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An Exploratory Study of High-Performance Computing Technology Adoption over the Stages of Entrepreneurship

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Abstract: The focus of this paper is to examine how and when technology adoption occurs over the stages of entrepreneurship. High-performance computing (HPC) includes infrastructure and applications that are used for complex computational problems and can involve supercomputers and linked clusters. HPC can contribute to industry and firm competitiveness, particularly for SMEs. Against this background, there remains a limited understanding of how and when technology adoption occurs over the stages of entrepreneurship. In addressing this deficit our exploratory study identifies how and when technology adoption occurs over the stages of entrepreneurship. Our contribution is twofold. First, we develop a taxonomy of HPC with respect to the how and when of technology adoption. Second, we identify three categories of technology adoption – *emergent imitators*, *early adopters* and *growth assimilators* across two stages of entrepreneurship – emergent and late-stage.

Keywords: Entrepreneurship; Technology Adoption; High-Performance Computing; SMEs; Late-Stage Entrepreneurship; Emergent Entrepreneurship.

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Reference to this paper should be made as follows: Author. (xxxx) 'Title', *Int. J. xxxxxxxxxx xxxxxxxxxx*,

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1 Introduction

The entrepreneurs' perceptions of relative technology advantage, their innovativeness along with the social use of technology are antecedent factors that influence technology adoption (see Lee and Runge, 2001). The adoption of technology among small businesses and entrepreneurs and associated adoption behaviours varies across different technologies (Lee; 1995; Lee, 2004; Wamuyu, 2015). Several factors influence entrepreneurs in their technology adoption such as resources, however, the main adoption drivers are customers (Nguyen et al., 2015). Small businesses consider technology adoption due to external drivers and this entails other

considerations such as organisational and network factors (see Nguyen, 2009). Technology adoption can support a firm's efforts, particularly small businesses to grow and scale their business to enhance their competitive positioning (Ghobakhloo et al., 2012). The entrepreneurial orientation of the founder or the owner of a firm also influences technology adoption. For example, in a study of Malaysian SMEs Abdullah et al. (2012) found that along with internal factors the characteristics of the owner-managers had a significant influence on technology adoption. The entrepreneurial orientation of the small business owners in a study of small retailers' technology adoption for customer relationship management influenced their decision to adopt as well as seeking the relative advantages for their business. For technology adoption firms experience challenges in relation to cost, labour, institutional information and organizational (Baldwin and Lin, 2002). Through the stages of entrepreneurship technology adoption has the potential to support entrepreneurs in their efforts to ensure the survival, sustainability, and competitiveness of their venture. Limited resources are one of the main constraints for small business technology adoption (see Koller et al., 2015). Such technology adoption can also change the entrepreneurial processes (Nambisan, 2017). While technology adoption has been the focus of much research attention (see Nam et al., 2019; Tornatzky and Fleischer, 1990; Zhu et al., 2003) there has been limited focus on how technology adoption evolves over the stages of entrepreneurship.

High-performance computing (HPC) is seen as a key element in enabling technology innovation (see Wince-Smith, 2009) and has become an important technology encompassing both infrastructure and application. HPC consists of parallel processing computing systems that are used to solve demanding mathematical and computational problems (Dowd and Severance, 1998; Ezell and Atkinson, 2016). Multinational firms (MNC) have been investing in HPC through the creation of their own HPC centres. National governments have made been a significant public investment in HPC infrastructure (European Commission, 2021). While the majority of small businesses have been quick to adopt some of the cloud computing solutions (such as the use of online social media for example) that run on HPC infrastructure, hardly any have taken other advantages of that same infrastructure. The latter, however, have adapted their business models by understanding that potential benefits justify their initial investment as the ability to analyse, not collect, data is one of the most influential characteristics of their future success. Given the potential application of HPC in different industry settings and the benefits at the firm level there has been slow technology HPC adoption among small businesses and

entrepreneurs (Gupta et al., 2013). This remains a significant policy challenge. Moreover, within information technology fields there is a paucity of studies of HPCs (see Ezell and Atkinson, 2016) and there have been no studies to the best of our knowledge that have examined technology adoption over the stages of entrepreneurship. There is a lacuna of understanding of technology adoption over the stages of entrepreneurship.

Against this background, the purpose of this paper is to examine how and when technology adoption occurs over the stages of entrepreneurship. Our study is set in the context of higher performance computing in the Danube Region as part of a European Interreg funded project called High-Performance Computing for Effective Innovation in the Danube Region (InnoHPC) and draws on surveys, interviews, focus groups and other secondary source data.

Our exploratory study makes two contributions. First, we identify a taxonomy model of the how and when of technology adoption along the stages of entrepreneurship. Second, we identified three groups of HPC adoption across the stages of adoption – *emergent imitators; early adopters; growth assimilators* – across two stages of entrepreneurship - emergent and late-stage. The results of our study can give a good basis for future research in the area of HPC adoption by small businesses.

Our paper is structured as follows. With respect to our literature considerations, we focus on stages of entrepreneurship, technology adoption and HPC. We then outline our study methodology, data collection, analysis and limitations. After these considerations, we present our key findings. We then conclude the paper with a discussion of our findings along with outlining some future research directions and practical implications for entrepreneurs.

2 Literature Considerations

2.1 Stages of Entrepreneurship

Entrepreneurs' creation of new ventures contributes to economic wealth and growth (Acs et al., 2012). Technology and entrepreneurship matter to economies and how societies evolve and develop, and both evolve differently across different countries (see Audretsch et al., 2002 and Autio et al., 2018). Taking the stages of entrepreneurship approach to exploring and understanding entrepreneurship has been the focus of some empirical studies in the entrepreneurship field with many scholars using a stages of growth model (Levie and Lichtenstein, 2010). For example, a study by

Littunen and Niittykangas (2010) of growth among Finnish metal-based manufacturers over the stages of entrepreneurship found a link between high growth and entrepreneurs' know-how. Over the stages of entrepreneurship, the capabilities and resources change for a firm (Mickiewicz et al., (2017).

The stages of entrepreneurship consist of nascent, latent, emergent or early-stage and late-stage entrepreneurship (see Caiazzia et al., 2020). Nascent entrepreneurship centres on understanding the 'genesis' of a new venture (Johnson et al., 2006) and has been the focus of much empirical attention within the entrepreneurship field (see Gartner and Shaver, 2012; Lichtenstein et al., 2007; Obschonka et al., 2011; Renko et al., 2012; Wennekers et al., 2005). This empirical research has focused on such factors as antecedent factors and various process issues associated with the nascent entrepreneurial journey (Davidsson, 2006). At the nascent entrepreneurship stage as Hechavarria et al. (2012:698) argue: "Entrepreneurship involves human agency. People start businesses, they are not started by macro-economic conditions, presence of opportunities, availability of finance, social networks, positive entrepreneurial climate, regional/geographic attributes, or market characteristics." However, antecedent factors do shape the nascent entrepreneurial process (Hopp and Sonderegger, 2015). In particular, the local environment does influence the individual's initial decision to become an entrepreneur (Mueller, 2006). The person, process and human capital are predicators in whether an individual sets up a new venture (Kessler and Frank, 2009), however as Klyver and Schenkel (2013) suggest there is also a need to consider the combined effect of such factors.

Latent entrepreneurship is a further extension of nascent entrepreneurship as Caiazza et al. (2020) state: "A latent form of entrepreneurship exists until no one is able to use knowledge spilling out of its original source to implement entrepreneurial projects and introduce an innovation in the market. However, when an entrepreneur exploits knowledge spillovers to start a new firm, it emerges from its latent forms and is known as emergent entrepreneurship". According to Caiazza et al. (2020) latent to emergent entrepreneurship consists of four stages of a construction cycle and it is during stage three that the entrepreneur begins the process of setting up the new venture. Similar to earlier studies of nascent entrepreneurship, empirical studies of latent entrepreneurship have focused on such issues as determinants (Masuda, 2006), cultural identity (Audretsch et al., 2017), institutional environments (Gohmann, 2012), gender (Bönte and Piegeler, 2013) R&D (Cunningham and Link, 2020).

Emergent or early-stage entrepreneurship is when the new venture is created. Societal legitimacy influences this early-stage entrepreneurial

process (see Kibler and Kautonen, 2016) and much of the entrepreneurial focus and effort is on getting into the marketplace. For early-stage entrepreneurial firms to survive beyond the valley of death – the first three years – there is a need to focus on how they create value, thereby generating a competitive advantage, but also the deployment of their resources and the ability to adapt and learn through this process (see Boccardelli and Magnusson, 2006).

Late-stage entrepreneurship provides the conditions for firms to harness and leverage their capabilities, particularly technological to grow and create what Deeds (2001:29) terms additional "entrepreneurial wealth" and as a result, they have different characteristics (Lockett et al., 2008). This may mean that the firm has more established and formal processes in place, and this might be enhanced further if there is venture capital investment. During this stage, the firm has established itself in the marketplace. This also involves leveraging and expanding on existing networks that were created during the earlier stages of entrepreneurship (Anderson et al., 2010). Also, according to Brush et al. (2009) 'management, marketing and money' play a role in determining their growth. To fund this growth and market establishment, the firm may secure venture capital investment which may come from independent or government-managed venture capitalists (see Grilli and Murtinu, 2014). However, at this stage, there may also be other entrepreneurs entering the market trying to disrupt the market (Ács and Naudé, 2013). There is also a need for policymakers to have specific policy supports to support their growth and development (Mason and Brown, 2013).

2.2 Technology Adoption and Entrepreneurship

Technology adoption is understood to deliver multiple benefits across a wide range of intra- and inter-firm business processes and transactions by influencing the company's knowledge management and potentially lowering transaction costs (Ongori and Migiro, 2010). One of the factors that determine small business' survival in a market is their ability to constantly adapt and make the best use of emerging information technology (IT) for innovation and business competitiveness (Chinedu Eze et al., 2014). By adopting such IT in their business processes (Levy et al., 2001) and R&D activities, small businesses aim to reap benefits such as lower costs (Gilbert et al., 2004) increased productivity (Lymer, 1997), improved systems connectivity and process innovation (Kannabiran and Dharmalingam, 2012; Raymond and Bergeron, 2008), enhanced competitiveness (Alberto and

Fernando, 2007), lower labour costs, added value to products and services (Corso et al., 2003; Levy et al., 2001; Nguyen et al., 2007; Premkumar, 2003).

By adopting emerging IT, small businesses have historically found themselves in an unfavourable position as the use of such advanced technologies has been designed for large corporations (Kannabiran and Dharmalingam, 2012). Furthermore, challenges small businesses need to overcome have been widely recognised, including ease-of-use, lack of financial capacity and financial security, lack of information quality and information security, lack of internal competencies, lack of necessary infrastructure (Dixon et al., 2002; Duncombe and Heeks, 2001; Gilbert et al., 2004; Kannabiran and Dharmalingam, 2012; MacGregor, 2004; Seyal et al., 2007), and lack of support by the government (Ongori et al., 2010). Nguyen (2009) summarised reasons for unsuccessful IT adoption in small businesses include an unclear vision of adoption, misunderstanding of what IT adoption brings to the company, and the lack of specialised IT competencies. While the former addresses company-related strategic perspectives and correlated barriers, the latter two address technology-related perspective (see Table 1).

Several technology adoption frameworks can be found, most of them overlapping to some extent (Beatty et al. 2001; Liu, 2008; Thong, 1999; Zhu et al., 2006). The technology adoption framework developed by Rogers (1983) classified technology adoption according to the leader, internal and external characteristics. While the internal characteristics address similar elements to the organisational perspective of the Technology-Organisation-Environment (TOE) framework (Tornatzky and Fleischer, 1990) such as adoption-related costs, size, scope and aims, the external ones focus on the systems' openness through the business's perception and external cooperation. From small business research, Julien and Raymond's (1994) model is another interesting contribution. The model includes organisational, structural, and strategic factors, but omits technological factors, which are however an important aspect for complex new technologies such as HPC as they focus on the infrastructure, data quality, technology complexity, and available skills and competencies. Davis et al.'s (1989) technology acceptance model, albeit an interesting model pointing out the importance of beliefs and attitudes, also suffers from a limited set of included factors, which has been criticised before (Karahanna et al., 1999). We posit that the TOE framework (Tornatzky and Fleischer, 1990) is most suited to explore the adoption of HPC.

Tornatzky and Fleischer (1990) created a theoretical TOE framework identifying three contexts of technology adoption by explaining the process of adopting and using (i.e. practising) technological innovations from the technological, organisational and environmental perspectives. The technological perspective deals with systems openness of the firm, incorporating owned technologies as well as those available on the market (Zhu et al., 2003), the organisational with elements such as company size and scope, managerial structure, human resources and available slack resources, while the environment perspective deals with the way the company communicates with external environments. The technological perspective in particular addresses concepts related to IT infrastructure as well as technology skills including necessary technology competencies as well as employee-specific IT knowledge (Davis et al., 1989; Nam et al., 2019; Kuan and Chau, 2001; Nguyen, 2009; Thong, 1999). Organisational perspective also looks into perceived barriers, particularly those related to financial costs, e-business know-how and organisational readiness (Borstnar and Ilijas, 2019; Gilbert et al., 2004, Globerman, 1975; Utterback, 1974; Kuan and Chau, 2001; Nguyen, 2009; Thong, 1999; Zhu et al., 2003; Watson, 2002). Finally, the environmental perspective focuses on concepts related to competitive intensity and pressure, overall cooperation and systems openness (Fletcher, 2002; Grover, 1993; Iacovou et al., 1995; Kuan and Chau, 2001; Nguyen, 2009; Ongori et al., 2010; Premkumar and Ramamurthy 1995). Overall, this framework has been used for new information technologies supporting business (e.g. Zhu et al., 2003), information systems or big data analytics (e.g. Nam et al., 2019). Table 1 highlights the three perspectives of the TOE framework (Tornatzky and Fleischer 1990) that identify factors resulting from small businesses' engagement in the market and links them with the perceived determinants and theoretical concepts.

Insert Table 1 about here

Technology adoption models, including for example TOE (Tornatzky and Fleischer, 1990) or Julien and Raymond's (1994) model of organisational, structural, and strategic factors, include size as one of the factors. Mostly, size is seen as one of the organisational factors. However, small business research also points out that it might not be so much (only) the 'size' that matters when exploring small businesses, but 'time' does as well – mostly by emphasising the 'age' factor (Haltiwanger et al., 2013; Henrekson and Johansson, 2010). Nonetheless, we do not focus in our time dimension on 'age' as such, but rather focus on the 'time since adoption'

following works that examine differences in adoption beliefs and attitudes following the passage of time (Karahanna et al., 1999). Furthermore, the process of introducing an innovation – when not subjected to a lack of gradational understanding (Nam et al., 2019), i.e. not taking into account that introducing a technology is not a single stage – is often seen as a stage-based process (Grover, 1993). The three stages the author points out are the initiation (including initial steps culminating in the adoption), adoption (decision to commit (further) resources) and implementation (development and further activities that ensure the realization of benefits) (ibid). Similarly, Grover (1993) researched the adoption of telecommunication technology within organisations by identifying three adoption stages – the operations era (the impact of adoption on operational details and costs), the internal utility era (how to lower costs and complexity by implementing data processing), and the business infrastructure era (how can adoption escalate companies' performance).

2.3 High-Performance Computing and Small Businesses

There has been no research to date on HPC and entrepreneurship. Research on HPC adoption in small businesses is at an embryonic stage (see Ezell and Atkinson, 2016; Kindratenko and Trancoso, 2011; Wince-Smith, 2009). HPC technology (including both the application and the infrastructure side) is deployed to expeditiously compute and enumerate sets of intricate mathematical calculations, especially in comparison to using personal computers. It refers to systems that employ a combination of massively parallel processing capability and storage capacity, to solve complex computational problems through computer modelling, simulation, and data analysis, across a diverse range of scientific, engineering, and business fields (Dowd and Severance, 1998; Ezell and Atkinson, 2016) in a reasonable amount of time (Arora, 2016). Hence, HPC technology supporting extreme modelling, simulation and analysis is a strategic driver of innovation and a source of competitive advantage for businesses (Brochard, 2006; Ezell and Atkinson, 2016) across various industry sectors (Wince-Smith, 2009; Shephard et al., 2013; Osseyran and Giles, 2015).

HPC has emerged as one of the most relevant technologies today (Kindratenko and Trancoso, 2011). HPC encompasses the use of supercomputers and linked clusters (Arora, 2016) and has been seen as a key component enabling technology innovation, concentrating on solving national and international challenges (Wince-Smith, 2009). Different technology adoption frameworks have been used in studies of small

businesses and found to reduce production costs and shorten time-to-market (Fortissimo, 2020), as well as lowering vehicle design costs in the automotive sector (Ezell and Atkinson, 2016). Similar benefits can be pointed out for companies in the electronics sector.

The benefits of HPC adoption are extensively being applied in large organisations, national governments and agencies to use the available large computational power of HPC to model and simulate their products or services. A similar level of adoption of HPC to SME processes is, on the other hand, almost polar opposite (as seen with emerging IT adoption in general) with a low level of enablement of HPC infrastructure. With SMEs predominately dealing with limited resources and at the same time experiencing lower public funding opportunities that subsequently contribute to the greater gap in tech-savvy competencies, investments in HPC infrastructure is not their top priority, regardless of potential cost-effective options of HPC as a service (Koller et al., 2015).

Despite the initiatives, the deployment of HPC technologies among small businesses has been scarce (Lee and Jeong, 2020) due to high purchase and maintenance costs (Geist and Reed, 2017), lack of HPC specific knowledge, skills and competencies, and low awareness about how HPC can boost the levels of innovative capacities and offer a competitive edge (Borštnar and Ilijaš, 2019). While these characteristics are widely known and create a high barrier for SMEs to overcome, few of them have explored their options further. Like many cloud computing solutions, HPC infrastructure can also be utilised as a service rather than owned, thus bringing SMEs' costs of HPC adoption to a fraction of the price of purchasing their own technology. In addition, being able to hire appropriate knowledge to use the technology, when necessary, rather than employing it, reduces the cost of HPC adoption even further. By comparing this investment compared to an investment in developing and building a new prototype of a future product, small businesses can find themselves in a situation where HPC adoption is not only financially more viable but also gives them more room to explore many variations of their future products. Albeit the 'why' is clear, we need to also understand the 'how' and 'when' to gain a comprehensive picture of HPC adoption.

3 Methodology

3.1 The Exploratory Approach and the Research Setting

Our choice of an exploratory study was motivated by the fact that HPC has been the focus of few empirical studies (Ezell and Atkinson, 2016), with

almost no comprehensive data on companies adopting and using the HPC available. An exploratory study can however expose the patterns of HPC adoption with respect to when and why. This approach enables a wider understanding of the adoption stages and the relationships between adoption and entrepreneurship stages concepts.

The study is set in the Danube region of Europe and includes small and medium-sized companies from the automotive, electronics and IT sectors. The Danube region is an interesting European macro-region, which includes some of the most developed (e.g. Austria) and least developed (e.g. Bulgaria) parts of Europe. Hence, it allows exploration of organisations embedded in a variety of environments, without the need to focus on only those that are typically studied, i.e. those from more well-off parts, which allows us to overcome one of the potential limitations of studies related to information technologies adoption (Zhu et al., 2003). The European Union Strategy for Danube Region (EUSDR) aims to develop policies and actions to support and strengthen the development of this region. The digital transformation and the adoption of HPC is seen as the path toward re-industrialising the region and closing the gap between dispersed parts of this region (Besednjak Valič, 2019).

HPC is seen as a tool to increase competitiveness for small and medium-sized companies, which represent the backbone of the European economy – making the adoption of HPC by entrepreneurs in small and medium-sized companies an important goal. Nonetheless, these entrepreneurs can be faced with unique sets of problems, which can affect the how and when of HPC being adopted. Similarly, as for some other newly deployed information technology and big data analytics methods (compare e.g., with Nam et al., 2019), companies, especially smaller companies and entrepreneurs, are hesitant to actively apply HPC, hence it remains challenging to collect adoption and usage data on HPC.

The automotive, electronics and IT sectors were chosen because this limits the amount of low-technology companies we might contend with within the study. Many of the included companies are suppliers for original equipment manufacturers. Another consideration was that companies from these industries are characterised by the relatively rapid uptake of this technology.

3.2 The Taxonomy

Our goal is to classify the cases into several groups in terms of their adoption of HPC. One of the main problems in many disciplines is the

classification of objects of interest into taxonomies (Bailey, 1994; Sokal, 1966). We use the term 'taxonomy' since our classification system is derived empirically; in contrast, a 'typology' would be derived strictly conceptually (Bailey, 1994). This problem is relevant also when engaging in exploratory studies, such as ours, which focus on an underresearched theme. A taxonomy approach has been used in many studies related to information technologies (e.g., Nickerson et al., 2013; Addas and Pinsonneault, 2015; Oberländer et al., 2019), as well as in innovation (e.g., the seminal work of Pavitt, 1984) and entrepreneurship studies (e.g., Wiklund et al., 2009; Zahra, 1993). This corresponds to Bailey's (1994) understanding of classification as a process in which entities are ordered into groups based on similarity. Subsequently, by exploring also the differences between our groups of cases, we are then able to develop a taxonomy of HPC adopters. Finally, we interlace these groups of HPC adopters with stages of entrepreneurship.

Furthermore, we aimed to avoid the situation of 'naïve empiricism' (Aldenderfer and Blashfeld, 1984), where we would simply examine several related or unrelated determinants in the hope that some pattern will emerge. We thus wanted to avoid the criticism of using an *ad hoc* taxonomy approach and to surpass what Bailey (1994) calls the intuitive approach, where researchers use only their understanding of the cases to propose a taxonomy (model) based on the researcher's perceptions of what makes sense. In contrast, we start off exploring the more complex 'how' with theory-based dimensions based on the TOE framework (Nam et al., 2019; Zhu et al., 2003): technological, organisational and environment, and their related determinants (in taxonomy papers also referred to as 'variables' or simply 'dimensions'). Our approach includes several elements of the iterative taxonomy approach (Nickerson et al., 2013).

3.3 Data

Departing from a single-case study approach, which is relatively common in research on new IT solutions adoptions, we relied on data collected as part of the High-performance Computing for Effective Innovation in the Danube Region (InnoHPC) project. The project was a multinational endeavour, with data collections taking place during 2017-2018 (InnoHPC, 2020). The project included several surveys as well as interviews and focus groups. This includes the InnoHPC (ANON) survey we primarily rely on, as well other data collections, such as focus groups, inside the Danube Region from which we draw some additional context information. This

approach is well suited to classify our cases and reveal the HPC adoption patterns as related to 'when' and 'how'.

The empirical evidence for both 'how' and 'when' inside this study is drawn primarily from the InnoHPC enterprise (ANON) survey data, which includes data from smaller companies from Austria, Bosnia and Herzegovina, Bulgaria, Croatia, Czech Republic, Germany, Montenegro, Romania, Slovakia and Slovenia. The ANON dataset represents the first comprehensive list of companies using, or considering using, HPC in the Danube region. The data collection instrument and procedures were identical at all the locations. To ensure this, the questionnaire has been previously developed inside the InnoHPC consortium, together with an extensive protocol document.

The survey was conducted with a total of 41 companies, which have at the time of data collection been using HPC [2]. These companies were both large and small and active in the automotive, electronics and IT sectors, with different ages (time since incorporation). Since we are not interested in large companies, we focus in this article only on the 28 small companies (including also companies with under 10 employees) that used HPC. The cases we focus on in this article share the following four broad characteristics that allowed for critical case sampling (Onwuegbuzie and Collins, 2007): 1) they are companies active in the Danube region at the time of data collection; 2) the companies were active in one of the predesignated sectors; 3) companies have less than 249 employees, and 4) all companies use HPC at the time of data collection. Table 2 summarises the sample characteristics, including firm size, industry category, time since incorporation (age) and time since HPC adoption.

Insert Table 2 about here

Two strategies were used when identifying the relevant respondents and collecting this data. Firstly, the InnoHPC consortium used the networks of its outreach partners (e.g. the Slovenian Chamber of Commerce, via its Electronics and Electrical Industry Association) and other relevant support organisations (e.g. the Slovenian Automotive Cluster, ACS) to compile and engage potential relevant organisations. Secondly, web searches and screening questions were used to understand whether the companies use HPC and who would be the most appropriate respondents, which would correspond to the notion of elite informants in qualitative research. Elite informants can be highly skilled professionals, which are ideally a part of the technology adopting unit, or top-ranking executives (Kincaid and

Bright, 1957; Hage, 1980), in our case persons with an adequate overview over the adoption and use of HPC in their company.

The authors had access to additional data including companies' details, as well as additional access to the focus groups and interview materials since some of the surveyed companies were also later included in the focus groups (for example all three small companies from Slovenia). However, the authors use the focus groups and interview data only to better understand the underlying context of HPC adoption in the surveyed companies.

3.4 Data Analysis

To proceed with our taxonomy exercise, we need to first determine the so-called meta-characteristic, i.e. the attributes of the object of interest themselves. Their choice should be based on the purpose of the taxonomy (Nickerson et al., 2013). In our case, we aim to explore the HPC adoption process in relation to the 'how' and 'when' perspectives. Thus our meta-characteristic is the time-how nexus. For the 'how' nexus we apply the TOE framework which is mirrored in the three dimensions of our taxonomy model. The 'when' is based on time since adoption and included in our final taxonomy model.

For our analysis, we take into account Nickerson et al.'s (2013) iterative taxonomy approach. The analysis in the first step let us break down the determinants (dictated by the TOE framework) into characteristics, e.g. the determinant 'benefits' into characteristics 'strategic' and 'operational'. From the bottom-up, we systematically clustered the value descriptions into higher-order characteristics to develop, relate and segregate them. For example, the initial value descriptions related to individual characteristics ranged from 'faster time to work' to e.g. 'increased competitiveness. We re-coded the data (i.e. collapsed the value descriptions) several times to better reflect individual characteristics according to our evolving understanding of the data, thereby creating an initial classification system. We have done so in the need to avoid redundancy and to increase their explanatory power. To illustrate more in-depth using the example of 'domains', i.e. fields in which HPC is used in the organisation, we recoded domains' value descriptions in the characteristic 'Type I' and in the characteristic 'Type I & Type III' innovations following Swanson's (1994) classification. Type I (dealing with technical tasks) includes, for example, its use in R&D and engineering (design), Type II includes supporting the administration of the business and Type III integrates the new technology (the innovation) with the core business processes. However, most likely due to the nature of the HPC, we

do not come across examples with only Type II innovations, but we have found companies declaring besides Type I also Type III innovation especially related to large data management. The re-coding was done jointly by two of the co-authors of this paper.

Our initial taxonomy T_1 included the classification of the determinants into the three TOE dimensions [$_{DIM}$]. It consisted of determinant D_1 = Benefit with characteristics C_{11} = Operational and C_{12} = Strategic; of determinant D_2 = Technology approach with characteristics C_{21} = Inward focused and C_{22}= Outward focused, and so on. Put more simply our initial taxonomy T_1 was:

T_1 = {Technological$_{DIM1}$
[Benefits$_{D1}$ (Operational$_{C11}$, Strategic$_{C12}$),
Technology approach$_{D2}$ (Inward focused$_{C21}$, Outward focused$_{C22}$),
Available technology skills$_{D3}$ (Lacking$_{C31}$, Sufficient$_{C32}$)],
Organisational $_{DIM2}$
[Barriers$_{D4}$ (Internal $_{C41}$, External $_{C42}$),
Domains $_{D5}$ (Type I innovation only $_{C51}$, Type I & Type III inno.$_{C52}$),
Aims $_{D6}$ (Operational $_{C61}$, Strategic $_{C62}$),
Size $_{D7}$ (Small $_{C71}$, Medium $_{C72}$)],
Environmental $_{DIM3}$
[Perception $_{D8}$ (Weak $_{C81}$, Strong $_{C82}$),
Cooperation $_{D9}$ (None $_{C91}$, Existing $_{C92}$),
Openness $_{D10}$ (Less restricted $_{C101}$, More restricted $_{C102}$)] }

This led us to the step in which we aimed to reach so-called ‘ending conditions’ (Nickerson et al., 2013). This also meant that from an initially identified set of characteristics, some needed to be grouped to increase the potential to group and differentiate between the groups of HPC adopters. This can be achieved in various ways, including informally, i.e. using a manual or graphical process (Nickerson et al., 2013). For example, the factor “benefits” originally (as seen above) had themes “strategic” and “operational”, based on the question of “direct benefits of HPC for the organisation”, but as several types of organisations in relation to HPC adoption and entrepreneurial stages slowly emerged, we also introduced the characteristic “emerging strategic”. Furthermore, this enabled us for example to discover that there is a group of companies that use a specific mixed approach in terms of ‘technology approach’, which is diverse from

companies that use either an inward or outward-focused approach; these companies were later identified as part of the early adopters' group. In the end, this led us to our finalised taxonomy model of $T_{FIN\ (how\ x\ when)}$:

$T_{FIN(how\ x\ when)}$ = {Technological$_{DIM1}$
[Benefits$_{D1}$ (Operational$_{C11}$, Strategic$_{C12}$, Emergent strategic $_{C13}$),
Technology Approach$_{D2}$ (Inward focused$_{C21}$, Outward focused$_{C22}$, Mixed $_{C23}$),
Available technology skills$_{D3}$ (Lacking$_{C31}$, Sufficient$_{C32}$],
Organisational $_{DIM2}$
[Barriers$_{D4}$ (Int. only $_{C41}$, Inter. & external $_{C42}$, Mult. int, & ext. $_{C43}$),
Domains $_{D5}$ (Type I innovation only $_{C51}$, Type I & Type III inno. $_{C52}$),
Aims $_{D6}$ (Operational $_{C61}$, Strategic $_{C62}$, Emergent strategic $_{C63}$),
Size $_{D7}$ (Small $_{C71}$, Medium $_{C72}$)],
Environmental $_{DIM3}$
[Perception $_{D8}$ (Weak $_{C81}$, Strong $_{C82}$),
Cooperation $_{D9}$ (None $_{C91}$, Existing $_{C92}$),
Openness $_{D10}$ (Less restricted $_{C101}$, More restricted $_{C102}$)]
}
x {Time $_{DIM4}$ [Time since adoption $_{D11}$ (Shorter $_{C111}$, Mid-term $_{C112}$, Longer $_{C113}$)] }

This addition of determinants or characteristics allowed our model to be more robust. Our final taxonomy model $T_{FIN\ (how\ x\ when)}$ also includes the additional 'time' dimension, answering the 'when'. This dimension is based on the time since HPC adoption with three values (i.e. characteristics): shorter, mid-term and longer.

Always when adding to the model, or recoding inside the model, we updated the determinants with detailed definitions and parameters for each determinant, to provide a way to explore differences between cases and potential types of cases across our determinants and characteristics (compare Shankar and Shepherd (2019) as they do this on the level of categories, i.e. on the level corresponding to our characteristics). Appendix 1 provides an overview of the dimensions, determinants and their descriptions, characteristics as well as the original questions from the survey for the final taxonomy model.

We believe the number of determinants allows the taxonomy to be meaningful without being unwieldy or overwhelming, i.e. we trust it complies with the ending condition of conciseness by Nickerson et al. (2013). All our cases can be classified along our characteristics (comprehensiveness). The dimensions and determinants not only allow us to say something meaningful about our cases but also provide sufficient differentiation between our cases (robustness). Figure 1 shows not only the relevant 'how' dimensions, determinants, characteristics and value descriptions but also adds on the left-hand side the 'when', which is added after the original iteration.

Insert Figure 1 about here

We have proceeded by exploring the individual dimensions. We expose various determinants in which we can see differences along with the how-when nexus. However, among determinants used to compare our cases, several also seem to be untouched by the 'when'. For example, under the technology dimension, albeit we can see that SMEs, as time goes by, can recognise strategic benefits, however, the operational benefits (accelerated innovation and faster time to work) also remain in focus regardless of the length of HPC adoption within the company. We can see several other such elements: e.g., within the 'aims' or 'barriers' inside the organisational dimension, or 'openness' inside the environmental dimension, that seems time resistant.

We initially grouped companies into four groups according to the length of their HPC adoption (i.e. the 'when' dimension). Due to the nature of the HPC, we included in the *initiation stage* also the act of the initial adoption, since practically any use of HPC already requires relatively high commitments of initial resources, when compared to other technologies. Secondly, we acknowledged that in the *adoption stage* considerable additional resources typically need to be deployed, to enable broadened scope of use (domains) of HPC. Lastly, the full implementation would require *ad minimum* an understanding of strategic benefits and a striving to reach strategic aims. Through our iterative analysis we in the end identified three categories of HPC adopters – which are based on the 'how' in addition to the 'when' – collapsing the previous two categories of under one year (nascent) and the one to three years (emergent), into a single group of emergent adopters, due to corresponding 'how' dimensions.

4 Findings

We have organised our findings into two sections. In the first section, we present our findings according to the how-when nexus. In this regard, we analysed our data according to the above-described TOE framework for the 'how' dimension and added the 'when' dimension to explore the HPC adoption. For our second part, we present technology adoption across the stages of entrepreneurship as applicable to our study.

4.1 Taxonomy of Technology Adoption How-When Nexus

Based on the available data we first analysed the 'how', using the key factors of the TOE framework in observed SMEs for the three groups of technology adoption over the stages of entrepreneurship (Emergent Initiators, Early Adopters and Growth Assimilators) (see Table 3). While there is an evident shift in Technological and Organisational factors dependent on the length of HPC adoption within the companies (both in factors as well as their strength), the Environmental key observed factors vary only slightly in strength. Although we found some commonalities across the cases, we also found identifiable differences between distinct types of HPC adopters according to time since adoption over the stages of entrepreneurship.

Insert Table 3 about here

4.1.1 Technology Dimension Determinants

Within the technology dimension, the benefits of using HPC for the companies that have recently (i.e., within the last year) adopted HPC, are connected especially with faster time to work and thus with accelerated innovation. But for the companies that have used this technology a bit longer (i.e., for at least three years) they additionally recognise the benefits connected to increased competitiveness. The emphasis of benefits especially for SMEs that use HPC the longest also focuses on increased productivity. Interestingly, only a single SME in the sample mentioned concrete increased sales through a HPC related solution. Hence, customer-related reasons seemingly play less of a role in HPC adoption. Customer-related reasons have been also overall in terms of adopting new solutions limited to more e-business intensive countries (compare e.g., Zhu et al., 2006). In terms of the technology approach, the majority of SMEs use externally developed software, but surprisingly many of the SMEs have

purchased in at least some infrastructure. SMEs that have used HPC for more than five years have an inward-focused approach to technology. Connected to available technology skills interestingly more than three-fifths of our sample companies (17 SMEs) know how to identify both the relevant HPC skills they already possess, as well as those they still want to acquire: ranging from HPC Code Development to Linux Shell Scripting. In general, the perception of available skills slowly improves with the age since HPC adoption.

4.1.2 Organisation Dimension Determinants

In terms of 'domains', i.e. fields in which HPC is used in the organisation, all of the companies declare either only 'Type I' or both 'Type I & Type III' innovations – most likely due to the nature of the HPC. Type I includes for example its use in R&D and engineering (design). To exemplify, we turn to one of the small companies included in our sample and use additional material available to us (i.e. deriving from an interview). We can see that this medium-sized company from the south-eastern part of Europe is a small original equipment manufacturer from the automotive sector. The company uses HPC for engineering (design) of new car model features; and has used HPC for modelling and complex simulations deriving the optimum design in connection to the airflow when driving at different speeds. HPC simulation provided results closer to the real driving performance than those obtained through the use of conventional computers, i.e. computing power. Whereas firms adapting the technologies more recently reported only 'Type I' innovation, other firms in our sample have also reported 'Type III' innovations (besides 'Type I').

In terms of operational aims solving problems and development of new products/services persist across time. Nonetheless, as time from adoption lengthens, first an additional strong focus is on recognising some strategic aims, especially the potential for improvement of processes as such, i.e. what we name emergent strategic. In addition, characteristics such as facing external barriers are found throughout, yet the number of diverse barriers also increase as the time since adoption lengthens. Those companies that adopted HPC more than five years ago are the first ones that recognise not only the lack of immediately needed skills and knowledge but are also are concerned with a more systemic lack of appropriate training opportunities – an area where new solutions are emerging, due to reported benefits of such training (Fernández et al., 2019).

The organisational dimension also includes the size of the company in line with other taxonomies using the TOE framework, and with medium-

sized companies being proportionally distributed across our adoption groups we identify in Section 4.2. A simple alternative explanation for the differences between adoption groups could be the size of the adopter; however, in our sample, we have, for example, several smaller companies (micro or small) that adopted HPC more than five years ago (eight small businesses) and we also have several medium-sized companies that have adopted HPC less than three years ago (six such SMEs).

4.1.3 Environmental Dimensions

In terms of the perception characteristic, which is a part of the environmental dimension, we observe that the perception of HPC use within their focal industries by the SMEs in our sample is surprisingly strong. This is in line with ideas that (perceived) competition pressure can have a positive influence on the adoption of new IT and big data solutions (compare e.g., Gangwar, 2018). However, six of the companies that adopted HPC less than three years ago seemed unable to provide an answer to this question.

In terms of cooperation, we observe the SMEs' participation in international projects. We do so due to two reasons: first, the HPC is in terms of infrastructure, not space-bound – meaning dislocated capacities, often located in centers or even across borders, can be reached; and second, that the whole field is strongly influenced by the ability to cooperate, often with public research centres with HPC capabilities. We can observe that as time passes there is an interesting focus on private-sector partnerships. On the other hand, a restricted openness to other companies in terms of the environmental dimension somewhat persists, and seems to be less affected by the lengthening of time since adoption – only the companies that adopted HPC more than five years ago report a somewhat less restricted approach, but could still be restricted within controlled partnerships.

We turn to these distinct HPC adopters groups in the next section.

4.2 HPC Technology Adoption and Stages of Entrepreneurship

We classified the surveyed SMEs into three distinct categories according to the length of their HPC adoption, i.e., on 'when': *emergent initiators* consists of companies using HPC for three years or less, early adopters of those using HPC between four and five years, and *growth assimilators* of those adopting HPC (infrastructure and broadly related solutions) for more

than five years. We however believe they correspond to only two stages of entrepreneurship.

4.2.1 Emergent Initiators – Emergent Stage of Entrepreneurship

Their main aims in HPC adoption are linked with their increasing day-to-day HPC use, thus addressing operational aims such as identifying solutions to existing problems, developing new products/services and/or working more efficiently. While they do recognise the accelerated innovation and faster time to work as the key benefits of the adoption in the long term, in the first year of the adoption the benefits are still connected to operational aims, and not strategic ones. A slight shift emerges after a year of HPC adoption, where strategic aims gain some recognition and are linked with additional benefits such as increased competitiveness and reduced costs. While HPC is first applied and primarily focused in the R&D domain, with time additional domains such as engineering and manufacturing become of interest, thus slowly becoming embedded in the whole production cycle. While HPC adoption commences with companies mainly using open-source software applications and leased infrastructure due to limited use of their own software and hardware, after the first year a change of approach to technology is evident, with a strong emphasis on an inward (internal) focused approach by applying commercial software applications on their own infrastructure. The lack of ownership of their own hardware and software solutions as well as lack of cooperation in (international) projects, seem to go hand in hand with restricted openness of their own solutions. In addition, identified barriers include the lack of (internal) funding, high costs of adoption and the lack of available HR/tech knowledge (internal by nature), thus forcing the companies to look for cooperation outside by seeking involvement in publicly funded international projects related to HPC topics. This consequently shifts the openness in terms of allowing access to their own facilities to be less restricted and has a key impact on successful mid and long term HPC adoption within the company. Finally, the recognised perception of HPC adoption and its consequential justifiable use in the respective sectors/industries is weak.

4.2.2 Early Adopter – Emergent Stage of Entrepreneurship

These firms are pursuing an increased number of strategic aims, primarily emphasising those directly connected to improving business process innovation, while still focusing on achieving the Emergent Initiators' aims. We classify the day-to-day use of HPC and its benefits as emerging strategic

with higher numbers of recognised benefits, with increased productivity at the forefront. These companies are still focused on the R&D, engineering and manufacturing domains with a new addition of large-scale data management domain, thus adding to embeddedness in the whole production cycle also the potential from big data management. A mixed-focused approach to technology is evident by companies opening up to also include open-source software applications and hire additional hardware capacities when needed. Yet, the openness to their own facilities remains restricted. Identified challenges have increased in numbers, and are both internal and external, and additionally include lack of partners/ecosystem/public initiatives. Finally, after four or five years of HPC adoption, the perception within the same industries is growing stronger.

4.2.3 Growth Assimilators – Late Stage Entrepreneurship

Growth assimilator firms have successfully adopted HPC the longest. They are pursuing a high number of strategic aims, primarily emphasising improving business process innovation as well as solving problems and working more efficiently. Strategic benefits such as increased competitiveness are the focus, in addition to faster time to work and increased productivity. They continue to be embedded in the whole production cycle and big data management domains within the HPC application approach. Another shift in approach to technology, however, is evident by companies again adopting a more inward focus by in-house developed software applications and the use of their own infrastructure. Maintaining a strong perception of HPC use and registering both internal and external challenges (also including lack of education/training as one of the key ones) the companies are now having to look for cooperation outside such as involvement in the privately funded international projects related to HPC topics.

4.2.4. Three Groups of HPC Adopters and the Two Stages of Entrepreneurship

To summarise our findings, three distinct groups of SMEs adopting HPC technology were identified in regard to when and how the HPC adoption occurs (see Figure 2). In Figure 2, we present the three groups of companies and how they are connected to stages of entrepreneurship. Our findings show that only two stages of entrepreneurship are relevant with respect to technology adoption in our exploratory study – emergent and late-stage entrepreneurship. We found no evidence of technology adoption in

the nascent stage of entrepreneurship. A reason for this may be due to the highly specialised nature of the IT, costs and specialised know-how and human capital. The growth assimilator companies are linked to the late-stage entrepreneurship, and the emergent initiators and emergent adopters to the emergent stage of entrepreneurship. However, there are nuanced differences between them in terms of technology adoption. For emergent imitators, their initial aim and benefits focus is operational whereas, the early adopters' aim and benefits are more strategic. Our findings highlight there are some differences in the how when nexus with respect to technology adoption within a stage of entrepreneurship. Furthermore, we identified elements that influence the successful adoption of HPC in SMEs, by addressing our research focus of how and when technology adoption happens. Eight elements were identified, and SMEs' ability to focus on them plays a key role in how HPC adoption happens (see Figure 2).

Insert Figure 2 about here

5 Concluding Remarks

The purpose of our paper is to examine how and when technology adoption occurs over the stages of entrepreneurship. Our exploratory study is not without limitations. For our study, we relied on secondary data available within the confines of an applied funded research project. The additional documentation that we were able to access enabled us to provide some additional insights. Furthermore, our exploratory study has a small sample study based on a survey; a larger sample study could include, for example, also latent HPC entrepreneurs. Our exploratory study only investigated HPC adoption as such. The study was also only able to capture a static picture of adoption – hence we cannot observe the (potential) mobility of these organisations through various stages of adoption and entrepreneurship. We also do not explicitly address the issue of the age (time since incorporation), but with our companies representing a wide time range; from 2 years to 28 years since incorporation, and is well balanced. Since we have collected this information at a later stage manually, we could not recover data for all the companies in our sample. Furthermore, albeit our quick overview of intergroup variability does not reveal any particular insights, we urge others to explore also the age of the companies in relation to the adoption of HPC, especially for the variables we identified as time-resistant. Lastly, our definition of small companies, which includes also

micro-companies – albeit making sense for our study, which takes place in a diverse European setting, and is related to a new general-purpose technology, which is often taken over either by large companies or by highly innovative small ventures – may limit the comparability of our results to other future studies. However, the different definitions employed is a problem not uncommon to other (taxonomy) studies on small companies, (see Wiklund et al., 2009)).

Our exploratory study, whilst acknowledging the limitations, has identified technology adoption across the stages of entrepreneurship (see Caiazza et al., 2020). Our study focused on the *how* and *when* nexus with respect to HPC technology adoption and to our knowledge it is the first study of its kind with respect to this technology. Our first contribution focuses on a taxonomy model of technology adoption along the stages of entrepreneurship with respect to when and how. This addresses the paucity of research attention and focus on this topic. Specifically, we identify *how* dimensions with respect to technological, operational and environmental and *when* dimensions – time since technology adoption across the stages of entrepreneurship. This advances our understanding at the micro-level in relation to how specialised and advanced technology adoption matters (see Autio et al., 2018). It highlights how specialised technology adoption can be utilised to address strategic and operational aims at one stage of entrepreneurship, the emergent stage. In doing so we study extend the studies of technology adoption that have to consider such wider issues as IT technology skills and knowledge (Nam et al., 2019; Nguyen, 2009; Thong, 1999) and organisational barriers and challenges such as financial costs, organisational readiness (see Borstnar and IIijas, 2019; Gilbert et al., 2004). Our study extends these wider considerations as we specifically identified the dimensions, determinants and characteristics of HPC technology adoption over the stages of entrepreneurship. Acknowledging the limitations of our study we suggest that future studies could use a similar approach to extend our findings for technology adoption across the stages of entrepreneurship for different technologies such as augmented/virtual reality, civic technologies, exascale computing. Our study contributes to the ongoing debate whether SMEs should buy in externally developed technology (infrastructure and software) or should they develop in house (Daneshgar et al., 2013). For HPC our study findings would suggest that SMEs technology adoption approach across the stages of entrepreneurship is predominately focused on buying in (see Borstnar et al., 2015). This technology adoption approach seems to be dependent on know-how and having the necessary in skills- in our study HPC skills.

Our second contribution lies in identifying three categories of HPC technology adoption – *emergent imitators, early adopters, growth assimilators* – across the two stages of entrepreneurship, emergent and late-stage entrepreneurship. We found technology adoption differences within a stage of entrepreneurship. Such difference may be explained by the societal context (see Kibler and Kautonen, 2016) and the resources available to the firm as well as how they learn at the stage of entrepreneurship (see Boccardellie and Magnusson, 2006). Such differences could also be accounted for by the entrepreneurial intent and behaviour of the firm founder within this critical stage of entrepreneurship (see Gartner and Carter, 2003; McAdam and Cunningham, 2019; Schlaegel and Koenig, 2014; Welter, 2005).

Our findings with respect to the how and when nexus for late-stage entrepreneurship are reflected in the growth assimilator category. Firms in this category have taken a strategic approach to technology adoption and therein, have adopted a more open approach, while having a more inward technology focus. One explanation for this is that these firms have adopted some competencies and trust that enable them to operate in such a manner (see Lee and Kim, 2018; Panda et al., 2020). Also, the late-stage entrepreneurship characteristics affords such firms the ability to adopt and pursue technology adoption in such a manner (see Lockett et al., 2008). Interestingly we did not find any firms in our study that aligned with the nascent and latent stages of entrepreneurship. This points out that the adoption of HPC solutions is relatively new to the market and the financial costs are high particularly for a nascent entrepreneur. Also, the use by small businesses of HPC is less related to more customer-oriented reasons as is commonly seen for adoption (Nguyen et al., 2015).

Our study has some practice and policy implications. For entrepreneurs considering adopting technology through emergent and late-stage entrepreneurship, our study provides practical dimensions that they need to consider about how they go about technology adoption and integration as part of their firm's activities and operations. In practice it may mean enhancing the existing technology skills in the firm, investing in IT applications or securing access to HPC infrastructure. Such efforts may also require entrepreneurs to collaborate with a variety of external service providers and other actors to utilise HPC effectively and to accrue the benefits. Moreover, it highlights for entrepreneurs at a practical level how they can use technology adoption to overcome some operational challenges thereby meeting existing customer requirements. Entrepreneurs should consider integrating technology adoption as one element of wider organisational responses to operational challenges.

Alternatively, they can use technology adoption at the emergent stage to take a more strategic approach that addresses anticipated or identified external market opportunities. In this case, they are taking a medium to long term view of their environment and how they secure a sustainable competitive position through HPC integration (infrastructure and application) in all aspects of their operations. This requires a knowledge of HPC but also the capacity to identify market opportunities in which HPC can be deployed to the greatest effect. Furthermore, from a practical perspective, it affirms the need for entrepreneurs to maintain an open mindset and approach to technology adoption. This means they need to be open-minded to learn and become familiar with consistently and systematically exploring new technologies and then being able to determine their potential application or not in the context of their firm.

For policymakers pursuing technology policy with respect to emergent technologies designed to have economic, societal and public good they need to carefully consider how different industry stakeholders – MNCs, SMEs and entrepreneurs at all stages – can access and adopt technology within their context. Our study highlights to policymakers the need to give careful attention to how they can support technology adoption for entrepreneurs at all stages of entrepreneurship across different industry settings. This may require a more nuanced set of policy and incentive responses to encourage greater technology adoption among entrepreneurs across the stages of entrepreneurship.

Finally, our exploratory study opens up future avenues of research as our study adds to the limited studies of HPC (see Ezell and Atkinson, 2016). There is a general need for more studies on HPC within entrepreneurship, information technology and public policy fields. There is a need for studies to focus on nascent and latent entrepreneurship and technology adoption with respect to the how and when nexus. With additional data, it would be possible to expand on our study and take an in-depth approach to examine HPC implementation processes across a range of industry settings. Further studies should examine the benefits (economic, technological and societal) on HPC performance. There is also a need to undertake comparative technology policy studies of HPC across various different country and industry settings.

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Notes

[1] The interview and focus groups included both representatives of SMEs and of other stakeholders.

[2]There were 97 companies in total, however in this paper we are not focusing on the companies that responded they either do not use HPC or only are thinking of maybe adopting HPC.

Table 1. HPC emerging technology adoption contextual considerations.

Perspective	Perceived determinants	Concepts	References
Technology related	Technology approach	IT infrastructure	Nam et al. (2019), Kannabiran and Dharmalingam (2012), Kuan and Chau (2001), Iacovou et al. (1995); Gilbert et al. (2004), Nguyen (2009)
	Available tech skills	Technology skills (including tech competences, employee specific IT knowledge)	Kuan and Chau (2001), Nam et al. (2019), Nguyen (2009), Thong (1999), Borstnar and Ilijas (2019)
	Benefits	Perceived benefits	Davis et al. (1989); Karahanna (1999)
Organisation related	Barriers	Perceived barriers/Perceived financial cost	Kuan and Chau (2001), Gilbert et al. (2004), Borstnar and Ilijas (2019)
	Domains	E-business know-how/Implementation domains	Nguyen (2009), Thong (1999), Gray (2006), Borstnar and Ilijas (2019)
	Size	Business Size	Globerman (1975), Utterback (1974), Thong (1999)
	Aims	Organisational readiness	Nguyen (2009), Zhu et al. (2003), Iacovou et al. (1995), Thong (1999), Watson (2002)
Environment related	Perception	Competitive intensity/pressure	Grover (1993), Iacovou et al. (1995), Kuan and Chau (2001), Premkumar and Ramamurthy (1995)
	Cooperation	Cooperation (trading partners)	Fletcher (2002), Nguyen (2009)
	Openness	Systems openness	Ongori et al. (2010), Kuan and Chau (2001)

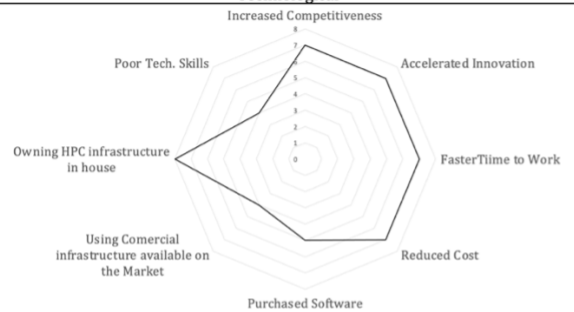
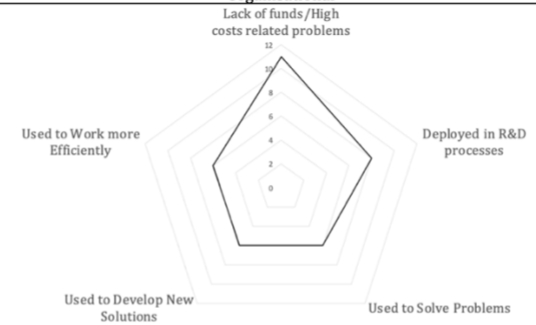
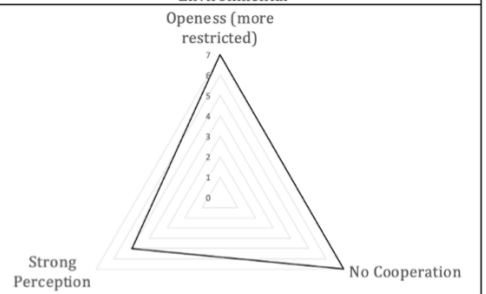
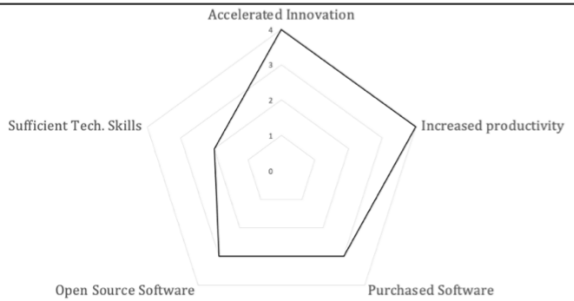
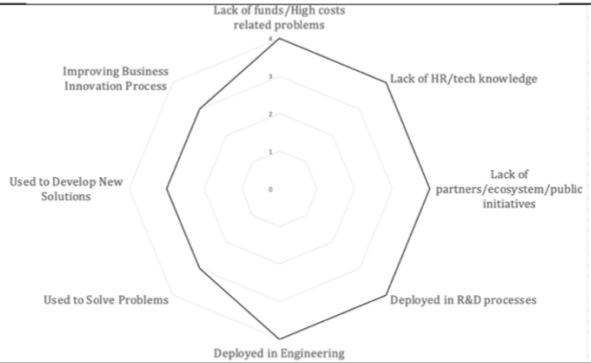
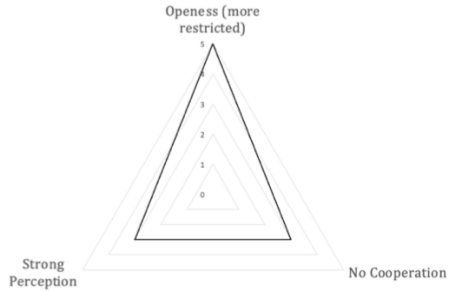
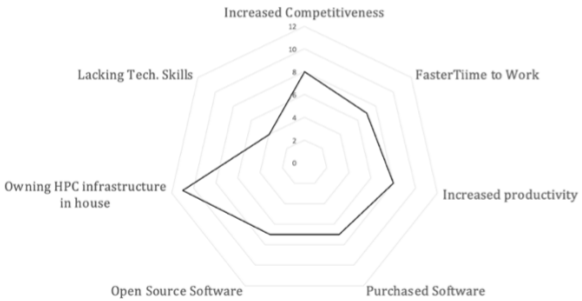
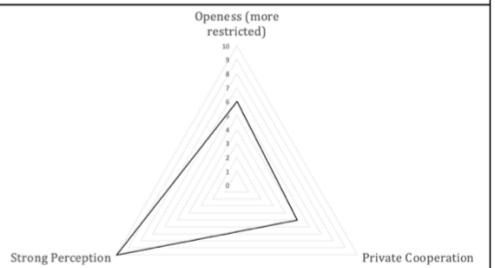
Table 2. Study firm characteristics

	Observations	Percentage (%)
Size (no. of employees)		
<10	8	28.6
10-49	9	32.1
50-249	11	39.3
Industry		
Automotive	11	39.3
Electronics (including IT)	13	46.4
Other	4	14.3
Age		
0-10yrs	8	28.6
11-20yrs	8	28.6
21yhrs-	7	25.0
n/a	5	17.9
Time since HPC adoption		
Shorter	12	42.9
Mid-term	5	17.9
Longer	11	39.3

Notes. Electronics & IT sector includes seven companies from the IT sector. The category other includes instances when the companies operate at the cross-section of automotive and electronics.

Title

Table 3. Key TOE factors based on the length of HPC adoption within SMEs

When	*How*		
	Technological	**Organisational**	**Environmental**
Shorter			
Mid-term			
Longer			

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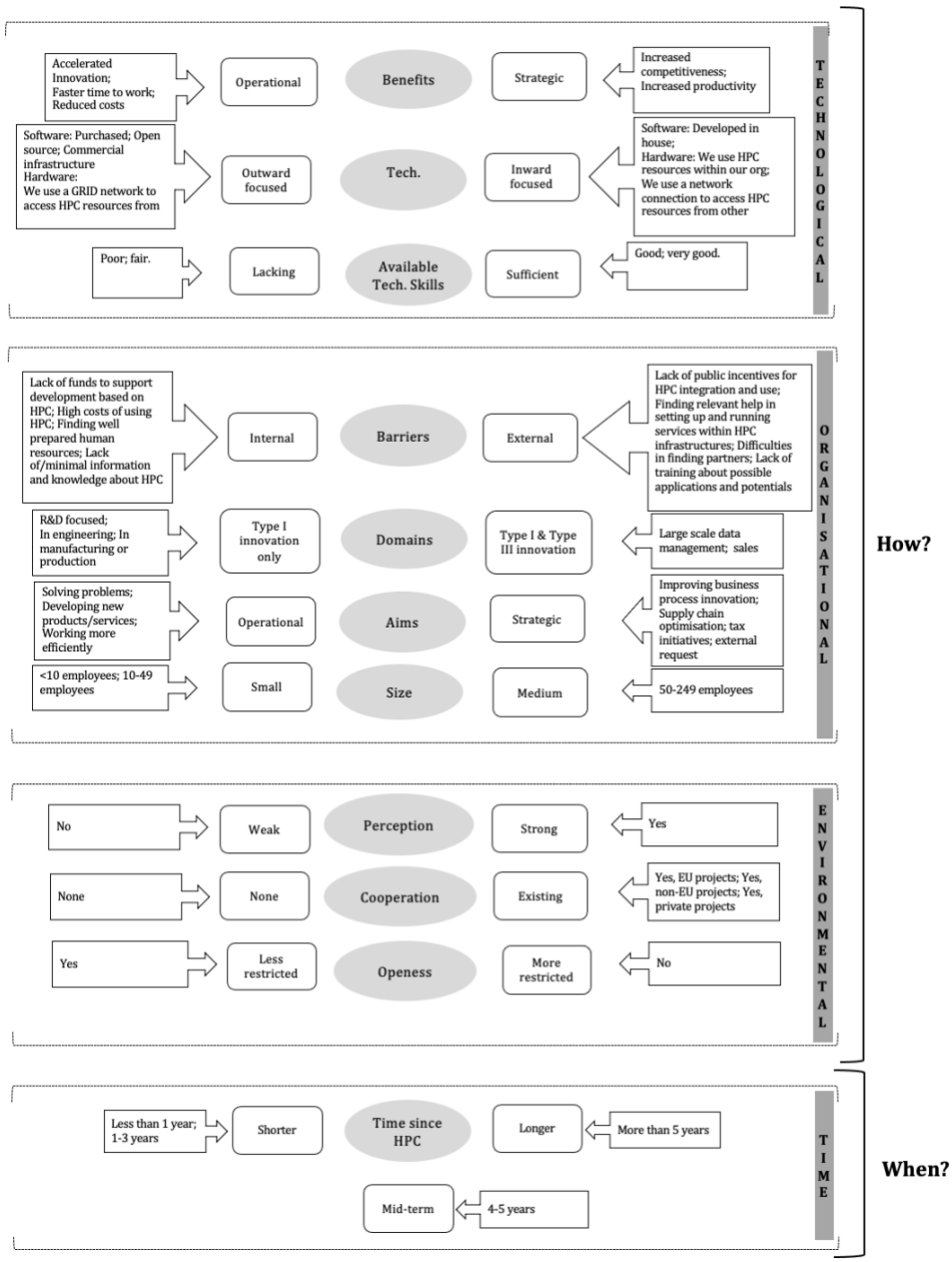
Title

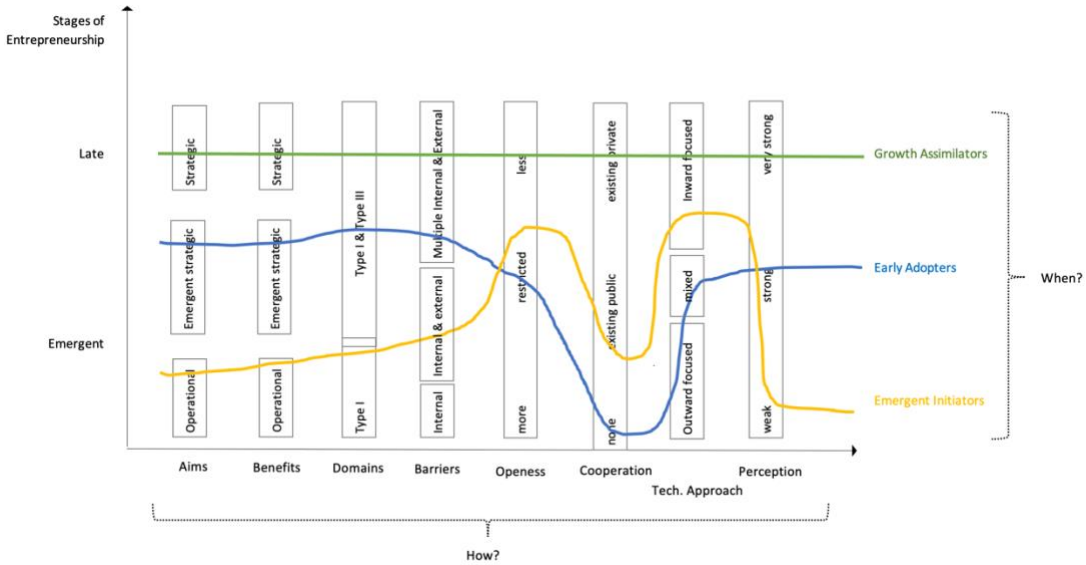
Figure 1. Taxonomy model along the 'when' and 'how' perspectives



Note. Value descriptions are in boxes with arrows, characteristics are in white boxes, determinants are in grey ovals, and dimensions are in grey rectangles.

Author

Figure 2. HPC Adoption by SMEs in relation to stages of entrepreneurship.



Appendix 1 Dimensions, determinants, characteristics, descriptions and questions for the 'how' and 'when' taxonomy model

	Dimensions	*Determinants*	*Characteristics*	*Description*	*Original Question* (type of Q&A)
When?	*Time*	Time since HPC	=<3 years 4-5 years >5 years	Time since adoption of HPC in small businesses originally had four categories, however less than one year and one to three years were later collapsed.	*For how long has your company used HPC solutions?* (Structured response (Multiple-choice- single answer); ordinal interval scale)
How?	*Technological Perspective*	Benefits	Operational Emergent strategic Strategic	For distinction of benefits, we use two criteria: scope (operational vs. strategic) and width (more or less beneficial). The latter (i.e., the width) effects the creation of the 'emergent strategic'.	*What are the direct benefits of HPC for the organisation?* (Structured response (Multiple-choice- multiple answer); nominal)
		Tech. approach	Outward focused Inward focused Mixed	Software and hardware information is merged, to gain insight into tech. approach. The companies could use purchased or in-house software (inward focused), or open access or commercial infrastructures (outward focused). In terms of hardware infrastructure, they can own it (inward focused) or use that owned by other organisations – e.g., using grid capabilities (outward focused).	*What type of HPC software applications and infrastructure are used? Related to HPC, the software applications and infrastructure that you use are:* (Structured response (Multiple-choice- multiple answer); nominal) *Does your organization use HPC resources over a grid or a network?* (Structured response (Multiple-choice- multiple answer); nominal)
		Available technology skills	Lacking Sufficient	Availability of skilled human resources are coded by the authors as sufficient or as lacking – in the coding of this answer also the answers on the comparison of actual possessed HPC technical skills with those that they still need (i.e., expressing demand for training) was done, also taking into account the answers to the questions of technical skills of the personnel working with HPC in the company, as compared to the questions on the personnel demand for [HPC] training.	*With which technical skills is the personnel working with HPC in your organisation equipped?* (Structured response (Multiple-choice- multiple answer); nominal) *Does your personnel have demand for training in one of the following skill categories?* (Structured response (Multiple-choice- multiple answer); nominal)
	Organisational Perspective	Barriers	Internal External Internal & external Multiple internal & external	Perceived barriers were re-coded by the authors using the internal and external classification (in relation to the origin of the problem – inside/outside the company), as well as taking into account the width (more or fewer barriers recognised).	*What are the top three business problems related to the use of HPC?* (Structured response (Multiple-choice- multiple answer); ordinal)
		Domains	Type I innovation Type I & Type III innovation	Areas of HPC usage within the SME was coded into different types following Swanson (1994) and allowing us to understand the diffusion, i.e. all the domains the HPC is used. Type I innovation includes R&D focused and used in production cycle; for Type I and Type III it also needs large scale/big data management	*How broadly is HPC used in your organization?* (Structured response (Multiple-choice- multiple answer); ordinal)
		Size	Small Medium	The size is based on companies' reported employment numbers (micro: <10 employees; small: 10-49 employees; medium: 50-249).	*How many employees does your organization have? Is your company:* (Structured response (Multiple-choice- single answer); ordinal interval scale)
		Aims	Operational Emergent strategic Strategic	The aims of organisational use of HPC were coded twofold: regarding scope, where values are coded in operational (emphasising solving concrete problems or developing new solutions) or strategic, and regarding width (more or less aims). The latter is decisive for the difference between emergent strategic (fewer aims) and strategic (more aims)	*Why you decided to use HPC solutions in your daily work?* (Structured response (Multiple-choice- multiple answer); ordinal)
	Environmental Perspective	Perception	Weak Strong	The perception of HPC use was marked either as weak or strong.	*Taking into consideration your experience, do other companies in your field use HPC?* (Structured response (Dichotomous))
		Cooperation	None Existing	HPC use in smaller companies is still nascent. Hence, cooperation is of key importance – which is reflected in mutual projects with others. The codes used are none or existing (when company is involved in projects with others – either privately or publicly funded).	*Has your organisation been involved in international projects related to HPC?* (Structured response (Multiple-choice- single answer); nominal)
		Openness	Less restricted Restricted	Openness allows for sharing of resources. Openness has been defined as less restricted (based on the companies answering 'yes') or more restricted (based on the companies answering 'no), depending on whether the companies allow for resource sharing in terms of equipment or infrastructure.	*Is there any HPC infrastructure and/or equipment own by your company that can be used by other companies (and if they pay for this)?* (Structured response (Dichotomous))

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