandemic. There are also other relevant issues such as the difference between incremental or radical innovation that remains to be explored. In addition, when the 2020 CIS was carried out, it is possible that the exact impact of the pandemic was still being evaluated. As data during this disruptive period are accumulated, the full implications of COVID-19 may be revealed; this is also relevant for EI research.

[6] The different format of the Norwegian CIS in previous waves did not allow for the inclusion of lagged variables.

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