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REGULAR ARTICLE

Explaining differences in entrepreneurs' ICT use frequency between urban and rural regions

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Abstract

We investigate if and how the degree of urbanization of an entrepreneur's living area influences its ICT use frequency at work. Earlier research has shown that more intensive ICT use by entrepreneurs is associated with stronger entrepreneurial performance. At the regional level this implies that a higher ICT use frequency by the region's entrepreneurs is associated with stronger regional performance and more scope for regional development. Hence it is important to understand entrepreneurs' ICT use frequency and the role of regional context. Using survey data for 305 NUTS-2 regions in 35 European countries, and controlling for the regional level of digital infrastructure, we find that ICT use frequency by entrepreneurs is substantially higher in urban areas compared to rural territories. Importantly, when investigating various moderation effects, we also find that the impact of urbanization on entrepreneurs' ICT use frequency at work is smaller in regions with a higher level of general human capital and/or a higher level of digital infrastructure, that is, the lower ICT use frequency of entrepreneurs living in rural areas can partly be compensated for by higher regional levels of general human capital and digital infrastructure. Moreover, we also identify compensating effects related to entrepreneurs' characteristics such as age and household's income level. Policy implications for the economic development of rural areas are discussed.

Keywords ICT usage frequency · Degree of urbanization · Entrepreneurship · Self-employment · Regional knowledge spillovers · Europe

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1 Introduction

In nowadays' economies there is an ever-increasing importance of ICT knowledge and skills (Falk & Hagsten, 2021). It is also well-known that access to and implementation of ICT is more widespread in urban areas compared to rural ones (Wagg & Simeonova, 2022). The literature dealing with ICT differences between urban and rural regions (also called *digital divide*) can be segmented in connectivity research and inclusion research (Salemink et al., 2017). The first strand is concerned with the different levels of access to the internet and focuses on the limited availability of reliable broadband services in many rural and suburban areas (see for example Grubesic & Murray, 2002). This strand is thus concerned with differences in digital infrastructure between urban and rural regions. A recent study by Morris et al. (2022) for rural regions in Wales shows that, despite infrastructure investments, this type of digital divide is still present.

The second stream, inclusion research, is concerned with the actual adoption and usage of ICT applications, and the considerable differences in digital inclusion between rural and urban regions (Gomes & Dias, 2023). Thus, in order to understand the impact of the digital divide, one must not only consider digital connectivity as having internet access but also the actual adoption and usage of ICT applications by the actors in a region — firms and entrepreneurs as well as inhabitants.[1]

Our present paper makes a contribution to this second stream of research by measuring how the degree of urbanization of an entrepreneur's living area influences its ICT use frequency at work. In particular, we investigate differences in ICT use frequency between entrepreneurs in rural regions, urban regions, and regions with intermediate levels of urbanization, while controlling for several determinants of ICT use frequency at the regional and individual level. Recent research has shown that —ceteris paribus the sector of economic activity— more intensive ICT use by entrepreneurs is associated with stronger entrepreneurial performance (Gómez-Sánchez et al., 2024; Van Stel et al., 2023). At the regional level this implies that a higher ICT use frequency by the region's entrepreneurs is associated with a higher scope for regional development. Hence it is important to understand entrepreneurs' ICT adoption and use frequency and the role of regional context, especially when considering that internet use in the EU digital market is not homogeneous (Billon et al., 2017; Gomes & Dias, 2023).

Besides our main hypothesis dealing with the impact of the degree of urbanization on entrepreneurs' ICT use frequency, we also develop and test several moderation hypotheses where this impact is dependent on various regional-level and individual-level factors. At the regional level we investigate the role of the region's knowledge stock and the region's digital infrastructure, which are sources of regional knowledge spillovers and regional digital infrastructure spillovers, respectively. We also investigate the potential moderating roles of individual characteristics of the entrepreneurs.

[1] While the term 'digital divide' is often used to refer to differences in levels of digital connectivity between urban and rural areas (e.g., Morris et al., 2022), in the present paper we use a broader definition of the term to also include urban-rural differences in actual ICT adoption and usage. Hence, in our paper digital divide covers both the fields of digital connectivity and digital inclusion.

The purpose of the moderation hypotheses is to test whether certain factors potentially increase the digital divide in terms of ICT use frequency by entrepreneurs in urban and rural regions (divergence), or instead decreases the gap (convergence).

We employ the theoretical framework of the absorptive capacity theory of knowledge spillover entrepreneurship (Qian & Acs, 2013). In a nutshell, using this theory we will argue that ICT adoption and usage are an important means for entrepreneurs to update and maintain their ICT knowledge and skills as part of their *entrepreneurial absorptive capacity*, which in turn forms a necessary condition to be able to benefit from —that is, *absorb*— local knowledge spillovers. As the amount of potential knowledge spillovers is bigger in urban areas, entrepreneurs in these areas have a bigger incentive to maintain their ICT skills, enabling them to benefit from the bigger amounts of knowledge spillovers. These different incentives are then expected to result in a different ICT use frequency by entrepreneurs in urban versus rural regions.

We employ econometric models making use of survey data for 305 NUTS-2 regions in 35 European countries. Our data set distinguishes between three degrees of urbanization: urban, intermediate and rural. To measure ICT adoption and usage frequency, respondents in our sample are asked to rate on a seven-point Likert scale how often they use smartphones, laptops and other electronic devices in their daily work. Such a scale of ICT usage by entrepreneurs is similar to the four clusters of digital maturity identified by Henderson et al. (2018) where firms vary between *digitally disengaged* (lowest level) to *digitally embedded* (highest level). Besides individual-level determinants of the extent of ICT usage by self-employed workers, we also investigate the role of *regional-level general human capital* (Ramos-Poyatos et al., 2025) and the *regional-level digital infrastructure*, while controlling for regional GDP per capita. The regional level of human capital captures potential regional knowledge spillovers originating from the regions' general knowledge stock (Acs et al., 2013), while the second variable captures regional digital infrastructure spillovers, i.e., higher ICT adoption and use resulting from the availability of a better digital infrastructure. Moreover, we also investigate whether these two types of regional spillover effects contribute to a convergence process in the frequency of ICT usage at work between entrepreneurs in rural and urban regions.

We contribute to the existing research literature in several ways. First, we contribute to the stream of research on the urban-rural divide in digital inclusion. Within urban-rural studies, digital inclusion is relatively less researched than digital connectivity (Roberts et al., 2017). Moreover, while the inclusion stream concerns the digital inclusion of both firms/entrepreneurs and the regional population more generally, research on the urban-rural digital divide for firms and entrepreneurs —rather than the general population— seems to be less researched (Salemink et al., 2017). And those studies that do focus on the business side of the urban-rural digital divide primarily focus on firms rather than entrepreneurs. For instance, Labrianidis and Kalogeressis (2006) investigate ICT use in 996 innovative firms in 10 European rural regions. Jarvis et al. (2006) investigate technology adoption by small and medium-sized enterprises (SMEs) in two rural areas in the UK, while Galliano and Roux (2008) focus on internet adoption and use in French industrial firms. Norris (2020) investigates business digitalization by rural SMEs in Wales. All of these studies thus focus on ICT adoption and usage in firms, more specifically firms with considerable numbers of employees. Accordingly, this firm-level research is mostly concerned with ICT adoption and usage by the employees in these firms. In contrast, in this study we take the entrepreneur as the unit of analysis, rather than the firm. For an individual entrepreneur or self-employed, in particular one without employees, it is the ICT adoption and usage of the entrepreneur itself that matters, rather than the ICT adoption and usage of employees and managers, as is usual in research at the firm-level. As the majority of self-employed individuals in European labour markets are own-account workers or solo entrepreneurs who operate without employees, and since the share of this group continues to grow in modern labour markets (Reuschke & Zhang, 2022), we argue that besides firm-level research, it is also important to study ICT use and adoption at the entrepreneur-level. Our study belongs to the first studies taking the entrepreneur-level as unit of analysis when studying ICT adoption and usage; see Millán et al. (2021) and Ramos-Poyatos et al. (2025) as recent examples.

Second, although our main contribution is to the digital inclusion literature, we make a contribution to digital connectivity research as well by investigating if and how higher levels of the regional digital infrastructure affects ICT use frequency by entrepreneurs in the regions involved. We label such effects regional digital infrastructure spillovers.

Third, while most studies on the urban-rural digital divide study one or a small number of regions or countries, our study makes a systematic analysis of ICT adoption and usage for all regions in Europe at the NUTS-2 spatial aggregation level, while distinguishing between different levels of urbanization of these regions. Notwithstanding the importance of location-specific context when studying urban-rural divides (Salemink et al., 2017), we argue that an important contribution of our work is that we make a first attempt in systematically analyzing the extent of digital divide between urban and rural regions across the whole spectrum of regions in Europe.

Fourth, we make a theoretical contribution by employing a conceptual framework in which we focus on the roles of the regional knowledge stock and of local knowledge spillovers in determining local entrepreneurs' intensity of ICT usage in urban versus rural areas, where ICT skills are argued to be part of an entrepreneur's absorptive capacity (Qian & Acs, 2013), required to benefit from or absorb such spillovers.

The next section provides a brief literature review (subsection 2.1), then continues with the theoretical framework (subsection 2.2), and finally derives three sets of hypotheses (subsections 2.3 to 2.5) to be tested empirically. Sections 3–5 then present the methods, data, and results sections, respectively. We conclude our paper with conclusions and policy implications.

2 Literature review, theoretical framework and hypotheses

2.1 Literature review: the digital divide between urban and rural areas

The last two decades have seen an array of literature emerging on entrepreneurial activity in rural and urban areas (see for example Stathopoulou et al., 2004; Muñoz & Cohen, 2016; Muñoz & Kimmitt, 2019). The effect rurality has on the entrepreneurial creation and activity is a key feature that segregates rural and urban entrepreneurs.

On one side, rural entrepreneurship offers individuals a certain type of lifestyle stemming from rural idyll and sense of nostalgic appeal (Pato & Teixera, 2018); on the other side, rural entrepreneurship can be hampered by a lack of digital connectivity (Malecki, 2004; Morris et al., 2022), which results in the lack of access to current technological developments. It is clear from past research that rural areas find it difficult to keep up with developments in digital connectivity (Salemink et al., 2017). Limited access to internet connectivity and poor broadband infrastructure and service provisions are listed as some of the hurdles rural businesses and entrepreneurs are faced with in rural regions (Norris, 2020).

According to AlBar and Hoque (2019), the adoption of ICT in SMEs in recent years has resulted in a revolution of such businesses (p. 716). The use of ICT in businesses can have several advantages such as cost reduction and enhanced efficiency (Añón-Higón, 2012) which can enable these SMEs to compete more effectively with larger businesses. Salemink et al.'s (2017) systematic literature review highlights that rural areas still struggle with use and access to ICTs, compared to urban areas where ICT usage is highly evident. The deployment of technology access to rural areas can be seen as incurring high costs that offer poor economies of scale and therefore may result in limited returns on investment (Grubesic, 2010; Glass & Stefanova, 2012). This lack of access to ICTs in rural areas compounds issues surrounding rural businesses' remoteness from suppliers and markets, making it more difficult for them to succeed or potentially grow their business (Morris et al., 2022). Within rural regions, ICT awareness, access, support and usage can play a key role in rural development sustainability (Kamarudin et al., 2019). Interestingly, limited resilience literature exists surrounding the use of technology and digital engagement (Roberts et al., 2017). While community broadband initiatives are linked in research to resilience (Ashmore et al., 2015), the concepts of digital inclusion and engagement with new digital technologies appear sparse (Roberts et al., 2017).

Summarizing the above, decades of research highlight the digital divide between urban and rural areas. The literature on digital divide between urban and rural regions can be divided in connectivity research and inclusion research (Salemink et al., 2017). The first strand considers the mismatch between digital connectivity in urban and rural areas, studying topics such as accessibility to differing technologies and equipment, and provision of technologies in terms of telecommunication infrastructure (see for example Cambini & Jiang, 2009; Morris et al., 2022). The second strand, inclusion research, considers the degree of technology usage and usage patterns by firms, entrepreneurs and inhabitants in rural areas (Salemink et al., 2017). This strand does not necessarily focus on access to internet connectivity, but rather the acceptance, ability and willingness of rural entrepreneurs to use technology (at various growth points) when engaging in entrepreneurship. Explanatory factors such as the rural population's educational attainment and the required knowledge surrounding the use of the differing technologies play an important role in this stream of research (Salemink et al., 2017).

Our current paper primarily contributes to this second strand of research, i.e., digital inclusion research, by focusing on entrepreneurs' ICT adoption and use frequency in urban and rural regions. However, we also make a contribution to digital connectivity research by testing the role of the regional digital infrastructure, both as a driver of ICT adoption and usage and as a moderator of the impact of urbanization on ICT use frequency by entrepreneurs; see sub-Sect. 2.4 below.

2.2 Theoretical framework: absorptive capacity theory of knowledge spillover entrepreneurship

Our theoretical framework is the absorptive capacity theory of knowledge spillover entrepreneurship (Qian & Acs, 2013) which in turn builds on the knowledge spillover theory of entrepreneurship (Acs et al., 2013). The latter theory established the crucial role in contemporary economies of new knowledge as a source of entrepreneurial opportunities. In particular, new knowledge created in large incumbent firms or research institutions can be commercialized by entrepreneurs by starting a new firm. Through the entrepreneur, new knowledge then spills over from the incumbent firm to a new venture. This is called knowledge spillover entrepreneurship. Because, compared to rural areas, urban areas form richer sources of new knowledge creation, opportunities to engage in lucrative knowledge spillover entrepreneurship are also larger in urban areas.

However, not everyone can take part in knowledge spillover entrepreneurship, even if one lives in an urban area where more knowledge-based entrepreneurial opportunities are available. Instead, as Qian and Acs (2013) argue, "… knowledge spillover entrepreneurship depends not only on new knowledge but more importantly on *entrepreneurial absorptive capacity* that allows entrepreneurs to understand new knowledge, recognize its value, and commercialize it by creating a firm." (p. 185).

As we will argue below, ICT knowledge and skills form an important part of someone's entrepreneurial absorptive capacity (EAC), and hence of his or her ability to benefit from knowledge spillovers. And because potential knowledge spillovers are more abundant in urban areas, the incentive to develop and maintain one's ICT knowledge and skills as part of one's EAC, is higher in urban areas. Hence, our key argument for expecting higher ICT use frequency among entrepreneurs in urban areas is that in such areas there is more to be gained from maintaining one's EAC as the opportunities for knowledge spillover entrepreneurship are larger.

2.3 Main hypothesis: the impact of urbanization on ICT use frequency

2.3.1 Urban areas as a fertile breeding ground of knowledge spillovers

Literature on the determinants of entrepreneurship has identified regional context as an important factor (Guerrero & Martínez-Chávez, 2020), especially urban versus rural (Bichler et al., 2022). Urban areas are attractive locations for prospective entrepreneurs to locate because in these areas one can benefit from the presence of agglomeration advantages (Arauzo-Carod, 2021). Such advantages include the access to a broader and more diversified customer base, easier access to input factors including suppliers and a highly qualified local labour market, and the proximity of government offices and universities (Bosma et al., 2008). Last but not least, in urban areas it is easier to benefit from knowledge spillovers. Notwithstanding that knowledge sharing also takes place in virtual environments, face-to-face contacts remain key in the transmission of tacit knowledge (Westlund, 2006). In urban regions such contacts occur more naturally than in less populated areas, providing more potential for knowledge spillovers to take place. In urban areas there are more other firms nearby from which tacit knowledge may spill over, for instance when firms cluster, or through worker mobility. Universities are also an important source of knowledge spillovers from which local SMEs can benefit. Knowledge spillovers also occur when academics decide to start their own business exploiting their knowledge obtained at the university (Guerrero & Urbano, 2014), or when a wage-worker in an incumbent, often technological firm decides to exploit his knowledge obtained in the incumbent firm for his own benefit by setting up a new firm (Acs et al., 2013). Knowledge spillovers are very important in contemporary economies as knowledge is becoming an ever more important input factor in the production process which needs to be carefully managed (Harris et al., 2013). The increased importance of knowledge and knowledge spillovers in today's economy contributes to the competitive advantage of urban regions over rural regions (Westlund, 2006).[2]

2.3.2 Higher gains from EAC in urban areas as an extra incentive for high ICT use

However, although in urban regions the amount of knowledge spillovers is thus likely to be bigger, it is not straightforward that entrepreneurs can benefit. Instead, they require a sufficient level of EAC to actually discover and exploit the entrepreneurial opportunities that emerge from new knowledge creation in the region (Qian & Acs, 2013). Such exploitation may take place by conducting R&D and innovation while absorbing the local knowledge spillovers. In this regard, absorptive capacity has been found to be an important determinant of the economic performance of enterprises (Lehmann et al., 2022). Human capital is the key determinant of entrepreneurial absorptive capacity (Qian & Acs, 2013). We argue here that in today's economies, where digital transformation becomes more and more important for business performance (Xu et al., 2024), ICT knowledge and skills is a key element of human capital and entrepreneurial absorptive capacity.

Hence, in order to be able to benefit from abundant knowledge spillovers in urban regions, entrepreneurs in these regions have an extra incentive to maintain and further develop their ICT knowledge and skills by frequently using ICT at work. Moreover, keeping up to date with the latest developments in ICT is also necessary to keep up with the typically stronger competition in urban regions. These arguments lead to the following hypothesis:

H1: In urban regions, entrepreneurs on average have a higher frequency of ICT usage at work, compared to entrepreneurs in rural regions.

[2] At the macro level, there is a trade-off between knowledge production and knowledge spillovers which is regulated by the level of Intellectual Property Rights (IPR). While strict IPR legislation protects knowledge production (e.g., R&D activity), it may hamper knowledge diffusion including imitation. Conversely, less strict IPR rules facilitates knowledge diffusion but makes knowledge production relatively less attractive (Van Stel et al., 2019, 2021).

2.4 Hypotheses where the impact of urbanization on ICT use frequency is moderated by regional-level variables

In regions with higher *general human capital endowment* levels, it may be argued that the general knowledge stock, and hence the potential amount of knowledge spillovers originating from the region's general knowledge stock, is bigger (Acs et al., 2013). Again, to benefit from these abundant knowledge spillovers —that is, to *absorb* them—, entrepreneurs need stronger ICT knowledge and skills, and hence the incentive to obtain and maintain these skills on the job are bigger. We thus hypothesize:

H2: In regions with higher levels of general human capital, entrepreneurs on average have a higher frequency of ICT usage at work.

Part of the agglomeration advantages in urban regions described above relate to the higher levels of general human capital of the regional population in urban regions. For instance, in regions with higher educated populations, it is easier for entrepreneurs to find highly qualified employees for their businesses (Bosma et al., 2008). Also, the larger regional knowledge stock implied by the higher educated population, provides a greater scope for knowledge spillovers to occur and to benefit from.

The role of the regional knowledge stock in agglomeration advantages suggests that the agglomeration disadvantages of rural regions can partly be compensated by a higher educated workforce. When comparing, hypothetically, two rural regions with equal population numbers, but where one region has a higher-educated workforce (that is, a higher regional level of human capital), and the other a lower-educated workforce (a lower level of human capital), we expect a bigger regional knowledge stock, and hence a bigger amount of potential knowledge spillovers, in the rural region with the higher-educated workforce. Hence, in these regions there is a bigger incentive for entrepreneurs to maintain their ICT skills, so that they are able to actually absorb these spillovers.

Thus, although a higher-educated workforce does not compensate for all agglomeration disadvantages of rurality, it can compensate for some of these disadvantages, and provide additional incentives for entrepreneurs to more frequently use ICT at work. We thus hypothesize:

H3: The impact of urbanization on ICT use frequency by entrepreneurs in the region is moderated by the regional level of general human capital such that in regions with high levels of general human capital, the difference in ICT use frequency between entrepreneurs in urban and rural regions is smaller.

As explained before, research on the digital divide between rural and urban areas can be split in connectivity research, dealing with (the lack of) access to technology in rural areas, and inclusion research, which deals with actual ICT adoption and usage. Although access to technology, as captured by the regional level of digital infrastructure, is only a necessary (but not a sufficient) condition for actual ICT adoption and usage (Salemink et al., 2017), it is clear that a higher regional level of digital infrastructure facilitates actual ICT adoption and usage. Hence, to an extent, an increased level of ICT availability in a region will translate into an increased adoption and ICT use by the entrepreneurs in the region. This effect may be called the *regional digital infrastructure spillover effect*. In our regression models we will control for this effect by including a measure of the regional level of digital infrastructure when explaining ICT use frequency of entrepreneurs.

Moreover, similar to the role of the regional knowledge stock in Hypothesis 3, also the digital infrastructure of a region can compensate for some of the disadvantages of rurality, and provide additional incentives for entrepreneurs to more frequently use ICT at work. In particular, when comparing two rural areas which are otherwise equal, the rural region with the better digital infrastructure is likely to produce a bigger amount of potential knowledge spillovers. Again, in these regions there is a bigger incentive for entrepreneurs to develop and maintain their ICT skills as part of their EAC, so that they are able to actually absorb these spillovers. We thus hypothesize:

H4: The impact of urbanization on ICT use frequency by entrepreneurs in the region is moderated by the regional level of digital infrastructure such that in regions with high levels of digital infrastructure, the difference in ICT use frequency between entrepreneurs in urban and rural regions is smaller.

2.5 Hypotheses where the impact of urbanization on ICT use frequency is moderated by individual characteristics of entrepreneurs

In Hypotheses 3 and 4, we considered that certain variables at the regional level, in particular the regional knowledge stock and the regional digital infrastructure, can compensate for some of the disadvantages of rurality, making the impact of urbanization smaller. Similarly, we hypothesize that also some individual-level characteristics of the entrepreneurs involved can compensate for some of the disadvantages of operating in a rural area. We consider four such individual characteristics below in Hypotheses 5–8.

The education level of the entrepreneur is expected to be positively related to its ICT use frequency, and hence we will control for education in our regression models. However, since the level of education co-determines an individual's human capital level (Unger et al., 2011), we expect the difference in ICT use frequency between two *higher*-educated entrepreneurs from an urban versus a rural area to be smaller —ceteris paribus— compared to two *lower*-educated entrepreneurs; one in an urban and one in a rural area. This is because the higher-educated entrepreneur, due to its higher human capital, will find it easier to adopt and frequently use ICT, regardless of whether the entrepreneur is located in an urban or rural area. In other words, a higher education level can partly compensate for the disadvantages of rurality. We thus hypothesize:

H5: The impact of urbanization on ICT use frequency by entrepreneurs is moderated by the education level of the entrepreneur such that for entrepreneurs with higher educational attainment, the difference in ICT use frequency between entrepreneurs in urban and rural regions is smaller.

The gender of the entrepreneur has been found to be a determinant of its ICT use frequency. In particular, ICT use frequency by male entrepreneurs has been found to be higher compared to female entrepreneurs (Olsson & Bernhard, 2021; Sánchez-Rivero et al., 2024). Given this higher inclination of male entrepreneurs to frequently use ICT at work —regardless of being located in an urban or rural location—, being located in a rural area may have a smaller impact on ICT use frequency for male entrepreneurs. We hypothesize:

H6: The impact of urbanization on ICT use frequency by entrepreneurs is moderated by the gender of the entrepreneur such that for male entrepreneurs, the difference in ICT use frequency between entrepreneurs in urban and rural regions is smaller.

The role of an individual's age in entrepreneurial outcomes, including the use of technology in entrepreneurship, has been the subject of a rapidly increasing body of research (Syed et al., 2024; Zhang et al., 2022). Earlier research has found that middle-aged entrepreneurs more frequently use ICT at work (Millán et al., 2021). Following the same logic as before, we argue that being middle-aged can partly compensate for the disadvantages of rurality. In other words, given the higher inclination of middle-aged entrepreneurs to frequently use ICT at work —regardless of being located in an urban or rural location—, being located in a rural area may have a smaller impact on ICT use frequency for middle-aged entrepreneurs. We hypothesize:

H7: The impact of urbanization on ICT use frequency by entrepreneurs is moderated by the age of the entrepreneur such that for middle-aged entrepreneurs, the difference in ICT use frequency between entrepreneurs in urban and rural regions is smaller.

An extensive literature has found that household wealth is an important determinant of entry into entrepreneurship (see Simoes et al., 2016, for an overview). This points at the importance of liquidity constraints (Fairlie et al. 2012), in part related to a lower access to ICT equipment by poorer individuals (Anrijs et al., 2021). Such liquidity constraints may hamper entry into entrepreneurship for poorer individuals (Simoes et al., 2016), and for those poorer individuals that do enter entrepreneurship, it may limit access to and adoption of ICT. Earlier research has found that the income level of the entrepreneur's household is positively related to the entrepreneur's ICT use frequency (Ramos-Poyatos et al., 2025). Given this higher inclination of entrepreneurs from higher-income households to frequently use ICT at work —regardless of being located in an urban or rural location—, being located in a rural area may have a smaller impact on ICT use frequency for higher-income entrepreneurs. We hypothesize:

H8: The impact of urbanization on ICT use frequency by entrepreneurs is moderated by the income level of the entrepreneur's household such that for entrepreneurs with higher income levels, the difference in ICT use frequency between entrepreneurs in urban and rural regions is smaller.

3 Methods

To handle the discrete ordered nature of the dependent variable ICT use frequency at work, ordered logit models are used. Moreover, a multi-level, hierarchical set-up is used to take account of the different levels of measurement (individual versus regional level) of the model variables (Guo & Zhao, 2000). We tested for intra-class correlations (ICC) and found an ICC coefficient of 0.217, confirming that the regional variations in ICT use frequency at work are high enough to justify the use of multi-level models (Bliese, 2000).

4 Data

4.1 Data and sample

Our data is drawn from the *Sixth European Working Conditions Survey* –EWCS 2015– (Eurofound, 2016, 2018). This sixth wave is the first in the EWCS series that allows the identification of the workers' region of residence at the NUTS-2 level. This feature is crucial for the purpose of this study. The institution in charge of carrying out this survey since 1991 is the EU Agency *Eurofound*, in full the *European Foundation for the Improvement of Living and Working Conditions*. The EWCS 2015 interviewed about 44,000 workers, including both employees and self-employed individuals, in 35 countries: the EU-27 member states, the UK, 5 candidate countries (Albania, Montenegro, North Macedonia, Serbia and Turkey) and 2 EFTA countries (Norway and Switzerland). This survey provides comprehensive information on several work-related issues, including exposure to physical and psychosocial risks, work organization, work–life balance, and health and well-being. After filtering the sample, our final dataset consists of 4,827 full-time self-employed workers aged 18 to 65, where full-time is defined as working at least 15 h per week.

4.2 Dependent variable

4.2.1 ICT use frequency at work

Respondents in the EWCS are asked to rate how often they use smartphones, laptops and other electronic devices in their workplace. This Likert scale varies from level 1 (*non-ICT user*) to 7 (*very intensive ICT user*). The discrete ordered nature of this variable is used to operationalize ICT use frequency in our analysis.

4.3 Independent variables

4.3.1 Degree of urbanization

The degree of urbanization of the entrepreneurs' area of residence is expected to influence the type of business that entrepreneurs venture into and, accordingly, his/

her ICT use frequency. Hence, these individual-level variables (urban, intermediate, rural) belong to the set of focal variables in this study.

The EWCS provides information on whether the workers' household is in an urban, intermediate or rural area, which is based on Eurostat's classification of degree of urbanization (DEGURBA). Based on the percentage of the local population living in urban centres, urban clusters and rural grid cells, this classification distinguishes between three types of territories: (i) cities (densely populated areas); (ii) towns and suburbs (intermediate density areas); and (iii) rural areas (thinly populated areas).

4.3.2 Macroeconomic indicators at the regional level

The regional context –both across and within countries– in which these self-employed individuals perform their activities is expected to be of great importance in explaining their ICT use frequency. For instance, in lower developed regions, some low-income self-employed workers may be especially disadvantaged in terms of ICT use due to a generally lower availability of financial resources in such regions. Similarly, existing differences in levels of ICT availability, i.e., *digital infrastructure*, across regions may also cause relevant divergences in terms of ICT adoption by self-employed workers.

Hence, including both regional GDP per capita and regional level of *digital infrastructure* seems crucial in order to control for the existing differences in terms of economic development, especially taking into consideration that entrepreneurs in our sample belong to 305 different NUTS-2 regions across 35 European countries. Data on GDP per capita measured in Purchasing Power Standards – PPS, and the percentage of households with broadband access, as a proxy of *digital infrastructure*, at the NUTS-2 regional level are provided by Eurostat.

Besides regional GDP per capita and *digital infrastructure*, we aim at investigating the role of the *general human capital endowment* of the regional population. In this sense, we strictly consider skilled or advanced human capital, proxied by the percentage of the regional population with tertiary education (Millán et al., 2014). In particular, Eurostat provides information at the NUTS-2 level on the share of population aged 25–64 with at least first stage of tertiary education.[3] Thus, ICT usage by individual entrepreneurs may be positively influenced by the number of highly-educated individuals in their region; this influence captures knowledge spillovers originating from the region's general knowledge stock. Table 1 below presents correlations for our macroeconomic indicators at the regional level and the degree of urbanization.[4]

[3] This variable definition is based on the UNESCO *International Standard Classification of Education* (ISCED), which aims to overcome the existing variability on education systems between countries. In particular, tertiary education comprises levels 5 and 6 in the ISCED-1997 classification and levels 5 to 8 in the ISCED-2011 revision.

[4] The correlation between GDP per capita and the portion of population with tertiary education is 0.70. Similarly, the correlation between GDP per capita and the percentage of households with broadband access is 0.60. Despite both correlations are high, removing GDP per capita and our proxy for digital infrastructure from our specifications is not an option since we are interested in identifying the general human capital endowment effect, once free from the effects of differences in regional levels of economic development and digital infrastructure.

Table 1 Correlation matrix for macroeconomic indicators at the NUTS-2 level and degree of urbanisation –DEGURBA

	1	2	3	4	5
1. GDP PPS per inhabitant					
2. % Households with broadband access	0.599				
3. % Population with tertiary education	0.700	0.495			
4. Rural	-0.172	-0.085	-0.202		
5. Intermediate	0.065	0.030	0.048	-0.450	
6. Urban	0.113	0.058	0.158	-0.592	-0.453

Importantly, our spillover effect variables at the regional level may also cause interaction effects with the degree of urbanization of the entrepreneurs' area of residence (urban, intermediate, rural). In particular, it is not unlikely that groups that are lagging behind in ICT usage, such as entrepreneurs operating in rural areas, are influenced more strongly by regional spillover effects if the regional knowledge stock is larger (Hypothesis 3) and/or if the regional level of digital infrastructure is higher (Hypothesis 4), and hence catch up in ICT usage with their peer entrepreneurs in urban regions. The interaction terms included in our analysis enable to test both hypotheses.

4.3.3 Entrepreneurs' characteristics

We control for several entrepreneurs' characteristics which are known to affect ICT use frequency at work; see for example Millán et al. (2021) and Ramos-Poyatos et al. (2025): level of education, job characteristics (tenure, working hours, business sector), demographic indicators (gender, born-abroad resident, age, cohabitation, children and health) and household level information (ability to make ends meet). Furthermore, in order to test some possible moderating effects of entrepreneurs' characteristics such as education, age or household's income level, we also include interaction terms between these individual variables and the degree of urbanization of the entrepreneurs' area of residence.

5 Results

5.1 Descriptive analysis

Firstly, we explore how ICT usage frequency varies with the degree of urbanization of the entrepreneurs' living area; see Table 2.

We observe that rural entrepreneurs are the least likely to use ICT at work whereas entrepreneurs living in urban and intermediate areas show a higher average ICT use frequency.

Table 3 shows some descriptive statistics from our sample, distinguishing among the degree of urbanization of the entrepreneurs' living area.

About 37% of the entrepreneurs in our dataset live in rural areas. Compared to those living in more urbanized territories, they are lower educated, higher tenured, less likely to be an immigrant and less likely to live in a couple. Furthermore, they

Table 2 Descriptive statistics on entrepreneurs' ICT use frequency at work by degree of urbanisation

ICT use frequency at work (1–7)													
	Obs.	Mean	Std. Dev.	Percentiles			Frequency distribution						
				25th	50th	75th	1	2	3	4	5	6	7
All self-employment	4,827	3.05	2.18	1	2	5	37.5	13.5	15.8	7.0	5.2	7.6	13.4
Degree of urbanisation													
Rural	1,787	2.58	2.03	1	2	3	48.6	13.0	13.4	5.6	5.0	5.0	9.4
Intermediate	1,237	3.33	2.19	1	3	5	30.1	13.9	18.7	7.4	5.4	9.6	14.9
Urban	1,803	3.33	2.23	1	3	6	31.6	13.7	16.2	8.3	5.1	8.8	16.3

Data source: EWCS 2015

more often report poor health and a higher portion of rural entrepreneurs are farmers. Finally, they work longer hours and more often have difficulties to make ends meet. About 37.4 and 25.6% of the individuals in our sample are entrepreneurs living in urban and intermediate areas, respectively. Compared to those living in less urbanized areas, urban entrepreneurs are higher educated, lower tenured, younger, healthier, more likely to be immigrants and live without partner, and more likely to work in the commerce and hospitality sector.

5.2 Multivariate analysis

In this section we will move beyond descriptive analysis and present the results of our multi-level ordered logit models.

5.2.1 Main results

Table 4 shows the results from four models regarding the determinants of ICT adoption and usage frequency at work, focusing on the role of the degree of urbanization of the entrepreneurs' living area.

ICT use frequency (1–7) is used as an ordered dependent variable in all specifications and, hence, ordered logit models are applied. In the framework of these models, a different set of results for each frequency of ICT use is generated. However, for brevity and focus, we only present results on the probability that the entrepreneur's ICT frequency (i) equals 1 (being a *non-ICT user* at work) and (ii) equals 7 (being a *very intensive ICT user*). Predicted probabilities for sample means are shown at the top of each specification. Below, the marginal effects of the explanatory variables on these predicted probabilities are presented in levels, and also in relative terms with respect to the predicted probabilities for the sample means. Finally, *p-values* associated with the significance levels of these marginal effects are also reported.

Our results from specification 1 show how the predicted probability of being a *non-ICT user* decreases by about 7.2% for urban entrepreneurs, when compared with rural entrepreneurs (Specification 1, left panel). Conversely, the predicted probability of being a *very intensive ICT user*, is observed to increase by about 10.6% for urban entrepreneurs, when compared with rural entrepreneurs (Specification 1, right panel). Although with a p-value of only 0.14, we also observe how the predicted probability of being a *non-ICT user* for entrepreneurs living in intermediate areas decreases by about 5.4%, when compared with rural entrepreneurs (Specification 1, left panel). With the same p-value, our results also show how the predicted probability of being a *very intensive ICT user* for entrepreneurs living in intermediate areas increases by about 7.9%, when compared with rural entrepreneurs (Specification 1, right panel). These results support Hypothesis 1.

Specification 2 focuses on the role of the regional population with tertiary education. Our findings indicate that there is a positive relationship between the portion of regional population with tertiary education and ICT usage frequency. In particular, the predicted probability of being a *non-ICT user* is observed to decrease by about 1% with each additional 1% of the regional population holding tertiary education (Specification 2, left panel). Analogously, the predicted probability of being a *very*

Table 3 Descriptive statistics on exogenous variables by degree of urbanisation

	All self-employment		Degree of urbanisation					
			Rural		Intermediate		Urban	
	N=4,827		N=1,803		N=1,237		N=1,787	
Independent variables (x)	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Macroeconomic indicators at the NUTS-2 level								
GDP '000 PPS per inhabitant (7–78)	25.7	13.8	22.6	13.5	27.2	12.2	27.7	14.6
% Households with broadband access (45–97)	76.8	9.90	75.7	9.46	77.3	10.2	77.5	10.0
% Population with tertiary education (10.3–55.1)	28.6	10.9	25.7	10.5	29.5	9.7	30.8	11.3
Educational attainment								
Basic education [a]	0.082		0.133		0.053		0.052	
Secondary education [a]	0.624		0.675		0.618		0.577	
Tertiary education [a]	0.294		0.193		0.329		0.371	
Demographic characteristics								
Female [a]	0.361		0.352		0.382		0.356	
Immigrant [a]	0.105		0.064		0.111		0.141	
Age (18–65)	45.5	11.0	46.3	11.0	46.2	10.9	44.1	10.9
Age band 18–30 [a]	0.110		0.101		0.099		0.125	
Age band 31–35 [a]	0.097		0.082		0.087		0.119	
Age band 36–40 [a]	0.130		0.125		0.126		0.139	
Age band 41–45 [a]	0.149		0.139		0.146		0.161	
Age band 46–50 [a]	0.157		0.171		0.155		0.145	
Age band 51–55 [a]	0.152		0.152		0.162		0.144	
Age band 56–65 [a]	0.205		0.229		0.226		0.166	
Cohabiting [a]	0.724		0.760		0.715		0.695	
Children under 14 [a]	0.293		0.293		0.286		0.299	
Health (1–5)	4.00	0.76	3.94	0.74	4.00	0.79	4.05	0.75
Household information								
Ends meet (1–6)	3.78	1.31	3.60	1.31	4.00	1.28	3.82	1.32
Job aspects								
Tenure (1–53)	13.3	10.7	15.2	11.3	13.6	10.8	11.3	9.6
Working hours (15–120)	45.9	14.6	46.4	14.8	45.1	14.7	46.0	14.5
Business sector dummies								
Agriculture [a]	0.180		0.367		0.116		0.039	
Industry [a]	0.100		0.091		0.105		0.105	
Construction [a]	0.101		0.091		0.102		0.110	
Commerce and hospitality [a]	0.265		0.222		0.271		0.303	
Transport [a]	0.041		0.036		0.027		0.055	
Financial services [a]	0.029		0.015		0.038		0.035	
Public administration and defence [a]	0.0008		0.002		0.0008		0	
Education [a]	0.014		0.009		0.015		0.019	
Health [a]	0.042		0.028		0.054		0.047	
Other services [a]	0.229		0.140		0.272		0.287	

Notes: N=4,827; [a] Dummy variable; Data source: EWCS 2015

Table 4 Determinants of ICT adoption and use frequency at work –Multilevel ordered logit models–

# Specification	1				2			
Hypothesis tested	H1				H2			
Average predicted probability (*y*)	P[ICT use = 1] = 0.363		P[ICT use = 7] = 0.140		P[ICT use = 1] = 0.364		P[ICT use = 7] = 0.141	
Independent variables (*x*)	$\frac{dy/dx}{y}\%$	p-value	$\frac{dy/dx}{y}\%$	p-value	$\frac{dy/dx}{y}\%$	p-value	$\frac{dy/dx}{y}\%$	p-value
Degree of urbanisation –DEGURBA–								
Rural [a] (*ref.*)								
Intermediate [a]	-5.42	0.139^{+}	7.91	0.140^{+}	-5.16	0.155	7.61	0.155
Urban [a]	-7.16	0.049**	10.6	0.049**	-5.93	0.100*	8.79	0.100*
Macroeconomic indicators at the NUTS-2 level								
GDP '000 PPS per inhabitant (7–78)	-0.73	0.001***	1.09	0.001***	-0.29	0.218	0.44	0.218
% Households with broadband access (45–97)	-0.80	0.004***	1.21	0.005***	-0.63	0.023**	0.95	0.024**
% Population with tertiary education (10.3–55.1)					-0.99	0.000***	1.50	0.001***
Interactions Macro indicators x DEGURBA								
% Households with broadband access x Rural (*ref.*)								
% Households with broadband access x Intermediate								
% Households with broadband access x Urban								
% Population with tertiary educ. x Rural (*ref.*)								
% Population with tertiary educ. x Intermediate								
% Population with tertiary educ. x Urban								
Educational attainment								
Basic education [a] (*ref.*)								
Secondary education [a]	-49.7	0.000***	36.2	0.000***	-48.3	0.000***	35.7	0.000***
Tertiary education [a]	-104.7	0.000***	131.5	0.000***	-102.3	0.000***	128.7	0.000***
Demographic characteristics								
Female [a]	19.6	0.000***	-28.6	0.000***	19.6	0.000***	-28.7	0.000***
Immigrant [a]	0.15	0.973	-0.22	0.973	0.27	0.951	-0.40	0.951
Age (18–65)	-3.91	0.000***	5.90	0.000***	-3.83	0.000***	5.79	0.000***
Age (squared)	0.05	0.000***	-0.07	0.000***	0.05	0.000***	-0.07	0.000***

Table 4 (continued)

# Specification	1				2			
Hypothesis tested	H1				H2			
Average predicted probability (*y*)	P[ICT use = 1] = 0.363		P[ICT use = 7] = 0.140		P[ICT use = 1] = 0.364		P[ICT use = 7] = 0.141	
Independent variables (*x*)	$\frac{dy/dx}{y}\%$	p-value	$\frac{dy/dx}{y}\%$	p-value	$\frac{dy/dx}{y}\%$	p-value	$\frac{dy/dx}{y}\%$	p-value
Cohabiting [a]	1.96	0.535	-2.97	0.538	2.11	0.502	-3.20	0.505
Number of children under 14	-1.53	0.646	2.31	0.647	-1.67	0.612	2.54	0.614
Health (1–5)	-1.66	0.375	2.51	0.376	-1.64	0.379	2.47	0.379
Household information								
Ends meet (1–6)	-10.9	0.000***	16.49	0.000***	-10.8	0.000***	16.3	0.000***
Job characteristics								
Tenure (1–53)	0.40	0.011**	-0.61	0.011**	0.39	0.013**	-0.59	0.013**
Working hours (15–120)	-1.59	0.000***	2.39	0.000***	-1.60	0.000***	2.42	0.000***
Working hours (squared)	0.01	0.000***	-0.02	0.000***	0.01	0.000***	-0.02	0.000***
Log likelihood	-7,316.8				-7,310.9			
# Specification	3				4			
Hypothesis tested	H3				H4			
Average predicted probability (y)	P[ICT use = 1] = 0.363		P[ICT use = 7] = 0.140		P[ICT use = 1] = 0.364		P[ICT use = 7] = 0.140	
Independent variables (x)	$\frac{dy/dx}{y}\%$	p-value	$\frac{dy/dx}{y}\%$	p-value	$\frac{dy/dx}{y}\%$	p-value	$\frac{dy/dx}{y}\%$	p-value
Degree of urbanisation –DEGURBA–								
Rural [a] (*ref.*)								
Intermediate [a]	-21.1	0.045**	34.6	0.045**	-62.4	0.005***	122.8	0.036**
Urban [a]	-34.2	0.000***	53.9	0.000***	-76.7	0.000***	135.1	0.006***
Macroeconomic indicators at the NUTS-2 level								
GDP '000 PPS per inhabitant (7–78)	-0.31	0.190	0.47	0.190	-0.31	0.192	0.47	0.192
% Households with broadband access (45–97)	-0.63	0.023**	0.95	0.023**	-1.24	0.000***	1.87	0.000***
% Population with tertiary education (10.3–55.1)	-1.54	0.000***	2.34	0.000***	-1.00	0.000***	1.51	0.001***

Table 4 (continued)

# Specification	3				4			
Hypothesis tested	H3				H4			
Average predicted probability (y)	P[ICT use = 1] = 0.363		P[ICT use = 7] = 0.140		P[ICT use = 1] = 0.364		P[ICT use = 7] = 0.140	
Independent variables (x)	$\frac{dy/dx}{y}\%$	p-value	$\frac{dy/dx}{y}\%$	p-value	$\frac{dy/dx}{y}\%$	p-value	$\frac{dy/dx}{y}\%$	p-value
Interactions Macro indicators x DEGURBA								
% Households with broadband access x Rural (*ref.*)								
% Households with broadband access x Intermediate					0.83	0.025**	-1.26	0.026**
% Households with broadband access x Urban					0.99	0.005***	-1.49	0.006***
% Population with tertiary educ. x Rural (*ref.*)								
% Population with tertiary educ. x Intermediate	0.60	0.095*	-0.91	0.095*				
% Population with tertiary educ. x Urban	1.01	0.002***	-1.53	0.002***				
Educational attainment								
Basic education [a] (*ref.*)								
Secondary education [a]	-47.0	0.000***	35.0	0.000***	-46.6	0.000***	34.8	0.000***
Tertiary education [a]	-100.8	0.000***	128.3	0.000***	-100.2	0.000***	127.0	0.000***
Demographic characteristics								
Female [a]	19.7	0.000***	-29.0	0.000***	19.6	0.000***	-28.8	0.000***
Immigrant [a]	-0.09	0.983	0.14	0.983	0.19	0.965	-0.29	0.965
Age (18–65)	-3.78	0.000***	5.76	0.000***	-3.77	0.000***	5.71	0.000***
Age (squared)	0.05	0.000***	-0.07	0.000***	0.05	0.000***	-0.07	0.000***
Cohabiting [a]	2.27	0.468	-3.48	0.468	2.42	0.440	-3.69	0.443
Number of children under 14	-1.49	0.651	2.28	0.651	-2.03	0.538	3.10	0.540
Health (1–5)	-1.49	0.422	2.26	0.422	-1.54	0.408	2.33	0.408
Household information								
Ends meet (1–6)	-10.8	0.000***	16.5	0.000***	-10.8	0.000***	16.3	0.000***
Job characteristics								
Tenure (1–53)	0.41	0.010***	-0.62	0.010***	0.40	0.011**	-0.61	0.011**

Table 4 (continued)

# Specification	3				4			
Hypothesis tested	H3				H4			
Average predicted probability (y)	P[ICT use = 1] = 0.363		P[ICT use = 7] = 0.140		P[ICT use = 1] = 0.364		P[ICT use = 7] = 0.140	
Independent variables (x)	$\frac{dy/dx}{y}\%$	p-value	$\frac{dy/dx}{y}\%$	p-value	$\frac{dy/dx}{y}\%$	p-value	$\frac{dy/dx}{y}\%$	p-value
Working hours (15–120)	-1.60	0.000***	2.44	0.000***	-1.62	0.000***	2.46	0.000***
Working hours (squared)	0.01	0.000***	-0.02	0.000***	0.01	0.000***	-0.02	0.000***
Log likelihood	-7,306.0				-7,306.7			

Notes: $N = 4,827$; For continuous variables, [(dy/dx)/y]% captures marginal effects, but expressed in relative terms with respect to predicted probabilities. In the context of dummy variables, it reflects the impact for a discrete change of the dummy variable from 0 to 1; $^{+}$ $0.15 \geq p > 0.1$; * $0.1 \geq p > 0.05$; ** $0.05 \geq p > 0.01$; *** $p \leq 0.01$;

[a] Dummy variable; 9 business sector dummies are used in our specifications: Agriculture, Industry, Construction (*ref.*), Commerce and hospitality, Transport, Financial services, Public administration and defence, Education, Health, Other services; A region indicator for 305 European NUTS-2 is used as our grouping variable in all our specifications. The ICC value is 0.217. Therefore, the NUTS-2 effects compose approximately 22% of the total residual variance; The maximum correlation is 0.70 (between GDP '000 PPS per inhabitant and % Population with tertiary education), and the VIFs values (from specification 2) range from 1.06 to 2.49. Thus, multicollinearity does not pose a concern, especially in consideration of the large size of our sample; Data source: EWCS 2015

intensive ICT user increases by about 1.50% with each additional 1% of the regional population holding tertiary education (Specification 2, right panel). These results support Hypothesis 2.

Interestingly, the inclusion of the percentage of regional population with tertiary education respectively turns the effects of living in an urban (vs. rural) area and living in an intermediate (vs. rural area) only significant at 10% ($p=0.100$) and 16% level ($p=0.155$), which raises doubts about the accurateness of the effect previously identified in our specification 1. Precisely to shed some light on the issue, our specification 3 also includes interaction terms between the portion of regional population with tertiary education and the degree of urbanization of the entrepreneurs' living area. These interactions are aimed to capture the possibly differentiated effect of the percentage of regional population with tertiary education on ICT usage frequency for entrepreneurs living in urban, intermediate and rural areas.

Our results from specification 3 show how the positive effect of the percentage of regional population with tertiary education on ICT usage frequency at work is weaker for urban entrepreneurs than for entrepreneurs living in intermediate and rural areas. In particular, we observe as, with each additional 1% of regional population holding tertiary education, the predicted probability of *never* using ICT respectively decreases by about 0.53, 0.94 and 1.54% for entrepreneurs living in urban, intermediate and rural areas (Specification 3, left panel). Analogously, the predicted probability of being a *very intensive ICT user* is observed to respectively increase, with each additional 1% of regional population holding tertiary education, by about 0.81, 1.43 and 2.34% for entrepreneurs living in urban, intermediate and rural areas (Specification 3, right panel). Otherwise stated, we observe how a higher portion of regional population with tertiary education, representing a regional knowledge spillover effect, contributes to a convergence process in ICT use frequency between entrepreneurs living in urban, intermediate and rural areas. The results from specification 3 support Hypothesis 3.

As expected, our findings in specifications 1 and 2 indicate that there is a positive relationship between our proxy of digital infrastructure, i.e., the percentage of households with broadband access, and ICT usage frequency. In particular, the predicted probability of being a *non-ICT user* is observed to decrease by about 0.63% with each additional 1% of households with broadband access (Specification 2, left panel). Analogously, the predicted probability of being a *very intensive ICT user* increases by about 0.95% with each additional 1% of households with broadband access (Specification 2, right panel).

Our results from specification 4 show how the positive effect of the percentage of households with broadband access on ICT usage frequency at work is weaker for urban entrepreneurs than for entrepreneurs living in intermediate and rural areas. In particular, we observe as, with each additional 1% of households with broadband access, the predicted probability of *never* using ICT respectively decreases by about 0.25, 0.41 and 1.24% for entrepreneurs living in urban, intermediate and rural areas (Specification 4, left panel). Analogously, the predicted probability of being a *very intensive ICT user* is observed to respectively increase, with each additional 1% of households with broadband access, by about 0.38, 0.61 and 1.87% for entrepreneurs living in urban, intermediate and rural areas (Specification 4, right panel). In other words, we observe how a higher portion of households with broadband access (regional digital infrastructure spillover effect) contributes to a convergence process in ICT use frequency between entrepreneurs living in urban, intermediate and rural areas. The results from specification 4 support Hypothesis 4.

Table 5 below shows predicted probabilities of ICT usage frequency for the sample means and simulated values (percentiles 5, 10, 25, 50, 75, 90 and 95) of the percentages of regional population holding tertiary education and households with broadband access. Calculation of predicted probabilities are based on specifications 3 and 4 in Table 4. The inspection of this table allows to evaluate the potential effects of variations of different magnitudes and directions in both regional macroeconomic indicators.

Simulation for specification 3 shows how the difference in predicted probability of *never* using ICT between urban and rural entrepreneurs decreases from 8.0 to 2.5 percentual points when the percentage of regional population with tertiary education increases from 13.9 (p.10) to 27.5 (p.50). When concentrating on the difference in predicted probability of being a *very intensive ICT user* between urban and rural entrepreneurs, we observe how this difference decreases from 3.5 to 1.3 percentual points when the portion of regional population with tertiary education increases from 13.9 (p.10) to 27.5 (p.50).

Analogously, simulation for specification 4 shows how the difference in predicted probability of *never* using ICT between urban and rural entrepreneurs decreases from 7.1 to 1.7 percentual points when the percentage of households with broadband access increases from 64 (p.10) to 78 (p.50). When focusing on the difference in predicted probability of being a *very intensive ICT user* between urban and rural entrepreneurs, we observe how this difference decreases from 3.4 to 1.0 percentual points when the share of households with broadband access increases from 64 (p.10) to 78 (p.50).

Table 6 below shows the results from five models focusing on the role of some entrepreneurs' characteristics as moderators on the impact of the degree of urbanization on the entrepreneurs' ICT use frequency. We use the same setup used for Table 4. However, we only present results on the probability that the entrepreneur's ICT frequency equals 7, i.e., being a *very intensive ICT user*.

Contrary to our Hypothesis 5, our results from specification 5 do not show any moderation effect of the entrepreneurs' education level on the relationship between ICT adoption and usage frequency at work and the degree of urbanization of the entrepreneurs' living area. More concretely, the marginal effects of the interaction terms between education levels and the degree of urbanization are not significant.

Similarly, based on our results from specification 6 we observe how our Hypothesis 6 is not supported either, i.e., the impact of urbanization on ICT use frequency by entrepreneurs is not moderated by the gender of the entrepreneur. In particular, we observe as the marginal effects of the interaction terms between our gender dummy and the degree of urbanization are not significant.

With the exception of our specifications 7 A and 7B, all our specifications in Tables 4 and 6 include both a linear and a quadratic term for age in the analysis. Thus, we observe a positive non-linear impact of age on ICT adoption and usage where the turning point is reached at roughly the age of 42, indicating that past this age, entrepreneurs are less likely to use ICT at work.

Table 5 Predicted probabilities of ICT usage frequency for the sample means and simulated values of macroeconomic indicators (based on Table 4, specifications 3 and 4)

Specification 3	P[ICT use freq. = 1]							P[ICT use freq. = 7]						
% Population with tertiary education (percentil)	12.9 (p.5)	13.9 (p.10)	18.8 (p.25)	**27.5 (p.50)**	37.5 (p.75)	41.6 (p.90)	47.8 (p.95)	12.9 (p.5)	13.9 (p.10)	18.8 (p.25)	**27.5 (p.50)**	37.5 (p.75)	41.6 (p.90)	47.8 (p.95)
Degree of urbanisation														
Urban	37.9%	37.7%	36.7%	**35.0%**	33.0%	32.2%	31.0%	12.1%	12.2%	12.8%	**13.7%**	14.9%	15.4%	16.2%
Intermediate	40.8%	40.5%	38.7%	**35.5%**	32.1%	30.7%	28.7%	10.7%	10.9%	11.8%	**13.4%**	15.5%	16.4%	17.9%
Rural	46.4%	45.7%	42.7%	**37.5%**	31.7%	29.5%	26.3%	8.5%	8.7%	9.9%	**12.4%**	15.7%	17.3%	19.8%
Specification 4	P[ICT use freq. = 1]							P[ICT use freq. = 7]						
% Households with broadband access (percentil)	60 (p.5)	64 (p.10)	69 (p.25)	**78 (p.50)**	83 (p.75)	89 (p.90)	93 (p.95)	60 (p.5)	64 (p.10)	69 (p.25)	**78 (p.50)**	83 (p.75)	89 (p.90)	93 (p.95)
Degree of urbanisation														
Urban	36.7%	36.4%	35.9%	**35.1%**	34.6%	34.0%	33.7%	13.2%	13.4%	13.7%	**14.2%**	14.5%	14.8%	15.0%
Intermediate	38.0%	37.3%	36.6%	**35.2%**	34.5%	33.6%	33.0%	12.6%	12.9%	13.3%	**14.1%**	14.5%	15.1%	15.5%
Rural	45.5%	43.5%	41.1%	**36.8%**	34.5%	31.8%	30.1%	9.2%	10.0%	11.0%	**13.2%**	14.5%	16.2%	17.4%

Our specification 7 A includes instead a set of seven age bands and uses those entrepreneurs aged between 56 and 65 years old as the comparison group. Our results in specification 7 A confirms the positive non-linear impact of age on ICT adoption and usage. More concretely, we observe how the predicted probability of being a *very intensive ICT user* increases by about 23% for entrepreneurs aged between 41 and 50 years old. We also observe how the predicted probability of being a *very intensive ICT user* increases by about 20% for entrepreneurs aged between 51 and 55 and between 36 and 40 years old. Our results also indicate how the predicted probability of being a *very intensive ICT user* increases by about 17% for entrepreneurs aged between 31 and 35 years old. Finally, our results show no difference in the predicted probability of being a *very intensive ICT user* between entrepreneurs aged between 18 and 30 years old and the reference category, i.e., those aged between 56 and 65.

Our results from specification 7B show how the predicted probability of being a *very intensive ICT user* increases by about 27.3% for urban entrepreneurs aged between 18 and 35 and between 56 and 65 years old, when compared with rural entrepreneurs in the same age bands. Conversely, the positive effect of the degree of urbanization on ICT usage frequency at work is much weaker for entrepreneurs aged between 36 and 45 —about 2% and 5% for age bands 36–40 and 41–45, respectively—, and simply not observed for entrepreneurs aged between 46 and 55 years old. In other words, our results show a moderating effect of age on the positive impact of urbanization on ICT usage by entrepreneurs, where the impact is smaller for middle-aged entrepreneurs. These results support Hypothesis 7.

Finally, our results from specification 8 show how the predicted probability of being a *very intensive ICT user* for rural entrepreneurs increases by about 23.7% with each additional point in the six-point Likert scale in their households' ability to make ends meet. For entrepreneurs living in intermediate areas, however, the predicted probability of being a *very intensive ICT user* only increases by about 10% with each additional point in their households' ability to make ends meet. Similarly, for urban entrepreneurs, the predicted probability of being a *very intensive ICT user* increases by about 15% with each additional point in their households' ability to make ends meet. Otherwise stated, our results indicate a moderating effect of the income level of the entrepreneur's household on the positive impact of urbanization on ICT usage by entrepreneurs, where the impact is smaller for entrepreneurs with higher income levels. These results support Hypothesis 8.

A full overview of our results in relation to our hypotheses is presented in Table 7.

5.2.2 Robustness checks

Some robustness tests are also part of this analysis. First, our results remain significant to the use of single-level ordered logit models. When doing so, our results are robust to the estimation of standard errors that are clustered at both the country and the NUTS 2 level (Moulton, 1986, 1990). Second, our results are robust to including an alternative proxy for digital infrastructure such as the average internet speed at the NUTS 2 level (European Data Journalism Network – EDJNet). We can thus rule out the possibility that our results are due to urban-rural differences in digital

Table 6 Determinants of ICT adoption and use frequency at work *–Multilevel ordered logit models–*

# Specification	5		6		7A		7B		8	
Hypothesis tested	H5		H6		H7		H7		H8	
Average predicted probability [ICT use = 7] (y)	0.141		0.131		0.141		0.141		0.140	
Independent variables (x)	$\frac{dy/dx}{y}\%$	p-value	$\frac{dy/dx}{y}\%$	p-value	$\frac{dy/dx}{y}\%$	p-value	$\frac{dy/dx}{y}\%$	p-value	$\frac{dy/dx}{y}\%$	p-value
Degree of urbanisation –DEGURBA–										
Rural [a] (*ref.*)										
Intermediate [a]	22.3	0.350	12.6	0.052*	7.49	0.161	14.0	0.173	60.7	0.001***
Urban [a]	0.60	0.976	9.80	0.116	8.77	0.102^{+}	27.3	0.011**	38.4	0.006***
Macroeconomic indicators at the NUTS-2 level										
GDP '000 PPS per inhabitant (7–78)	0.44	0.218	0.46	0.203	0.46	0.204	0.45	0.218	0.40	0.269
% Households with broadband access (45–97)	0.96	0.022**	0.94	0.025**	0.93	0.028**	0.94	0.026**	0.99	0.018**
% Population with tertiary education (10.3–55.1)	1.49	0.001***	1.49	0.001***	1.50	0.001***	1.48	0.001***	1.52	0.000***
Educational attainment										
Basic education [a] (*ref.*)										
Secondary education [a]	37.7	0.000***	35.7	0.000***	35.8	0.000***	35.7	0.000***	35.3	0.000***
Tertiary education [a]	121.3	0.000***	128.6	0.000***	129.2	0.000***	129.4	0.000***	129.1	0.000***
Interactions Educational attainment x DEGURBA										
Secondary education x Rural [a] (*ref.*)										
Secondary education x Intermediate [a]	-17.8	0.405								
Secondary education x Urban [a]	6.29	0.773								
Tertiary education x Rural [a] (*ref.*)										
Tertiary education x Intermediate [a]	-4.82	0.839								
Tertiary education x Urban [a]	14.8	0.538								
Demographic characteristics										
Female [a]	-28.6	0.000***	-23.7	0.001***	-28.5	0.000***	-28.2	0.000***	-28.9	0.000***
Immigrant [a]	-0.28	0.966	-0.52	0.936	-0.01	0.998	0.23	0.972	0.04	0.996
Age (18–65)	5.77	0.000***	5.82	0.000***					5.79	0.000***
Age (squared)	-0.07	0.000***	-0.07	0.000***					-0.07	0.000***

Table 6 (continued)

# Specification	5		6		7A		7B		8	
Hypothesis tested	H5		H6		H7		H7		H8	
Average predicted probability [ICT use=7] (y)	0.141		0.131		0.141		0.141		0.140	
Independent variables (x)	$\frac{dy/dx}{y}$%	p-value	$\frac{dy/dx}{y}$%	p-value	$\frac{dy/dx}{y}$%	p-value	$\frac{dy/dx}{y}$%	p-value	$\frac{dy/dx}{y}$%	p-value
Age band 18–30 [a]					9.22	0.308	9.63	0.497		
Age band 31–35 [a]					16.8	0.058*	27.0	0.054*		
Age band 36–40 [a]					19.7	0.016**	29.9	0.018**		
Age band 41–45 [a]					23.3	0.002***	38.0	0.001***		
Age band 46–50 [a]					23.5	0.001***	32.1	0.004***		
Age band 51–55 [a]					20.1	0.003***	34.9	0.002***		
Age band 56–65 [a] (*ref.*)										
Cohabiting [a]	-3.08	0.520	-3.36	0.483	-2.62	0.583	-2.92	0.542	-2.64	0.583
Number of children under 14	2.70	0.591	2.66	0.597	4.61	0.380	4.53	0.389	2.30	0.650
Health (1–5)	2.50	0.374	2.38	0.397	2.47	0.379	2.47	0.379	2.48	0.381
Interactions Gender x DEGURBA										
Female x Rural [a] (*ref.*)										
Female x Intermediate [a]			-13.5	0.155			6.90	0.724		
Female x Urban [a]			-3.36	0.719			2.75	0.874		
Interactions Age bands x DEGURBA										
Age band 18–30 × Rural [a] (*ref.*)										
Age band 18–30 × Intermediate [a]							-6.90	0.724		
Age band 18–30 × Urban [a]							-2.75	0.874		
Age band 31–35 × Rural [a] (*ref.*)										
Age band 31–35 × Intermediate [a]							-11.0	0.569		
Age band 31–35 × Urban [a]							-21.4	0.223		
Age band 36–40 × Rural [a] (*ref.*)										
Age band 36–40 × Intermediate [a]							-4.91	0.775		
Age band 36–40 × Urban [a]							-25.5	0.112^{+}		

Table 6 (continued)

# Specification	5		6		7A		7B		8	
Hypothesis tested	H5		H6		H7		H7		H8	
Average predicted probability [ICT use = 7] (y)	0.141		0.131		0.141		0.141		0.140	
Independent variables (x)	$\frac{dy/dx}{y}\%$	p-value	$\frac{dy/dx}{y}\%$	p-value	$\frac{dy/dx}{y}\%$	p-value	$\frac{dy/dx}{y}\%$	p-value	$\frac{dy/dx}{y}\%$	p-value
Age band 41–45 × Rural [a] (*ref.*)										
Age band 41–45 × Intermediate [a]							-26.3	0.114^{+}		
Age band 41–45 × Urban [a]							-22.4	0.150^{+}		
Age band 46–50 × Rural [a] (*ref.*)										
Age band 46–50 × Intermediate [a]							7.36	0.647		
Age band 46–50 × Urban [a]							-31.2	0.044**		
Age band 51–55 × Rural [a] (*ref.*)										
Age band 51–55 × Intermediate [a]							-15.0	0.353		
Age band 51–55 × Urban [a]							-30.6	0.048**		
Household information										
Ends meet (1–6)	16.2	0.000***	12.1	0.000***	16.2	0.000***	16.2	0.000***	23.7	0.000***
Interactions Ends meet x DEGURBA										
Ends meet x Rural (*ref.*)										
Ends meet x Intermediate									-13.7	0.001***
Ends meet x Urban									-8.72	0.020**
Job characteristics										
Tenure (1–53)	-0.59	0.013**	-0.11	0.013**	-0.63	0.008***	-0.65	0.006***	-0.60	0.012**
Working hours (15–120)	2.42	0.000***	2.39	0.000***	2.46	0.000***	2.49	0.000**	2.45	0.000**

Table 6 (continued)

# Specification	5		6		7A		7B		8	
Hypothesis tested	H5		H6		H7		H7		H8	
Average predicted probability [ICT use=7] (y)	0.141		0.131		0.141		0.141		0.140	
Independent variables (x)	$\frac{dy/dx}{y}\%$	p-value	$\frac{dy/dx}{y}\%$	p-value	$\frac{dy/dx}{y}\%$	p-value	$\frac{dy/dx}{y}\%$	p-value	$\frac{dy/dx}{y}\%$	p-value
Working hours (squared)	-0.02	0.000***	-0.02	0.000***	-0.02	0.000***	-0.02	0.000**	-0.02	0.000**
Log likelihood	-7,309.7		-7,309.9		-7,311.9		-7,304.7		-7,305.0	

Notes: N=4,827; For continuous variables, [(dy/dx)/y]% captures marginal effects, but expressed in relative terms with respect to predicted probabilities. In the context of dummy variables, it reflects the impact for a discrete change of the dummy variable from 0 to 1; $^{+}$ $0.15 \geq p > 0.1$; * $0.1 \geq p > 0.05$; ** $0.05 \geq p > 0.01$; *** $p \leq 0.01$;

[a] Dummy variable; 9 business sector dummies are used in all our specifications: Agriculture, Industry, Construction (*ref.*), Commerce and hospitality, Transport, Financial services, Public administration and defence, Education, Health, Other services; A region indicator for 305 European NUTS-2 is used as our grouping variable in all our specifications. The ICC value is 0.217. Therefore, the NUTS-2 effects compose approximately 22% of the total residual variance; The maximum correlation is 0.70 (between GDP '000 PPS per inhabitant and % Population with tertiary education), and the VIFs values (from specification 2 in Table 4) range from 1.06 to 2.49. Thus, multicollinearity does not pose a concern, especially in consideration of the large size of our sample; Data source: EWCS 2015

Table 7 Overview of results

#	Hypothesis	Supported
	The impact of urbanization on ICT use frequency	
H1	In urban regions, entrepreneurs on average have a higher frequency of ICT usage at work, compared to entrepreneurs in rural regions	Yes
	The impact of regional level of general human capital on ICT use frequency	
H2	In regions with higher levels of general human capital, entrepreneurs on average have a higher frequency of ICT usage at work	Yes
	Moderation hypotheses for the impact of urbanization on ICT use frequency — regional-level moderator variables	
H3	Moderator: regional level of general human capital	Yes
H4	Moderator: regional level of digital infrastructure	Yes
	Moderation hypotheses for the impact of urbanization on ICT use frequency — individual-level moderator variables	
H5	Moderator: education level of entrepreneur	No
H6	Moderator: gender of entrepreneur	No
H7	Moderator: age of entrepreneur	Yes
H8	Moderator: income level of the entrepreneur's household	Yes

infrastructure or digital connectivity (Roberts et al., 2017; Salemink et al., 2017). Full regression results for this robustness test are available on request from the authors.

6 Conclusions and policy implications

In this paper we measured regional differences in entrepreneurs' ICT use frequency at work based on the degree of urbanization in the living area, and investigated the determinants of such differences. Extensive ICT use by entrepreneurs enables them to create competitive advantages in terms of training, learning, research, collaboration, participation on the global market, and other areas of business (Olsson & Bernhard, 2021; Sassetti et al., 2022). Earlier research has shown that for poor individuals, the ability to use ICT-based products can lead the way out of poverty via entrepreneurial activity (Abubakar & Mitra, 2013), and that —ceteris paribus the sector of economic activity— more intensive ICT use by entrepreneurs is associated with stronger entrepreneurial performance (Millán et al., 2021; Barrientos-Marín et al., 2021). At the regional level this implies that a higher ICT use frequency by the region's entrepreneurs is associated with stronger regional performance and more scope for regional development. Hence it is important to understand entrepreneurs' ICT use frequency and the role of regional context. We presented a theoretical framework based on the knowledge spillover theory of entrepreneurship (Acs et al., 2013) and the absorptive capacity theory of knowledge spillover entrepreneurship (Qian & Acs, 2013), which predicted different ICT use frequencies between entrepreneurs in urban and rural regions stemming from different incentives to maintain ICT knowledge and skills needed to be able to absorb local knowledge spillovers. We also hypothesized moderating roles for the regional levels of general human capital and digital infrastructure and four individual-level characteristics of entrepreneurs.

Using survey data for 305 NUTS-2 regions in 35 European countries, we found that ICT use frequency by entrepreneurs is substantially higher in urban areas compared to rural territories, in line with our hypothesis. Importantly, we also found that this relationship between the degree of urbanization in the entrepreneurs' living area and their ICT use frequency at work is moderated by the regional population's share with tertiary education, that is, the digital gap between entrepreneurs living in urban and rural areas is smaller in regions with a higher percentage of population with tertiary education. Similarly, the spatial difference in entrepreneurs' ICT use frequency is also smaller in regions with a better digital infrastructure, as captured by the region's percentage of households with broadband access.

Moreover, regarding entrepreneurs' individual characteristics, it was found that being middle-aged and/or having a higher household income can compensate for some of the disadvantages of operating in a rural area, thus reducing the impact of urbanization on ICT use frequency. By contrast, we did not find such compensating effects for the entrepreneur's education level and gender. This suggests that, although ICT use frequency is generally higher among male and higher-educated entrepreneurs, these individual differences do not alter the urban–rural gap. A possible explanation is that formal educational attainment does not automatically translate into digital literacy or advanced ICT skills applicable to entrepreneurship (Van Dijk, 2020; Helsper, 2021). In rural settings, structural barriers such as limited infrastructure, lack of peer networks, and fewer opportunities for continuous digital learning (Selwyn, 2004; Salemink et al., 2017) may offset the advantages of individual education. Similarly, while gender differences in ICT use remain observable (Cooper, 2006; Cooper & Weaver, 2003), they appear to affect overall levels of adoption rather than moderating the role of location, since contextual factors such as connectivity and digital inclusion remain the dominant drivers of rural disadvantage. In other words, education and gender exert direct effects on ICT use but do not interact with agglomeration advantages, reinforcing the conclusion that regional and structural conditions weigh more heavily than personal attributes in explaining the persistence of the rural–urban digital divide.

Our analysis shows that, even when controlling for sector structure, entrepreneurs in rural regions use ICT less frequently than their counterparts in urban regions. This is problematic since ICT use frequency is positively related with entrepreneurial performance, also in rural areas (Polo-Peña et al., 2011). However, our findings for Hypothesis 4 also imply that rural regions can offset part of the gap in ICT use frequency with entrepreneurs in urban regions if they improve their digital infrastructure, allowing for regional digital infrastructure spillovers to occur. An obvious policy implication for regions lagging in broadband access is therefore to improve such access, i.e., increase the coverage of the broadband network in the region. Moreover, our results for Hypothesis 3 imply that rural regions can also decrease the digital gap with urban regions if they can upgrade the average education level of their inhabitants, thereby increasing rural resilience. Although such processes take time, regional policy makers can try to speed up such process by attracting higher-educated workers and citizens to their regions.

A noticeable target group in this regard is formed by those higher-educated individuals who were born and raised in rural areas but left the region at a young age to study at university or other higher education institutions, a phenomenon known as rural brain drain. It often happens that after finishing education, these individuals find a job in urban regions near their place of study, and do not come back to the region of origin (Lovén et al., 2020). Oftentimes this is not because they do not want to come back but because there are no high-quality jobs in which they can utilize their education. Indeed, research by Yu and Artz (2019) shows that college-educated rural entrepreneurs in the United States start businesses in their region of origin because of a clear location preference. Moreover, these authors report that this location choice is also productive because the entrepreneurs are able to benefit from location-specific capital obtained during their youth. So arguably there is potential to draw highly-educated individuals back to the countryside, but it needs to be made more attractive for bigger groups of people.

To attract more highly educated individuals to rural areas, policy makers at the regional level may consider attracting high-quality government institutes and high-quality, innovative firms to the region. This will often have to be realized with the help of federal governments in the framework of regional development initiatives. But if successful, a rural region may then be able to offer more high-quality jobs which will attract highly educated workers. Besides providing direct high-quality wage jobs, such high-quality institutes and firms will likely also create indirect high-quality jobs for freelancers, as in modern knowledge economies, they tend to outsource several tasks to flexible and creative, high-skilled freelancers (Burke & Cowling, 2020). In this regard, it is promising that hybrid entrepreneurs (paid employed individuals with secondary self-employment activity) have been found to be overrepresented in rural areas (Dvouletý & Bögenhold, 2023). These hybrid entrepreneurs may turn into full-time entrepreneurs when the demand for freelancer work in rural areas increases.

These high-quality jobs for employees and freelancers will require considerable ICT skills (Dvouletý & Postepska, 2022). And with more highly educated workers in the region, there is more scope for knowledge spillovers to occur, which may cause some employees to start their own innovative start-ups (Colombelli et al., 2016). If successful, they will create additional jobs (Savin & Novitskaya, 2023). And the higher incomes associated with these jobs may lead to more spendings in the local economy, etc. In this way, considerable multiplier effects may emerge, which will slowly but surely increase the education level of the region's population. As shown in our paper, this will diminish the rural digital disadvantage in terms of a region's entrepreneurs' ICT use frequency. More generally, such a development may contribute to a change in the nature of rural businesses. Rural start-ups are often considered to be marginal businesses and to be a form of necessity-based entrepreneurship (Renski, 2008; Yu & Artz, 2019). However, in the above scenario, more opportunity-based, high-skilled freelancers with high value-added will become part of the rural labour market as well, thereby contributing to rural diversification and rural resilience (Quaranta & Salvia, 2014). In this regard, our results for Hypotheses 7 and 8 show that especially middle-aged individuals and/or individuals from higher household incomes are good candidates to become high-skilled freelancers who practice high ICT use frequency, thereby contributing to a digital convergence process between entrepreneurs in urban and rural regions. Indeed, in this scenario, the strong preference for urban locations of entrepreneurs in high-tech industries such as the knowledge-intensive businesses services (Ferreira et al., 2016) may be weakened or even reversed.

In the same vein, establishing local campuses of universities and other higher education institutions may also attract highly educated individuals to the region. Smith and Higley (2012) show that for highly educated couples with young children who consider relocating to rural places, the provision of high-quality education for their children is an important factor driving their decision. We argue that this will not only hold for the local availability of primary and secondary education institutes, but also tertiary education. Rural regions become more attractive for couples if they know that in time, their children will be able to visit university in the own region. Similarly, local campuses of universities may diminish the rural brain drain phenomenon as youngsters then have a tertiary education option in their region of origin (Guerrero et al., 2018).

A scenario in which rural regions are indeed successful in attracting higher educated inhabitants will likely prevent rural decline to a large extent as it will meet the three conditions identified by Li et al. (2019) for enhancing rural communities' resilient capacity in the knowledge economy. First, the higher educated workers in the new firms and government institutes, including local university branches, will be able to *develop new economic activities that can respond to potential urban demand*. Second, the new freelancers will contribute to rural development by *initiating local entrepreneurship that can establish and expand these new activities*. In particular, new freelancers can serve as suppliers of high-quality knowledge-intensive services to these new firms and institutes. Third, the new highly educated workers and freelancers moving from the city to the rural area to benefit from new high-quality job opportunities will likely have considerable networks in the urban regions they move out from, providing ample *social capital* to support the new local entrepreneurship initiatives (Li et al., 2019). At the same time, if entrepreneurial endeavours of new inhabitants of remote rural areas are to be successful, it is important that they fully integrate in the local community (Bichler et al., 2022).

Besides attracting highly-educated people from outside the region, rural areas may of course also invest in further training and education of their native inhabitants to increase the human capital of the regional population. Training and entrepreneurship education efforts may also be directed towards rural SME owners although training programs delivered by venture support agencies are not always effective (Jagoda et al., 2016). Another important condition for successful transformation of rural regions is their accessibility from urban regions as interaction with the big cities remains essential for the sustainability of rural economies (Li et al., 2019). For this condition to be met, improvements in road and rail infrastructure will still be needed in many remote regions. A final recent development favouring high-skilled ICT-based work in rural regions is the increased acceptance of working from home. This development will also have to be fostered by regional policy makers and firm managers in order to make it more attractive for workers and entrepreneurs to migrate to rural areas.

A recent example of a regional policy initiative to strengthen the socio-economic position of a rural region, containing several of the above-mentioned elements, involves the rural province of Zeeland in the southwest of the Netherlands. In collaboration with the federal Dutch government, a package of measures was initiated, including the establishment of a federal court and a new research institute in the province, as well as improving train connections between Zeeland and the urban

Randstad region, thereby shortening travel time (Wientjes, 2020). The aim of this package is to stimulate regional development by creating high-quality jobs in the region and improving accessibility of the region. The results of our study suggest that such regional policy initiatives may indeed be promising.

In conclusion, we believe our analysis has contributed to a better understanding of the urban-rural digital divide for entrepreneurs in European regions, and the specific role of the regional population's education level in fostering rural resilience in the knowledge economy. Moreover, our study has also provided new insights regarding the moderating roles of the region's digital infrastructure and four individual-level characteristics of entrepreneurs in reducing the urban-rural digital divide in terms of entrepreneurs' ICT use frequency at work.

Author contributions All authors contributed substantially and in a balanced manner to the study. Conceptualization, methodology, investigation, formal analysis, and validation were joint efforts of the five coauthors. E. Nolan and A. van Stel took the lead in writing and revising the manuscript, while J.D. Ramos-Poyatos, J. Barrientos-Marín and J.M. Millán led data curation and visualization. Overall project supervision and administration were undertaken by J.M. Millán and A. van Stel. Project funding was secured by J.M. Millán. This paper is part of the doctoral dissertation of J.D. Ramos-Poyatos.

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Declarations

Conflict of interest The authors have no relevant financial or non-financial interests to disclose.

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