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Bridging the gap in creative economy and ICT research: a regional analysis in Europe

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Abstract

Following Florida’s seminal work on the ‘creative class’ there is a great deal of interest concerning whether creativity, as an input, is important for regional growth. Answering this question requires developing a production framework that can distinguish creativity from other inputs. With data from Europe, this paper integrates the concept of information and communications technology (ICT) and the creative class into a theoretical production function. Findings reveal that not only is there a positive and interactive relationship between creative workers and ICT, but the combination of creative workers and ICT leads to higher levels of GVA growth. Moreover, creative workers were found to have a larger impact on growth in comparison with traditional human capital measures (i.e. graduates). Thus, findings from this research suggest that the creative class should not only pay attention to socio-economic preferences of individuals, but it must include wider social resources, such as ICT.

Key words: Creative Class; Human Capital; ICT; Regional Economic Development; Europe.

JEL Codes: R10, O10, J00

1. Introduction

As global competition has intensified the capacity to mobilize, attract and utilize innovative talents has become increasingly important. This is because talent plays a decisive role at different stages in converting a new idea or creativity into a successful innovation and economic output (Glaeser and Resseger, 2010; Glaeser *et al*., 2014). Creative cities and regional innovation has therefore grown in importance (Booyens, 2012; Baumol, 2010; Batabyal and Nijkamp, 2013; Scott, 2014) and the rise in such debates can be traced to Richard Florida. Florida's early ideas suggested that an agglomeration of bohemians creates an attractive environment for skilled and talented individuals. Consequently, these groups form the creative class which acts as a magnet for innovative industries and MNEs (Kottaridi *et al*., 2018) at the technological frontier (Florida, 2002a; 2002b). Florida's later assertions focused more on the consumer/amenity/living standards choices of the creative class and the territorial competition in attracting them (Florida, 2010b). Since then, multiple studies have also explored the relationship between the improvement of innovation capacity and socio-economic development from a perspective of 'occupation division' (Clifton, 2008; Markusen, 2006; Evans, 2009; Waitt and Gibson, 2009; Ponzini and Rossi, 2010). However, Florida's logic and empirical propositions have been heavily criticised (Marcuse, 2003; Hansen and Niedomysl, 2009; Reese, 2010; Scott, 2006, Navarro *et al*., 2014; Nathan, 2015). Yet, a notable feature of these criticisms is that it has broken away from the initial framework of the creative class theory. This is because it takes the concept of the creative class as a theoretical 'puzzle' and often combines it with other important economic and geographical theories to explore optimization of innovation structures (e.g. Mellander *et al*., 2017; Batabyal and Yoo, 2017).

Importantly, the crucial issue for evaluating the importance of the creative class concerns evaluating its embedded relationship with other factor inputs in a production system. We argue that there is a need to collaboratively link the creative class with other socio-economic factors in the context of urban and regional theories. In doing so, we combine the concept of the creative class with models that emphasise another important input to production, namely Information and Communication Technology (ICT).

ICT is undoubtedly a major driver of productivity and economic growth, with strong evidence for its importance in the aggregate growth literature (Jorgenson and Stiroh, 2000; Timmer *et al.*, 2010; Iammarino and Jona-Lasinio, 2015) as well as within firms (Bresnahan *et al.*, 2002). Moreover, the subsequent utilization of digital technologies, such as ICT, is also said to be likely to be highly present within creative regions (Batabyal and Nijkamp, 2015). According to Florida's theory, creative cities/regions are populated by members of the creative class who process creative capital (i.e. creativity and professional experience rather than formal education), yet, there is a scarcity in studies that have explicitly modelled the accumulation impact of the creative class and ICT. We measure the effects of the creative class, ICT and their interactions via the neoclassical production function framework, which in its most general form specifies that outputs depend on inputs and technology. Typically, previous research utilising these frameworks either use one of two approaches, growth accounting or regression analysis. In this paper we present estimates using the latter to answer the following research questions:

RQ (1) How do the creative class and ICT impact regional economic growth in Europe? This question is addressed by utilising both creative and ICT inputs into a standard economic model of production. This is a first step in extending the previous literature to quantify the magnitude of these inputs and gauge if they have a significance direct impact on regional growth.

RQ (2) Are there links between the use of creative inputs and the use of ICT? In this second step complementarities between ICT and creative input are investigated. This considers the significance and magnitude of impacts on growth in regions of having high (or low) levels of the two inputs simultaneously, after allowing for the direct impacts, in an econometric framework.

RQ (3) Is the creative input distinguishable from general human capital? Finally, an attempt is made to econometrically distinguish creative input from general human capital to answer Glaser's criticism that creative input is just picking up effects from general human capital.

The remainder of this paper is organized as follows. The next section provides a literature review on the two main elements of this paper, the creative class and ICT. Sections 3 outlines the methodology and more precisely the production function framework and data that is employed in section 4, which is the findings section. Section 5 provides the discussion, implications and conclusion to this study. Finally, section 6 outlines the limitations and avenues for future research.

2. Literature review

2.1 The creative class thesis

Theoretical and empirical research on factors that affect growth highlight an important role for human capital, which has commonly been defined as the skill levels of workers, e.g. in endogenous growth theory as set out in Lucas (1988) or growth accounting estimates in Jorgenson *et al*. (1987). Florida's creative class concept (Florida, 2002a; 2002b; 2010a; 2010b) focused on the contribution of creative skills rather than general human capital. Florida's creative class concept (Florida, 2002a; 2002b; 2010a; 2010b) focused on the contribution of creative skills rather than general human capital and this was coined as the Three T's (Technology, Talent, Tolerance). However, Florida's assertions has created a polarised debate in the literature (Thiel, 2017) and some have advocated that the logic and empirical claims of the creative class within Florida's thesis is to a certain degree disconnected with economic and social realities (Peck, 2005; Scott, 2014). The literature has specified deficiencies concerning the theoretical framework that Florida utilised, such as: illustrating no difference compared to the traditional human capital measure (the share of graduates) (Glaeser, 2005; Donegan *et al*., 2008; Nathan, 2015); only indicating a sense of static correlation but not causality between the presence of the creative class and economic growth (Boschma and Fritsch, 2009); failing to capture the role of the creative class when explaining economic growth in smaller urban and rural areas; and failing to acknowledge bi-directional (Neal, 2012) relationships i.e. whether jobs follow people or whether people follow jobs (Storper and Scott ,2009; Scott, 2006).

A number of studies developed disaggregate models which featured a range of variables that were thought to be related to creative workers and ultimately, the validity of the creative class theory. These models highlighted the reconstruction of the original 3T framework and that the values of the creative class depend on its level of contact with other factors within the eco-social system. As a result, the creative class research has integrated many social and economic dimensions including individual and collective characteristics, in order to capture the multi-dimensional nature of 'creativity'. These attempts have included the following: further decomposition of the creative class according to its economic function in the era of the knowledge economy (Markusen, 2006) combining human capital with the creative class measure within the same analytical framework (Marlet and van Woerkens, 2007; Marrocu and Paci, 2012); focusing on a particular function of the creative class, such as resistance on unemployment (Stolarick and Currid-Halket, 2013), increasing productivity (Florida *et al*., 2008); and reinforcing network effects in the workplace (Mellander *et al*., 2017).

Yet, despite the effort to include a range of factors reflecting the complexity associated with the creative class, a theoretical framework that can enhance the quality of complex innovation processes within regions is rarely investigated. Thus, there is a need to adopt a macro-model that integrates the creative class with other dimensions of the knowledge economy incorporating the idea of factor complementarity. As the widespread adoption and diffusion of ICT is another major change in knowledge inputs. We now turn to the literature on this important technological revolution .

2.2 ICT, human capital development and the creative class

Pervasive technologies, which can be in the form of ICT, have previously been outlined as being important contributors to economic growth (Jiménez *et al*., 2014; Iammarino and Jona-Lasinio, 2015; Hafner and Borrás, 2017). Numerous studies have suggested that rapid growth in ICT, observed over more than two decades, significantly impacts business performance and economic growth (Jorgenson and Stiroh, 2000; Ahmad *et al*., 2004), especially in the service sectors (Timmer *et al*., 2010). However, ICT alone is not enough to explain economic performance. Arvanitis (2005) suggested that ICT can contribute to generating complementary innovations as digital investment can go hand-in-hand with human capital development or institutional change. Baycan (2012) found that migrant entrepreneurs are more likely to work in new and non-traditional sectors like ICT. The relationship between social change and ICT has been identified as an internal determinant to explain disparities in economic or managerial performance. In other words, investments in ICT appear to be closely related to complementary innovations and they are most productive in institutions with previous experience from earlier innovations. This suggests that ICT can facilitate employee participation and communication, which subsequently can accelerate innovation processes (Hall *et al*., 2013).

Given the complementary relationship between ICT and human capital development (Jiménez *et al*., 2014), the notion of skill-biased technological change (SBTC) has been used to understand the shift in employment towards a more educated and skilled workforce (Autor *et al*., 1998). Fundamentally, the demand for college graduates outpaced supply shifts, leading to higher wages for these types of workers, and these shifts were related to use of ICT. There is widespread evidence for the existence of SBTC (Bresnahan *et al*., 2002), and more refined subsequent analysis further focused on the tasks carried out by workers rather than on certified skills. ICT is complementary to non-routine tasks, but a substitute for routine tasks (Autor *et al.*, 2003). Non-routine tasks have been ascribed to highly-skilled professionals and managers with the main losers being middle-skilled workers, such as bank clerks, whose tasks appear to be replaceable during the computerisation process. This is supported by Michaels *et al*. (2014), who investigated the U.S., Japan and nine European countries and found that industries with high levels of ICT growth faced a rise in demand for higher education, but a fall in demand for middle education. The phenomenon of SBTC has resulted in the notion that ICT does not give rise to economic growth or productivity gains until companies, industries and their workers achieve the acquired technological, educational, organizational or cultural competencies (Skorupinska and Joan Torrent-Sellens, 2017).

The relationship between ICT and human capital are inextricably linked with innovation capacity building. It not only contributes to building up knowledge and capabilities, but also helps us to cope with the rapidly changing social and economic realities (Batabyal and Yoo, 2017). From this perspective, prior research defined human capital as a vector of certified skills, often using the share of the workforce with graduate level qualifications as a proxy. However, this approach does not provide an insight into the advantages acquired by occupation-specific human capital (Poletaev and Robinson, 2008). The creative class thesis offers ways of understanding how technological progress and a specific aspect of human capital development relate to and enrich each other. By definition, creative workers belong within the class of occupations concerned with non-routine tasks, which cannot easily be substitutable by computers or automation processes, and are a more specific form of human capital that represents changes in social patterns such as identities, cultural preferences, lifestyles, values and consumptions, than the notion of human capital more generally.

In summary, we argue that the examination of technology with creativity can enrich the creativity-engendering literature (Baumol, 2010; Batabyal and Nijkamp, 2013). More specifically, this paper attempts to investigate the relationship between specific forms of human capital and technology by developing a production function framework that allows estimation of the direct impacts of creativity and its complementarity with ICT assets.

3. Methodology

3.1 Analysis

One of the mainstream approaches to estimate a production function was highlighted by Olley and Pakes' technique (OP technique) (1996). This was further revised by Levinsohn and Petrin (2003) (LP technique) and by Ackerberg *et al*. (2006) (ACF technique). These structural models utilise intermediate inputs or investment to control the unobservable productivity at the firm level. In contrast, the dynamic GMM approach has two advantages (Ackerberg *et al*., 2006). Frist, it accounts for fixed effects, thus unobservable effects in time-invariants can be effectively removed. Second, the dynamic GMM estimation does not require information concerning intermediate inputs or investment. This is particularly important to this study, as it is difficult to collect intermediate inputs or investment at the regional level, thus the application of the dynamic GMM model is better suited when estimating the European aggregate production function.

Basic model

We begin with a traditional log-linearised production function, estimated over the period 1995-2007 for the pooled dataset of 142 European regions (see data description in section 3.2).

$$\ln Y_{i,t} = \alpha_i + \beta_1 \ln CR_{i,t} + \beta_2 \ln NCR_{i,t} + \beta_3 \ln ICT_{i,t} + \beta_4 \ln NICT_{i,t} + \beta_5 (\ln CR_{i,t} * \ln ICT_{i,t}) + \delta_t + \tau_j + \mu_{i,t} \quad (1)$$

where time (δ_t) and country (τ_j) dummy variables are included to account for common macroeconomic shocks for all regions and country-specific effects in any period t. The interactive effect between creative labour services and ICT capital services is measured by the coefficient γ_1. At the country level, a TSLS (Two Stage Least Square) model can be used to estimate this regional production function with one period lagged values of the regressors used as instruments to (partially) deal with endogeneity issues. However, tackling endogeneity is difficult in this context due to the lack of good instruments so the econometric results, like the growth accounting estimates, can only be interpreted as associations.

Robustness test I: endogeneity corrected estimations

Given the issue mentioned above, it is possible to use the fixed effects model to control both unobservable region-specific characteristics and time-invariant observables. However, the typical fixed effects model may suffer from misspecification as it omits dynamic effects. GVA is likely to be determined by its current and the past realisations of independent variables. Therefore, the basic model can be further extended to an autoregressive panel model:

$$\ln Y_{i,t} = \alpha \ln Y_{i,t-1} + \beta_1 \ln CR_{i,t} + \beta_2 \ln CR_{i,t-1} + \beta_3 \ln NCR_{i,t} + \beta_4 \mathit{ln} NCR_{i,t-1} + \beta_5 \ln ICT_{i,t} + \beta_6 \ln ICT_{i,t-1} + \beta_7 \ln NICT_{i,t} + \beta_8 \ln NICT_{i,t-1} + \beta_9 (\ln ICT_{i,t} * \ln CR_{i,t}) + \beta_{10} (\ln ICT_{i,t-1} * \ln CR_{i,t-1}) + \tau_t + \mu_{i,t} \quad (2)$$

The level of GVA is not only determined by the current level of labour or capital inputs, but is also pre-determined by past economic situations. In this case, the traditional fixed effects estimation will produce dynamic bias as the process creates an association between $\ln Y_{i,t-1}$ and error term. Blundell-Bond's (1998) system GMM estimator is a powerful tool to overcome such bias. Roodman (2006) states that the main difference between this model and previous difference based models concerns the way of instrumenting. Thus, rewriting equation 2 in an error correction form yields the following equation:

$$\Delta \ln Y_{i,t} = \emptyset (\ln Y_{i,t-1} + \theta_1 \ln CR_{i,t} + \theta_2 \ln NCR_{i,t} + \theta_3 \ln ICT_{i,t} + \theta_4 \ln NICT_{i,t} + \theta_5 (\ln ICT_{i,t} * \ln CR_{i,t}) - \beta_2 \Delta \ln CR_{i,t} - \beta_4 \Delta \ln NCR_{i,t} - \beta_6 \Delta \ln ICT_{i,t} - \beta_8 \Delta \ln NICT_{i,t} - \beta_{10} \Delta (\ln ICT_{i,t} * \ln CR_{i,t}) + \tau_t + \mu_{i,t} \quad (3)$$

The long-run coefficients for each variables are

$$\theta_1 = \frac{\beta_1+\beta_2}{1-\alpha}, \theta_2 = \frac{\beta_3+\beta_4}{1-\alpha}, \theta_3 = \frac{\beta_5+\beta_6}{1-\alpha}, \theta_4 = \frac{\beta_7+\beta_8}{1-\alpha}, \theta_5 = \frac{\beta_9+\beta_{10}}{1-\alpha},$$

$$\emptyset = -(1-\alpha) \quad (4)$$

$\Delta \ln Y_{i,t}$, $\Delta \ln CR_{i,t}$, $\Delta \ln NCR_{i,t}$, $\Delta \ln ICT_{i,t}$, $\Delta \ln NICT_{i,t}$ and $\Delta(\ln ICT_{i,t} * \ln CR_{i,t})$ are all equal to 0 at the equilibrium point in the long run.

Robustness test II: distinguishing creative capital from general human capital

Importantly, Glaeser (2005) asserted that measures of the creative class rarely take into account different levels of education. Given this, we attempted to disentangle human capital and creativity in two ways. First, our model distinguishes graduates into those in creative occupations (GCR) and graduates in non-creative occupations (GNCR). A more robust test involves seeing if there is any impact of creative graduates over and above the fact that they are graduates per se. To do so we use the growth accounting approach which weights each type of labour by their wage bill shares, using the theoretical assumption that wages equals marginal products. If the contribution of creative graduates is greater than graduates in non-creative occupations then this should be related to these labour groups relative wage rates. We first take the ratio of average wages for creative graduates relative to non-creative graduates.

$$W^* = \text{wage GCR}/\ \text{wage GNCR}\ (5)$$

We then multiply ln(GCR) by W* to obtain a measure of the impact of being a creative worker over and above being a graduate. The revised production function is expressed as the following:

$$\ln Y_{i,t} = \alpha_i + \beta_1 \ln GCR_{i,t} + \beta_2 \ln GNCR_{i,t} + \beta_3 \ln NGCR_{i,t} + \beta_4 \ln NGNCR_{i,t} + \beta_5 (W * \times \ln GCR_{i,t}) + \beta_6 \ln ICT_{i,t} + \beta_7 \ln NICT_{i,t} + \beta_8 (\ln GCR_{i,t} * \ln ICT_{i,t}) + \tau_t + \mu_{i,t}\ (6)$$

3.2 Data

This research investigates regional development for the following European countries; Belgium, the Czech Republic, Finland, France, Germany, Hungary, Italy, Spain, Sweden and the UK. The regional classification is defined by Nomenclature of Territorial Units for Statistics (NUTS) at level 2[*†], which is a geocode standard for referencing the subdivisions of countries within the EU. Given the revision of the standard industry classification, from NACE1 to NACE 2, and the change in occupation codes, from ISCO88 to ISCO00, it was not

[*] This is the largest sample data we can collect from EU LFS with the valid variables that can be used in this study.
[†] In the U.K., data is only available at NUTS 1 level from the EU LFS.

possible to generate harmonised variables regarding the creative class and ICT concerning the period 1995-2015 or longer. Therefore, considering the issue of missing data and inconsistency, the time series in this study was limited to 1995-2007, with a shorter time span for some countries, e.g. 1999-2007 for the U.K. and 1999-2006 for Sweden.

Creative/non-creative labour services: Compared to previous studies, we provide an empirical contribution by proposing a new way in which to capture creative/non-creative workers. Frist, this study uses Florida's occupation categories, which divides occupations into three groups, creative professionals (mostly managers and technicians); bohemians (writers, artists and entertainment professionals) and the creative core (scientists, engineers, architects and health and education professionals). Given the significant difference in the standard occupation classification between the U.S. and Europe, the composition of the creative class is as similar as possible to Florida's construction (see Boschma and Fritsch, 2009). Using the EU harmonised labour force survey (EU LFS), 3-digit ISCO 88 codes and 2-digit NUTS codes were used to estimate the number of creative/non-creative workers by region. This was multiplied by their actual working hours, in the reference week, for estimating labour inputs produced by creative/non-creative workers at the NUTS 2 level in Europe. To our best knowledge, this is a novel mode, which directly measures the labour output of the creative class within a production function framework. This study used the variable "The Actual Working Hours in the Reference Week" (variable "HWACTUAL") in EU LFS to estimate total working hours in the reference year (this includes working hours of paid and unpaid overtime). In this study we make an assumption i.e. average working hours in a week is representative for an average week during the survey year, thus is multiplied by 52, to represent a year[‡].

[‡] $365/7=52.143\approx52$.

Labour services of creative sub-categories: An important issue to address concerns the overlap between graduates and creative occupations, as a large proportion of creative workers are indeed graduates. Thus, it is difficult to disentangle which effect on economic growth comes from the creativity and which to formal education. Given this, in our study creative and non-creative workers were decomposed into four sub-categories, namely: high-skilled creative workers (GCR); medium/low-skilled creative workers (NGCR); graduate non-creative workers (GNCR); and medium/low-skilled non-creative workers (NGNCR). These categories were used to analyse not only the creative class but also the associated effect from higher education. We expect that this technique, together with the model presented in the robustness test II, will be able to shed more light regarding the controversy concerning the impact of creative workers and graduate.

Output: based on Cambridge Econometrics, output is measured as real gross value added (GVA) in 1995 prices at NUTS 2 level.

ICT/non-ICT capital services: Another one of our methodological contributions concerns the measurement of ICT/non-ICT capital services (i.e. output) at the NUT 2 level in Europe. There are conceptual challenges when seeking to measure capital services growth, as the quantity of capital services is normally not observable in practice. Therefore, this study relies on theoretical assumptions to approximate the level of capital services. The most well-known approach was developed by Jorgenson (1963), Hall and Jorgenson (1967) and Jorgenson and Griliches (1967). Capital service flows are estimated by weighting the growth rate for each individual asset stock by the relevant marginal productivity based on estimating user costs of capital[§]. This method is used in constructing capital input in EU KLEMS (see O'Mahony and Timmer, 2009).

Importantly, at the regional level, as cross country estimates are not available to enable the calculation of capital services we construct a proxy measure based on the industrial composition of each region. Thus, capital-labour ratio by industry is assumed to be constant across regions in a country and employment (per industry) for each region is used to construct capital services. Given this, ICT and non-ICT capital services are defined as per hour term in the EU KLEMS (i.e. variable "CAPIT_QPH" and "CAPNIT_QPH"). Capital by industry over shares of employment in each industry were combined to calculate a proxy measure. The assumption that capital-labour ratio by industry constant results in the following equations:

$$\mathrm{K_{ICT,j,t}} = \mathrm{V_{ICT,j,t}} * \mathrm{H_{j,t}} \quad (7)$$

$$\mathrm{K_{NICT,j,t}} = \mathrm{V_{NICT,j,t}} * \mathrm{H_{j,t}}$$

$$\mathrm{ICT_{i,t}} = \sum_{j=1}^{j=17} \mathrm{K_{ICT,j,t}}/\mathrm{L_{j,t}} * \mathrm{L_{i,j,t}} \quad (8)$$

$$\mathrm{NICT_{i,t}} = \sum_{j=1}^{j=17} \mathrm{K_{NICT,j,t}}/\mathrm{L_{j,t}} * \mathrm{L_{i,j,t}}$$

$\mathrm{K_{ICT,j,t}}$, $\mathrm{K_{NICT,j,t}}$ and $\mathrm{L_{j,t}}$ are ICT, non-ICT capital services and number of labour by industry j at a national level at time t respectively. $\mathrm{K_{ICT,j,t}}$ is calculated by multiplying ICT capital services per hour worked ($\mathrm{V_{ICT,j,t}}$) by the total hours worked ($\mathrm{H_{j,t}}$) in industry j and similarly for non-ICT.

As capital-labour ratio is constant across regions in a country, for any particular region i at time t, the total regional $\mathrm{ICT_{it}}$ or $\mathrm{NICT_{it}}$ capital services is the sum of the arithmetic product

[§] The user cost for asset type k is estimated by $p_{k,t-1}^{I} i_t + \delta_k p_{k,t}^{I} - (p_{k,t}^{I} - p_{k,t-1}^{I})$ with i_t representing the nominal return, δ_t the depreciation rate of asset type and investment price of asset type k.

of the national capital-labour ratio $K_{ICT,j,t}/L_{j,t}$ or $K_{NICT,j,t}/L_{j,t}$ and the regional labour input $L_{i,j,t}$ by all industry. There are 17 industries in total according to the NACE 1.1 standard, and the EU KLEMS database was used to calculate ICT/non-ICT capital-labour ratio at the national level since 1975. However, the interpretation of the capital variables needs to be treated with caution as they are capturing regional differences in industrial structure according to different capital intensities. High levels of ICT capital refers to regions employing a concentrated workforce in ICT sectors.

4. Findings

4.1 Integrating creative skills with technology

Table 1 also shows summary statistics for the variables included in the regressions. It shows a further breakdown of labour input by skill level showing creative graduates (creative workers with a university degree), non-graduate creatives (creative workers without a university degree), graduate non-creatives (non-creative workers with a university degree) and non-graduate non-creatives (non-creative workers without a university degree). Both dependent and independent variables to a certain degree have wide distributions. The value of Gross Value Added varies from 455,196 to 765 and the standard deviation is 59710.5. Some of the independent variables exhibit similar variation, for example, non-ICT capital services varies between 63321 and 139. Hence, as described below, analytical models were adopted with different perspectives to deliver robust results. On average, creative workers account for about a third of all workers, with slightly more graduates than non-graduates in the creative workforce, and creative graduates make up about 70% of all graduates. However, these are averages across regions and vary considerably, as shown by the large standard deviations.

[*Insert* Table 1]

Table 2 presents the econometric results using our regional data. Observing Model I, the OLS model does not really produce meaningful results, with contributions from inputs, especially labour, mostly being negative. This inconsistency suggests mis-specification, most likely due to the large heterogeneity across the observations. In response, Model II addresses this by including year dummies for controlling jointly trending effects, such as common economic shocks, and country dummies to capture factors that affect specific countries, including that some enter the panel at different time points. In this variant the results suggest significantly positive impacts from ICT capital, creative labour and non-creative labour services but NICT capital services become insignificant. The interactive term, ICT*CR, is positive and significant.

In an attempt to partially tackle endogeneity concerns, it is assumed that past values of regressors are significantly correlated with their current values but not the current error terms. The inclusion of more than one-period lagged values as instruments significantly reduces the sample size in this study; therefore, only one-period lagged values of regressors were taken as the possible instrumental variables. As Model III shows, the sign and significance of variables do not largely change. These results, at the country level, indicate that estimates of the direct impact of ICT appear to be consistent with the findings from previous studies such as O'Mahony and Vecchi (2005), as ICT investment produces excess returns as compared to the predication from the growth accounting approach. This may be due to non-pecuniary spillovers associated with their usage, such as network externalities and learning by doing (Venturini, 2009). In comparison we see an insignificant impact of non-ICT capital services inputs on output growth. This suggests that non-ICT capital does not have a clear role in regional economic development. We also found a stronger direct effect of creative labour on GVA growth in this specification but the effect of non-creative labour decreased. The direct impact of creative workers is much stronger than non-creative workers in the regressions despite their generally lower labour shares. Importantly, the significant positive interactive effect between ICT capital and the creative class has a coefficient not very different from Model II. The complimentary role between ICT capital accumulation and creative workers suggests that greater accumulation of ICT capital will produce more units of output through the creative worker's labour services. Thus, the existence of more creative workers also contributes to the efficiency of ICT capital, which, to a certain extent, captures the effect of skill-biased technological change (SBTC). Autor *et al*. (1998, 2006) concluded that technological progress is complementary to skilled workers involved in non-routine tasks, such as graduates. By definition, the creative class belongs in the category of occupations concerning non-routine tasks which cannot be easily replaced by computers or automation. Given this, our findings demonstrate a complementary, but not substitutive, relationship between occupation-specific human capital and technology (Batabyal and Nijkamp, 2015).

[*Insert* Table 2]

4.2 Robustness test

Fixed effects estimation: a sub-level perspective

Next, we took group variations (i.e. regional variations) into account. As shown in Model IV, the fixed effects estimation reveals a smaller magnitude of coefficients. For example, the coefficient of the creative class was 0.285 in Model III which decreased to 0.043 in Model VI. European regions are significantly different in terms of socio-economic development, institution quality and industrial structure, therefore an estimated production function for most European regions leaves little variation in the data. In other words, if we consider the whole of Europe as an economic system, additional measurement error problems emerge from relying on the high variation in factor choices by economic agents over time in different regions and countries (Griliches and Mairesse, 1998). Thus, these misallocations would eventually lead to a significant decreasing return to scale (DRS). However, we can still reach similar conclusions; the effects of the creative class and ICT on GVA growth were higher than the effects of non-creative workers and non-ICT. Even though the independent effects of the creative class and ICT were no longer significant in the model with a interaction term[**], the significantly positive interaction between the creative class and ICT still indicates a strong complementary relationship at the regional level.

Dynamic GMM estimations: a long-run perspective

Based on the model specification, shown in Eqs.3, the normal within group transformation does not eliminate dynamic panel bias, as some of the lagged variables could be correlated with the fixed effects in error terms. In this case, dynamic GMM estimator outperforms fixed effects estimator as past changes are more predictive of current levels than past levels are of current changes. It is worth mentioning that the effects based on this specification can only be interpreted as long-run effects. As shown in Model V, the long-run coefficients of the creative class and ICT were (0.032-0.024)/(1-0.987)=0.615 and (0.014-0.012)/(1-0.987)=0.154. Also, the interactive term and non-creative workers were (0.004-0.003)/(1-0.987)=0.091 and (0.020-0.016)/(1-0.987)=0.307. Importantly, all four coefficients were of significance. In comparison, the 1 period lagged coefficient of non-ICT was -0.013. This finding shows a different pattern compared to Model III-IV, but the conclusion regarding the role of non-ICT capital is still consistent with what the previous had models predicted. From a long run perspective, this finding may indicate a significant economic structure change for many of the European regions

[**] The involvement of an interaction completely changes the way of interpreting results. Now the partial effect of the creative class or ICT on GVA growth not only depends on the accumulation of its individual input but also their interactive effect, thus the insignificance of the independent effects only indicates that when the value of ICT or the creative class is given to 0, the partial effect of the creative class or ICT is not significiant at the regional level. In reality, a region with 0 ICT or creative capital reserve does not exist.

on average, as the regional economic growth in Europe is usually accompanied with declines of outputs from traditional industrial investments, such as mining, construction or traditional manufacturing. Therefore, both the fixed effects and the dynamic GMM estimators obtained a consistent conclusion, that is, the present collaborative mechanism between the creative class and ICT well explains the disparity in economic growth across regions in Europe.

Distinguishing creative capital from human capital in general

Importantly, measures of the creative class merely pick up on different levels of education (Glaeser, 2005). Given this, in our study creative and non-creative workers were decomposed into four sub-categories, namely: high-skilled creative workers (GCR); medium/low-skilled creative workers (NGCR); graduate non-creative workers (GNCR); and medium/low-skilled non-creative workers (NGNCR). These categories were used to analyse not only the creative class but also the associated effect from higher education.

Model VI in **Table 3** also identified that the contribution of creative graduates and non-creative graduates are both significant, with the coefficient on the former greater than the latter, and the relative wage term GCR×W* is also highly significant, while the coefficients on GCR and GNCR remain significant. This finding suggests there is something more than just being a graduate associated with creative workers. Moreover, creative non-graduates is significant, as is ICT capital, but non-ICT capital is not significant. This model therefore supports the previous conclusions that cross region differences in GVA are intrinsically linked with new technology and creative inputs. The interactive term ICT*GCR was further included. Despite that the effect of GCR was moderated by ICT, this attempt did not obviously change the size of coefficients and the coefficient of ICT*GCR is positive and significant. We repeated Model III and V, with lagged instruments, including these additional labour type variables in Model VI. As shown in Model VII , now the coefficient of GCR is seen to be insignificant. However, the relative wage term and interactive term ICT*GCR remains positive and significant. This result can be also confirmed by Model VIII, after controlling for endogeneity based on the dynamic GMM model.

[*Insert* Table 3]

5. Discussion, implications and conclusion

The importance of regions in shaping national economic growth trajectories has been the subject of extensive research in recent years. When economic growth has been investigated internationally in different regions, economic models have also focused attention on knowledge generation and business spillovers, labour market characteristics and agglomeration effects (Clarke and Xu, 2016; Hafner and Borrás, 2017). These approaches have commonly involved an emphasis on human capital, labour force skills and city amenities as attractors of skills (Glaeser and Resseger, 2010; Glaeser *et al*., 2014) and a particular focus has been on creative workers, using frameworks associated with Richard Florida. In this study, we theoretically anchor our ideas on Florida's notion of the creative class. More specifically, we measure varying levels of human capital, to focus on the relationship between particular skills and ICT to gain an understanding of economic growth within Europe. One of our key contributions is the confirmation that a synergistic relationship exists between knowledge, location, technology and growth.

The literature suggests that technology, and more specifically ICT, is an important factor contributing to economic growth (Jiménez *et al*., 2014; Hafner and Borrás, 2017). However, we argue that ICT alone does not necessarily guarantee economic performance. Thus, we side with the assertion that ICT generates complementarities, which can go hand-in-hand with human capital development (Arvanitis, 2005). More precisely, our findings suggest that resources, in this case ICT, does not guarantee competitive advantage or economic growth, since the services provided by the resources are also important (Vasconcellos *et al*., 2018). These services are a function of the way in which a region utilises the acquired resources. However, when resources are combined, in this case ICT and creative class, the function of the way in which a region uses its resources may possess complementarities, may lead to greater levels of growth. Therefore, we argue that capabilities arise from the interaction between creative people in the region and ICT. With this in mind, and in accordance with RQ2, our findings suggest that the development and application of ICT rely on the availability of "creative capital". Thus, in terms of economic growth, creative skills should not be viewed on its own as it is positively associated with ICT. Moreover, with regards to RQ1, we find that changes in regional creative labour and ICT capital services demonstrated sound explanatory powers when explaining growth in gross value added. Interestingly, the co-existence of the creative class and ICT capital can result in a greater change of output in Europe through a positive interactive effect, rather than just through contributions from each of these inputs separately.

Finally, a limitation to the growth literature concerns using the share of the workforce with graduate level qualifications when making propositions. This is a limitation because it does not take into account of occupation-specific human capital (Poletaev and Robinson, 2008). We urge that arguments within the creative class can offers ways of understanding the specific aspects of human capital development and economic growth. However, it is important to note that the theoretical framework utilised by Florida has also been criticised, as it methodologically failed to account for differences in comparison with traditional estimating techniques made within the human capital literature (the share of graduates) (Glaeser, 2005; Nathan, 2015). Building on this, and with regards to RQ3, in this study we distinguished human capital and creativity more robustly in comparison with previous studies. Our findings suggest that there is more to the creative input than general skills acquired through by just being a university graduate. We find that the use of labour input from the creative class is crucial in terms of regional growth, which is consistent with previous assertions (Clifton, 2008; Stolarick and Currid-Halket, 2013). Moreover, we open further debates by stating that the application of ICT technologies could 'potentially' speed up the creative process.

Our findings have a range of policy and managerial implications. First, there is a need to focus on coordinating the efforts in the joint promotion of ICT use with human capital improvement. In comparison, partial policies to promote ICT applications or the creative milieu, without considering complementarities, may not deliver expected results. By focusing on both creative labour and ICT elements, it is possible to increase productivity and the positive effects of innovation activities. The implication is that urban policy makers should consider both creative and ICT capital when locating creative functions within cities and regions. Policy makers should not only focus on 'culture', which has commonly been associated with the creative class (Navarro *et al*., 2014; Thiel, 2017), but they should also encourage technological investment and applications such as ICT and the digital transformation more generally and ensuring creative workers gain access to it.

6. Limitations and future research

Evaluating the importance of the creative class concerns evaluating its embedded relationship with other factor inputs in a production system. In this paper, in terms of economic growth, we combine the concept of the creative class with models that emphasise ICT. Importantly, we also understand that economic growth and ideas behind the creative class are also contingent to other socio-economic factors. With this in mind we argue that there is a need to collaboratively link the creative class with other socio-economic factors in the context of urban and regional theories. The factors, which can contribute to economic growth, are: R&D;

education infrastructures; entrepreneurship; and venture capital impact. However, there are limitations concerning the availability of regional level. Given the importance of these topics, there is a need for more harmonised data in the regional accounts; data needs to be collected from the perspective of building up regional innovation systems; and indicators need to be generated at a more subdivided level (e.g. city or district). Moreover, we acknowledge that as this paper is on European data, the findings may not be applicable to emerging nations, however, this is an avenue which future research could look to explore.

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Table 1: Summary statistics

Based on avaliable time periods and142 European NUTS regions

Variable	Definition	Mean	Max	Min	Std. Dev.
GVA	Gross value added	52141.4	455196.0	765.0	59710.5
ICT	ICT capital services	2634.2	19880.5	40.9	3070.8
NICT	Non-ICT capital services	8218.0	63321.2	138.8	7943.3
CR	Hours worked by the total creative workers	448.7	3894.7	6.0	536.7
NCR	Hours worked by the total non-creative workers	912.7	5041.6	12.0	781.3
GCR	Hours worked by the creative graduates	247.5	2644.0	1.5	330.1
NGCR	Hours worked by the creative non-graduates	201.1	1578.0	2.9	227.7
GNCR	Hours worked by the graduate non-creatives	96.3	864.9	0.7	119.1
NGNCR	Hours worked by the non-graduate non-creatives	816.4	4183.0	10.9	685.5

Notes:

The unit of hours worked is millions. The value of gross value added and capital services are measured in million 1995 euros (ECU).

Only the NUTS 1 code is available in the U.K.

Sources: GVA: Cambridge Economics, ICT/NICT: EU KLEMS and the EU LFS, CR/ NCR/GCR/NGCR/ GNCR/NGNCR: the EU LFS.

Table 2: The contribution of creative labour and ICT capital services

	Model I		Model II		Model III		Model IV		Model V	
L.GVA									0.989*** (0.002)	0.987*** (0.003)
CR	0.238*** (0.030)	-0.236*** (0.043)	0.377*** (0.038)	0.230*** (0.050)	0.428*** (0.057)	0.285*** (0.069)	0.043*** (0.010)	0.002 (0.016)	0.004** (0.002)	0.032*** (0.004)
L.CR									-0.002 (0.001)	-0.024*** (0.004)
ICT	0.004 (0.020)	-0.316*** (0.029)	0.452*** (0.050)	0.328*** (0.057)	0.472*** (0.066)	0.357*** (0.071)	0.051*** (0.010)	0.019 (0.013)	-0.018*** (0.004)	-0.012*** (0.004)
L.ICT									0.032*** (0.003)	0.014*** (0.004)
NCR	-0.150** (0.032)	-0.061*** (0.031)	0.104*** (0.053)	0.155*** (0.053)	0.088 (0.069)	0.143*** (0.070)	0.034*** (0.014)	0.083*** (0.014)	0.023*** (0.003)	0.020*** (0.003)
L.NCR									-0.020*** (0.002)	-0.016*** (0.003)
NICT	0.934*** (0.024)	0.922*** (0.023)	-0.001 (0.073)	0.016 (0.073)	-0.058 (0.095)	-0.044 (0.094)	0.020 (0.018)	0.019 (0.018)	-0.008*** (0.004)	-0.004 (0.004)
L.NICT									-0.008** (0.005)	-0.013** (0.004)
ICT*CR		0.058*** (0.004)		0.017*** (0.004)		0.016*** (0.004)		0.006*** (0.001)		-0.003*** (0.001)
L.(ICT*CR)										0.004*** (0.001)
Year dummies	No	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Country dummies	No	No	Yes	Yes	Yes	Yes	Omitted	Omitted	Yes	Yes
Constant	1.956*** (0.075)	6.080*** (0.158)	4.363*** (0.192)	4.926*** (0.228)	4.482*** (0.267)	5.008*** (0.295)	8.941*** (0.111)	9.152*** (0.126)	0.088*** (0.016)	0.163*** (0.024)
R^2	0.92	0.92	0.96	0.96	0.96	0.96	0.85	0.86		
Obs	1,458	1458	1,458	1,458	1,316	1,316	1,458	1,458	1,316	1,316
AR(1)									z = -6.28	z= -6.12

	Pr > z = 0.000	Pr > z = 0.000
AR(2)	z = -0.83 Pr > z = 0.405	z= -1.05 Pr > z = 0.294
Sargan test	chi2(159)= 461.09 Prob>chi2= 0.000	chi2(191)= 563.30 Prob>chi2= 0.000
Hansen test	chi2(159) = 130.77 Prob>chi2= 0.951	chi2(191)=132.44 Prob>chi2= 0.997

Note: Model I:OLS,Model II: Pooled OLS,Model III: Pooled OLS(with 1 period lagged independent variables as IVs),Model IV: FE(controlling for individual effects),Model V: Dynamic GMM (controlling for dynamic bias +all independent variables are determined as endogenous).

Table 3: Creative skills versus human capital

	Model VI		Model VII		Model VIII	
L.GVA					0.997^{***} (0.004)	0.991^{***} (0.003)
GCR	0.134^{***} (0.033)	0.071^{***} (0.039)	0.131^{**} (0.074)	0.058 (0.077)	0.005^{**} (0.002)	0.036^{***} (0.005)
L.GCR					-0.004^{**} (0.001)	-0.041^{**} (0.004)
ICT	0.485^{***} (0.052)	0.414^{***} (0.057)	0.498^{***} (0.077)	0.485^{***} (0.052)	-0.049^{**} (0.005)	-0.039^{**} (0.006)
L.ICT					0.052^{**} (0.006)	0.032^{**} (0.007)
GNCR	0.072^{***} (0.026)	0.070^{***} (0.026)	0.124^{**} (0.069)	0.116^{***} (0.063)	-0.001 (0.003)	-0.005 (0.002)
L.GNCR					-0.018^{***} (0.001)	-0.008^{***} (0.002)
NGCR	0.125^{***} (0.026)	0.100^{***} (0.037)	0.172^{**} (0.079)	0.139^{**} (0.079)	0.006^{1} (0.002)	0.006^{***} (0.002)
L.NGCR					0.009^{***} (0.001)	0.007^{***} (0.001)

GCR×W*	0.036*** (0.006)	0.033*** (0.006)	0.036*** (0.004)	0.029*** (0.004)	-0.010*** (0.001)	-0.012*** (0.002)
L.(GCR×W*)					0.012*** (0.001)	0.013*** (0.002)
NGNCR	0.106*** (0.047)	0.138*** (0.048)	0.080 (0.067)	0.114*** (0.069)	0.024*** (0.005)	0.034*** (0.005)
L.NGNCR					-0.015*** (0.002)	-0.022*** (0.005)
NICT	-0.040 (0.072)	-0.026 (0.072)	-0.094 (0.095)	-0.078 (0.093)	0.024*** (0.006)	0.029** (0.008)
L.NICT					-0.040** (0.006)	-0.043** (0.007)
ICT*GCR		0.011*** (0.004)		0.010*** (0.004)		-0.004*** (0.001)
L.(ICT*GCR)						0.006*** (0.001)
Year dummies	Yes	Yes	Yes	Yes	Yes	Yes
Country dummies	Yes	Yes	Yes	Yes	Yes	Yes
Constant	4.863*** (0.224)	5.119*** (0.240)	4.547*** (0.366)	5.288*** (0.337)	0.086*** (0.019)	0.163*** (0.020)
R^2	0.96	0.96	0.96	0.96		
Obs	1,458	1,458	1,316	1,316	1,316	1,316
AR(1)					z = -6.78 Pr > z = 0.000	z= -6.42 Pr > z = 0.000
AR(2)					z = -0.85 Pr > z = 0.405	z= -1.00 Pr > z = 0.294
Sargan test					chi2(159)= 363.72 Prob>chi2= 0.000	chi2(179)= 377.47 Prob>chi2= 0.000
Hansen test					chi2(159) = 130.82 Prob>chi2= 0.950	chi2(179)=12 131.40 Prob>chi2= 0.997

Note: Model VI: Pooled OLS, Model VII: Pooled OLS(with 1 period lagged independent variables as IVs),Model VIII: Dynamic GMM (controlling for dynamic bias +all independent variables are determined as endogenous).