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Abstract

Intangibles such as tolerance, creativity and trust are increasingly seen as important for the geography of innovation. Yet these factors have often been poorly approximated in empirical research which has used generalised proxy measures to account for subtle personal differences. This paper argues that the psychological literature on personality traits can help address this issue and so provide important insights into the socio-institutional determinants of innovation. It uses a unique, large-scale psychological survey to investigate the relationship between the "Big Five" personality traits commonly used in psychology – openness to experience, neuroticism, extraversion, agreeableness and conscientiousness – and patenting in travel-to-work areas in England and Wales. The main personality trait associated with innovation is conscientiousness, a trait defined by organization, hard work and task completion. Instrumental variable analysis using religious observance in 1851 suggests that this is a causal relationship. Research on the role of intangibles in innovation has been preoccupied by factors such as creativity and trust. The results here suggests that a new focus is needed on hard work and organizational ability.

Keywords: Innovation; Culture; Personality traits; Institutions; Geography
JEL: O30; J24; O18; R1

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1. Introduction

Intangible factors are increasingly seen as important in regional innovation. The classic linear mode of innovation focused on tangible inputs, such as research and development (R&D) or human capital, and ignored socio-institutional factors. But more recently, researchers have suggested a range of intangible factors that may influence innovation. These include trust (Fukuyama, 1995), social capital (Putnam, 2000), a 'social filter' (Rodriguez-Pose 1999), 'buzz' (Storper & Venables, 2004; Bathelt et al, 2004), tolerance (Florida, 2003; 2005) and creativity (Marrocu & Paci, 2012). These often theoretical contributions have been followed by empirical studies testing the role of socio-institutional factors in regional innovation (e.g. Akçomak & ter Weel, 2009; Crescenzi et al. 2013; Lee & Rodríguez -Pose, 2014).

Yet socio-institutional factors are by their nature intangible and so hard to measure. Lacking a way of systematically identifying intangibles such as trust or creativity, researchers have been reliant on tangible proxy indicators. But these are often poor approximations of the theoretical concepts on which they are based. For example, Florida (2003) argues that tolerance is important for innovation but, as no actual indicator of open, tolerant personalities exists, used tangible indicators such as the share of gay couples to test his theories. Research on 'creativity' has used occupational or human capital indicators as a proxy indicator for actual creativity (Marrocu & Paci, 2012). Similarly, Rodríguez-Pose's (1999) intangible "social filter" is measured using tangible indicators such as the share of young people in the population. These are all valid empirical approaches given available data. But, given the importance placed on intangible factors in the geography of innovation, this lack of data on individual personality or mind-sets has been a significant problem for research.

This paper suggests that a fundamental intangible factor – personality – has been missing from research on the geography of innovation. Psychological research has identified a set of personality traits: the 'Big Five' of openness, extraversion, conscientiousness, neuroticism and agreeableness. These are empirically robust and have been shown to vary geographically (Zhao & Seibert, 2006). They also have some close links to the literature on the socio-institutional determinants of innovation.

For example, the psychological trait of agreeableness includes indicators on trust and engagement in society; that on openness includes measures of tolerance and creativity. Firm level studies have begun to investigate the relationship between personality and innovation (Fitjar & Rodríguez-Pose 2011), the related field of culture is an important area of research (Huggins & Thompson, 2014a; 2014b; 2016), and psychologists have considered how the geographical distribution of entrepreneurial personalities influences entrepreneurship (Obschonka et al., 2015). But the key question – how the geography of personality influences the geography of innovation – has gone unanswered.

To fill this gap, this paper uses a unique web-based personality test conducted by the British Broadcasting Corporation (BBC) and taken by almost 400,000 respondents in the UK. Building on psychological research using the same data (Rentfrow et al., 2015), the survey is used to develop indicators of the 'Big Five' personality traits commonly used in psychology at a travel-to-work area (TTWA) level (Digman, 1990). While they will never be perfect indicators of individual mind-sets, the use of personality data represents an improvement of the current proxies used in the literature to account for intangible factors. It also focuses attention on the individual, the key actor in innovation processes. The paper has links with emerging research in the overlap between psychology and management or innovation studies (e.g. Judge & Zapata, 2014; Obschonka et al., 2015) and that on the geography of personality (Rentfrow et al., 2015). These literatures have important implications for economic geography. Firstly, local culture or institutions may shape the personalities of those living in a city or region. Moreover, individuals with different characteristics will sort into particular areas: those who are open to new ideas may be accumulate in particular cities, while particular personalities may be more (or less) less likely to migrate (Rentfrow et al., 2015).

The literature on innovation and institutions has focused on factors such as openness, creativity and trust. Yet the results of this paper suggest that these are a secondary consideration. In contrast, conscientiousness – a personality trait associated with hard work, task completion and good organisation skills – is most strongly related to innovation at a local level. Instrumental variables analysis using religious attendance at Catholic churches in the 1850s suggests that this is a causal relationship. So while

research on innovation has stressed the exciting notions of creativity, openness and trust; in fact, simple hard work seems to be more important. It might be that the cities of boring but hard working geeks termed “nerdistans” by Kotkin (1997) are actually more important for innovation than the creative cities stressed in the literature.

This paper aims to link the psychological literature on personality and culture with the literature in economic geography and economics on the spatial distribution of innovation. It makes some significant contributions to the literature. First, it is the first study to examine the relationship between personality type and *innovation* at a local level in the UK, so developing a literature on entrepreneurial personality traits (Obschonka et al., 2015). Second, it is the first to use functional rather than administrative spatial units, so avoiding classic boundary problems. Third, in using an instrumental variable framework it investigates whether these relationships are causal and addresses concerns about omitted variable bias. Finally, past work on innovation at the national level and personality type has been limited by small cross-national sample sizes (Rossberger, 2014). Investigating these issues using sub-national data both increases the sample size and reduces the number of potential omitted variables.

The remainder of the paper is structured as followed. Section two briefly reviews the literature on institutions, before describing the “Big Five” personality traits and relating them to the literature on the geography of innovation. Section three describes the data and presents descriptive statistics on the geography of each factor. Section four presents a model of innovation at a local level and estimates results using both OLS and Instrumental Variable analysis. The final section considers the implications for policy and practice.

2. Personality, culture, institutions and innovation

Intangibles, institutions and innovation

Intangible or soft factors such as culture and institutions are now seen as important in economic geography (e.g. Amin & Thrift, 1995; Kemeny, 2012; Huggins & Thompson, 2014a; 2014b; Rodríguez-Pose, 2014). Theory in this area has considered many potential topics, but amongst the most important has been social capital. Fukuyama (1995) highlighted the importance of trust in enabling lowering transaction costs and reducing corruption. Similarly, Putnam's (1995; 2000) seminal work suggested that social capital might reduce coordination costs and so improve economic performance. Since then, researchers have considered a wide type of formal and informal institutions and their importance in economic performance (Rodríguez-Pose, 2014). Some of these informal institutions can have very long-term influences. Duranton et al. (2009) show the persistence of historic family type as an indicator of local social structures in Europe, to the extent that family types in the 1500s still help explain economic outcomes across Europe today.

Newer contributions in this literature have begun to consider how intangibles, culture and economic development are linked. Huggins and Thompson (2014a; 2014b; 2016) suggest that certain local cultures will be particularly conducive to entrepreneurship, a finding related to Weber's seminal studies of the Protestant work ethic. They argue that culture has an important relationship with entrepreneurship, which then influences economic development. Local culture is hard to change and ingrained in local production structures (Rodríguez-Pose & Storper, 2006). At a regional level, individuals will learn from each other and so individual mind-sets will be a reflection of, and partly determined by, local culture (Huggins and Thompson, 2006).

Another literature has considered the importance of creativity or the creative class for innovation processes. Florida's work suggested that a 'creative class' of mobile professionals would be attracted to cities where people were tolerant (Florida, 2003; 2005). Similar work has suggested that creativity has become increasingly important in a knowledge-based economy where competitiveness stems from differentiation. Studies in this vein have included research on the role of creative workers (proxied by the share of graduates in broadly defined 'creative' occupations) and regional

productivity (Maroccu & Paci, 2012); the share of workers in creative occupations and firm level innovation (Lee & Rodríguez-Pose, 2014), and; the interaction between Science Technology and Maths (STEM) graduates and arts graduates in firm innovation (Siepel et al., 2016).

The intangibles discussed above are all contextual, societal factors which can explain general conditions around innovation. Yet contextual factors can only partially explain the individual decision about whether to innovate. Moreover, while some theoretical work – such as that around Florida's Creative Class – does attempt to identify important individual characteristics such as 'tolerance' these tend to be identified using proxy indicators. For example, Florida (2003) famously argued that tolerant areas would attract more members of a 'creative class' of bohemians, musicians, high-tech workers and so on. However, unable to identify 'tolerance' he uses a 'gay index' based on the share of gay people in the local area as a proxy. Similarly, in the absence of reliable indicators of the creativity of the population Marrocu & Paci (2012) use indicators of human capital. Social capital is "proxied by blood donations and participation into voluntary association" by Crescenzi et al. (2013: 908). These are all reasonable decisions given the available data. But these two issues – a lack of individual data and the use of tangible proxy indicators – have limited work in this area.

The 'Big Five' personality types and the geography of innovation

There is a long tradition of psychological research seeking to categorise personality type. The dominant typology is the 'Big Five' personality traits of openness, extraversion, agreeableness, conscientiousness and neuroticism (Digman, 1990). Each of these traits can be conceived as a spectrum (i.e. individuals are somewhere between 'open' to experience or 'closed') and can be identified from a series of more specific questions about the personality of the individual. For example, neuroticism is assessed using questions about moodiness, emotional stability and ability to handle stress; agreeableness is assessed from questions about cooperation, trust and helpfulness and so on (full details on the questions used to construct local indicators of personality are given in table 1). These traits have proven robust to a range of different empirical tests, with a general consensus on the number of traits if less consensus on their exact definitions (Barrick and Mount 1991; Rentfrow et al. 2015).

Authors in psychology or management studies have begun to consider how these personality traits vary geographically and how this influences to economic performance and entrepreneurship. Personality type will vary geographically for two reasons. The first explanation is that there may be some form of local culture or behaviours which influence personalities. For example, local cultures of trust and shared values may, for example, lead to clusters of people with agreeable personalities. Rentfrow et al. (2015: 1) term this social influence, with "traditions, customs, lifestyles and daily practices common to an area affecting social norms, which in turn affect peoples attitudes and behaviours".

Sorting mechanisms and selective migration provide a second explanation for geographical variation in personality. Migration is selective and personality will influence both the decision to migrate and the choice of destination. For example, people moving to London are seen as particularly ambitious and seek to take advantage of the "human capital escalator" in the city (Gordon, 2015). Those with neurotic personalities may move to areas which have lower perceived risks. Sorting will be interlinked with local environmental factors such as particular natural environment or local economic strength (Rentfrow et al., 2015). Reflecting these issues, personality traits have been shown to be consistent geographically, with neighbouring countries and regions likely to have similar personality traits with those nearby (Schmitt et al., 2007; Rentfrow et al. 2015). For the US case, Foreman-Peck and Zhou (2013) show that some indicators of entrepreneurial culture are persistent over a relatively long time frame (from 1910 – 2000). However, there is relatively little work considering the extent to which individuals personalities develop over time and in different geographical contexts, with this being an important caveat to this finding.

There are strong theoretical relationships between the Big Five personality traits and the literature on the geography of innovation. Yet, while there is an awareness that personality traits vary geographically and that personality may play an important role in economic geography, little research has linked the two. Table 1 sets out the different components of these personality traits, how each links into the economic and geographical literature and the expected relationship with innovation.

Insert table 1 around here

The first trait is *openness to experience*. This captures the extent to which people are 'inventive', their interest in new things such as arts, music or literature, the degree to which individuals are curious or are 'deep thinkers'. It can be contrasted with closed minded thinkers who are inflexible to new ideas (Digman, 1990). Studies in management have shown that workers scoring highly on openness do better in occupations involving creativity or innovation (Judge and Zapata, 2014). There are also clear parallels between 'openness' and the literature in economic geography. One of the best-known economic geographers working in this area has been Florida (2002; 2005; 2015) who has written a series of books and articles outlining the importance of the three t's of talent, technology and tolerance in urban innovation processes. Florida argues that tolerant, and so open, cities would attract the kind of creative workers likely to produce new innovation. Openess may also help individuals learn from those nearby, taking advantage of the 'buzz' provided by urban areas to take in ideas from elsewhere and so develop new, creative innovations (Asheim, Coenen, and Vang 2007). Moreover, open individuals are also likely to be creative and have interests in the arts and in trying new things. Openness therefore also links to the broader literature on creativity. There is some evidence on this point: in a study which uses firm-level personality data to investigate innovation processes, Fitjar and Rodríguez-Pose (2011) show that openness is positively associated with international networking which is then related to innovation.

Openness to experience also relates to Chesborough's (2003) work on open innovation, which suggests that innovation is increasingly driven by the adoption and adaptation of external ideas to the firm. This 'open innovation' framework has "strong geographical contexts and drivers" and relates closely to the literature in economic geography (Howells & Bessant, 2012: 936). The open innovation paradigm has some significant implications for regional innovation, as it places "the firm at the centre of a series of networks and environments from which it draws ideas, collaborators and markets." (Shearmur, 2012: S11). Areas where the population scores higher on openess may be more tolerant and welcoming to outsiders, take new ideas in and so be more innovative.

The second trait is *extraversion*. This essentially measures the gregariousness of the population, their warmth and excitement seeking. It is measured using questions about talkativeness, assertiveness, enthusiasm and energy. Clearly, there may be some links between these factors and innovation – although these have not been explored in detail in theory. In their work on Buzz, Storper & Venables (2004) suggest that certain aspects of face-to-face contact may help economic activity. If populations are talkative and assertive, they may be particularly likely to engage in joint projects, they may be motivated to share information and produce new ideas together. Following this logic, the face-to-face contact which is helped by extraversion may lead to improved rates of innovation. In short, extraversion may help create a 'buzz' and this may then lead to innovation. Moreover, extraversion may be associated with greater social networks. Extraverts are particularly likely to be assertive when meeting other people and so are more likely to build networks of individuals.

The third trait is *conscientiousness*. This is associated with self-discipline, task completion and competence (Rossberger 2014). The questions used to identify it in the BBC survey include hard work, planning, reliability and intelligence. In a seminal meta-analysis of evidence on the 'Big Five', Barrick and Mount (1991) show conscientiousness is a key predictor of job performance, although other personality types may be related to success in certain types of employment (i.e. extraversion is related to achievement in managerial work).

The links between conscientiousness and the economic geography literature are not immediately apparent. In one related study on regional culture, Huggins and Thompson (2014a) develop an indicator of 'Embracement of Work' although they have to proxy this with employment rates. But they argue that there are parallels with Weber's (1930) classic study on the protestant work ethic in which certain areas had institutions which helped locals work hard. In the management literature, a number of studies have argued that hard work is important for innovation. Drucker (1998: 102) argued that innovation often relied on seemingly obvious solutions which were put together through hard work, commitment and discipline rather than sudden moment of creativity:

> "In innovation, as in any other endeavor, there is talent, there is ingenuity, and there is knowledge. But when all is said and done, what innovation requires is hard, focused, purposeful work. If diligence, persistence, and commitment are lacking, talent, ingenuity, and knowledge are of no avail."

In some respects, conscientiousness may reflect an additional element of human capital: the ability not simply to develop human capital, but also to make best use of it.

The fourth trait is *agreeableness*. This trait captures the extent to which individuals are considerate, forgiving and their desire to cooperate and help each other. It is associated with trust and unselfishness and so has strong conceptual links with the literature on social capital and informal institutions. Theoretical work has suggested that trust is an informal economic institution which can reduce transaction costs and increase team-working, with the result that trust can have significant economic payoffs (Rodríguez-Pose and Storper 2006). Similarly, social capital is seen as important for innovation as the trust it entails can allow better financing of innovations and reduce coordination costs (Akçomak and ter Weel 2009). Trust might be expected to improve cooperation between partners (Fukuyama 1995). Indeed, research suggests that personality relations are highly important for knowledge sourcing and so innovation (Huber, 2012).

However, the literature relating trust to local economic outcomes is ambiguous in at least two ways. First, some contributions in Psychology have suggested there two main forms of trust: individual (or particular) trust, between family, friends or other acquaintances, or; generalized trust in other members of wider society (Carl & Billari, 2014). This is similar to the notion used by economic geographers of the relationship between trust in specific people (a notion similar to community) or the more generic trust at a societal level (similar to society) – and these two trusts may have different impacts on economic performance (Rodríguez-Pose & Storper, 2006). The second issue is that, as Huber (2009) argues, despite the extent of research on the subject, social capital remains a fuzzy concept. Many factors – such as norms or social values – which are commonly claimed as being part of social capital are actually either outcomes. Portes (2000: 2) argues in a similar fashion that there are two meanings to

the term social capital, and that it is used both to mean individual characteristics and to describe 'collectivities'. Trust may fall into this category. So the impact of agreeableness on economic outcomes may be ambigous.

It is less clear how the fifth trait – *neuroticism* – is likely to be associated with innovation. This is associated with anxiety, hostility and depression. Questions used to identify it include whether individuals worry a lot, how they handle stress, nervousness and moodiness. But little theoretical work, in economic geography at least, considers these traits as being related either positively or negatively with innovation processes. In contrast, people who are calm, relaxed and even headed are less neurotic. Zhao and Seibert (2006) show that entrepreneurs are less likely to be neurotic than workers in managerial positions, and argue this is because neuroticism reduces the risk taking behavior associated with entrepreneurship. A similar argument can be made about innovation.

Individual psychology and local economic outcomes

The theoretical mechanisms outlined above reflect the relationship between individual characteristics and innovation. Yet individual psychological factors will both shape and be shaped by regional factors and so understanding how these are related is important. The notion of regional culture is helpful here. Huggins and Thompson (2016: 3) develop the concept of "community culture", the "broader societal traits and relations that underpin places in terms of prevailing mind-sets and the overall way of life within particular places." Their definition includes mind-sets which might reflect personality traits, and their conceptualization also provides explanations why individual characteristics may interrelated with group behavior. For example, certain behaviours - in their case, entrepreneurial attitudes - may be legitimated if others in the local area hold similar attitudes. In a similar manner, traits related to innovation may be shared by individuals in particular localities – for example, the risk taking attitudes commonly attributed to the Bay Area. The link between individual characteristics and regional factors is particularly clear for traits such as agreeableness, which are inherently social. But other traits such as conscientiousness or openness may also be learnt, and so reflect local culture as well as individual personality.

A second potential intermediary factor between psychology and innovation will be the nature and composition of firms in an area. Innovation will often be the result of deliberate firm-level investment decisions. R&D may take place particularly in large organisations, and multinational firms may potentially be attracted to areas where workers are seen as particularly creative, high quality or hard working. Some studies have used surveys of multinational firms to consider what individual attributes are associated with investment decisions. For example, Tindle et al (2014) find that multinationals cite both workforce skills and the 'work ethic' as determinants of investment decisions, although the basic factor of access to market is more so. Firms are also attracted by a general reputation for innovation. So a circular relationship is conceivable between innovation, the attraction of research intensive firms, and migration of individuals with particular psychological profiles.

Few if any studies have linked these personality traits with innovation at a local level. Yet some national level studies exist. Steel et al. (2012) investigate links between personality traits at a national level and innovation. They find openness to be positively associated with both input and output measures of innovation, agreeableness to be associated with input measures, but no relationship with conscientiousness – a finding they argue is curious but explained by the correlation with other national level factors such as government spending. Past research has hypothesised that agreeableness and openness are most likely to be associated with innovation at a national level. Rossberger (2014) shows that agreeableness and openness have positive links with national level cultural practices such as high future orientation, performance orientation and low in-group collectivism which are likely to be associated with innovation.

However, there are both theoretical and practical advantages to using regional data. Economic geographers have long argued that regional approaches to innovation help explain patterns of innovation better. The Regional Innovation System approach, for instance, is based on the idea that firm innovation is determined partly by the activities of the firm, but also by "localized capabilities such as specialized resources, skills, institutions and share of common social and cultural values" (Doloreux & Parto, 2005: 134). Moreover, individuals can collectively develop know-how about innovation in a local area (Morgan, 1997). The result is that it is local

interdependencies and, in the context examined here, personality traits which will help develop innovation processes. Studies at a national level will miss these nuances and avoid the skewed regional distribution of innovation, in which some cities or regions tend to be responsible for a disproportionate share of innovation. Moreover, there is a clear practical justification for such an investigation: focusing on regional level data helps strip out some of the omitted variables which might exist at a national level. Despite this, little research has yet considered the relationship between psychology and innovation at a local level in the UK.

3. Data on personality types and innovation

Measuring personality types

The data for personality traits comes from the British Broadcasting Corporation (BBC) Big Personality Test, a unique survey of personality across England and Wales. This is a large-scale internet survey which resulted from a collaboration between the Department of Psychology at the University of Cambridge and the BBC (University of Cambridge & BBC, 2015). The survey was conducted between November 2009 and April 2011. Around 580,000 people across the UK were surveyed. The survey was accessed via the BBC website, which asked them to complete questions about their personality. An ID was created for each user to prevent them completing the file more than once. Once those who did not complete the sections on personality are excluded (and those for which postcode data was not completed) the final sample is 386,375 people.[1]

The BBC sample is large and includes a wide spread of the population, but it is not a perfectly representative sample. Rentfrow et al. (2015) present some tests to evaluate how much the responses matches the population of the UK, in terms of ethnicity, age and population. Using Local Authority (LA) data, they show a correlation of 0.84 between the number of respondents in an LA and the total population of that LA in the 2011 Census. This correlation was slightly lower for age, suggesting some minor age bias, but higher when considering ethnic composition of the local population. While these caveats need to be considered, these suggest the data is reasonably representative at a local level.

A second challenge is the potential for limited sample sizes in some of the smaller TTWAs. Fortunately, the large scale of the survey means this is unlikely to be a significant problem: the median number of observations for each TTWA is 920 (the mean is 1,897). A small number of TTWAs have relatively low numbers of observations (the lowest number of participants is 68, but only 4 TTWAs have fewer

[1] The BBC has a relatively unique place in British society, reaching both young and old and of most social classes. However, there are potential issues with an internet survey such as this where sampling procedures were not fully followed. There may be some under-representation of groups (92% of respondents were White, for example, compared to around 86% of the population). However, Rentfrow et al. (2014) test the relationship between the survey responses and the characteristics of local areas and show that the local area samples have a close correlation with the demographic output of these areas.

than 100 participants). However, excluding these does not seem to effect the overall results significantly.[2]

Following Rentfrew et al. (2015: 2) the Big Five framework of personality traits is used. The questions in the BBC survey are assessed on a likert scale of 1 - 5 and Principal Component Analysis (PCA) is then used to construct indicators of different personality types (table 1 gives details of the questions dominant in each personality type; full details including factor loadings are available in the methodological report in Rentfrew et al., 2015). As set out above, these indicators have some strong links to the literature on innovation.

To ensure data represents genuine economic units, rather than administrative areas, the postcode sector is used to create personality indicators at a travel-to-work area (TTWA) level. The TTWAs are defined using the 2001 Census as local labour markets in which there is around 75% self containment, where around three quarters of all workers both live and work in the same TTWA (Coombes and Bond 2008). TTWAs are increasingly used as the standard unit of sub-national economic analysis in the UK as they are reflections of 'real' functional areas rather than administrative economic units (e.g. Gibbons et al., 2010; Nathan, 2011; Lee, 2014). Individuals are allocated into 184 TTWAs based on their postcode sector, of which there are around 10,500 in the UK. This should give a relatively fine-grained boundaries for the TTWAs. In later sections historic religious attendance is used as an Instrumental Variable approach. Because this data is not available for Scotland and Northern Ireland, only TTWAs located in England and Wales are included.

Insert figures 1 – 5 around here

The average values of these personality traits are given in figures 1 – 5. These show significant variation in the average proportion of the population in each TTWA displaying each. Extraversion is high in London, the South and some parts of the North. London also scores highly for Openness, although this is also high in Wales and some parts of southern England. Neuroticism has a clear geography, highest in

[2] For example running column 9 of table 4 excluding the TTWAs with the fewest observations leads to a slight change in the main effect: from 3.19 to 4.27, statistically significant at <0.01.

Wales, parts of the South West and the North of England. Conscientiousness is consistently high in the area surrounding London, but also in the North East of England. Finally, agreeableness is relatively low in London but relatively high in the South West, parts of Wales and the urban North West.

An important caveat to these indicators is that they are average values for each TTWA. Innovation will be the result of only by a small proportion of people in each area, and their personality traits may be unrelated to those around them. However, these indicators will be useful because we would expect local cultures to develop. These would be reflected in "prevailing mind-sets" (Huggins and Thompson, 2016: 4) in the local area, which are likely to be reflected in both innovators and the wider local culture. Nevertheless, it is important to be cautious about the extent to which local averages will reflect the personality of the often atypical individuals involved in innovation.

Measuring innovation

The measure of innovation used here is the log of total patents lodged per 100,000 population (aged 16 – 64) between 2009 - 2011. Patenting is one of the most commonly used indicators of innovation, and one of the most robust. I adapt the approach outlined by Centre for Cities (2015) in their Cities Outlook publication. Using raw data of all patent applications made to the UK Intellectual Property Office (IPO), each patent is linked to a TTWA by the postcode sector in which it is registered. Descriptive statistics suggests significant year-on-year variation in local patent counts. To avoid erratic results, total patent applications for the three-year period 2009 – 2011 is used (to align the results to those of the BBC survey).

This indicator is relatively objective and consistent and patents will generally represent non-trivial innovations (as it is not worth patenting very small improvements). But clearly it cannot account for the actual significance of the innovation, nor will it capture other forms of innovation in services. For example, Hall et al. (2013) suggest that only 4 percent of innovative firms actually produce patents. The results here need to be interpreted with this caveat in mind, as particular personality traits may be associated with industries which are disproportionately likely to patent, with other personality traits associated with other indicators of

innovation. The relationship between different personality types and other forms of innovation is an important future area of research. Moreover, as with all indicators of patenting there is an additional caveat which needs to be considered, as patenting at the local level may not always be the result of innovative activity which is conducted in the same area – particularly when conducted by large firms. However, testing suggests that the results are not skewed by a small number of firms making a large number of patents.[3]

Considering the most innovative TTWAs by this measure, in absolute terms, most patents were registered in (1) London, (2) Swindon, (3) Guildford & Aldershot, (4) Newbury, and (5) Cambridge. These are all relatively affluent places with strong industrial bases. When population weighted, a number of smaller, more rural areas have high values (1) Newbury (home of Vodaphone) is most innovative, followed by (2) Swindon, (3) Cambridge and (4) Andover.

[3] To test this I construct a new variable which only counts the first patent from each applicant firm – essentially, the number of patenting firms per capita, rather than patents per capita. This variable is highly correlated with the initial dependent variable (correlation coefficient = 0.81, significant at $p<0.01$). Re-running the results set out in section 4 with this new variable leads to little change in the key findings.

4. Model & Results

The model

The model used here is a variation on the classic knowledge production function developed by authors such as Griliches (1979). This assumes that innovation (patenting) is a function of a set of inputs, including both human capital and city size but also the personality traits of the individuals in the local area. The model is specified as follows:

$$Innovation_i = \alpha + \beta_1 Personality_i + \beta_2 Size_i + \beta_3 Skills_i + \beta_4 Science_i + \beta_5 Manufacturing_i + \beta_6 Div_i + \beta_7 GSE_i + \beta_8 Wales_i + \varepsilon \quad (1)$$

For TTWA '*i*'. Where the dependent variable, *Innovation*, is the number of patent applications lodged in the period 2009 – 2011 per 100,000 population aged 16 – 64. *Personality* is one of the Big Five personality traits. The control variables are: *Size*, the log of total population; *Skills*, the share qualified to NVQ 4 and above; *Science*, the share of scientists in the local population; *Manufacturing*, the share of employment in manufacturing; *Diversity*, the fractionalization index by country of birth; and dummies for location in the South East or London (Greater South East or GSE), or Wales. The constant is 'α' and the error term is 'ε'.

Control variables

Control variables are calculated using the 2011 Census, the most robust local-level data available in the UK. Data is aggregated from Mid-Layer Super Output Areas (MSOA) to TTWAs. MSOAs have a population of between 5,000 and 15,000 people so this gives a high level of detail.[4] Summary statistics are given in table 2.

Insert table 2 around here

The traditional innovation production function should include an indicator of human capital, proxied through education. The indicator here is the share of the population

[4] An additional step is aligning the Census data which is based on 2011 MSOAs to the 2001 MSOAs from which it is possible to get boundary data for TTWAs. For a very small share of MSOAs there are overlaps between the two definitions of MSOAs. Where this is the case, the MSOA with the largest overlap is preferred.

qualified to National Vocational Qualification (NVQ) level 4 and above (qualifications including Certificate of Higher Education, Diplomas, Masters degrees and above). As skills are associated with innovation, this should be positively associated with patenting.

There is no data on R&D at the TTWA level in the UK, but the amount of human capital invested directly in innovation is a good alternative: the share of workers in 'scientific' occupations. This is defined as two categories in the 2010 Standard Industrial Classification: "Science, research, engineering and technology professionals" and "Science, engineering and technology associate professionals". Together, these categories include R&D Manager, Scientists, Engineers, Lab Technicians and other technical employment likely to be associated with innovation. This variable should be positively associated with patenting.[56]

A variable is also included for the size of the TTWA: the log of total population aged 16+. Urban density will be associated with improved knowledge spillovers, more workers in specialized occupations and better matching of workers to employers (Duranton and Puga 2004). In this case, larger TTWAs should be more innovative. Yet other research has suggested that the benefits of urban density for innovation may be overstated. For example, Lee and Rodríguez-Pose (2013) suggest that cities facilitate the rapid dissemination of new ideas, but not necessarily their creation. And in the case of the UK, the benefits of urban locations may be outweighed by local economies specialized solely in a small number of innovative sectors.

[5] The first category, Science, Research, Engineering and Technology Professionals includes: Chemical scientists; Biological scientists and biochemists; Physical scientists; Social and humanities scientists; Natural and social science professionals n.e.c; Civil engineers; Mechanical engineers; Electrical engineers; Electronics engineers; Design and development engineers; Production and process engineers; Engineering professionals n.e.c. **;** IT specialist managers; IT project and programme managers; IT business analysts, architects and systems designers; Programmers and software development professionals; Web design and development professionals; Information technology and telecommunications professionals n.e.c; Conservation professionals; Environment professionals; Research and development managers. The second category, Science, Engineering and Technology Associate Professionals, includes Laboratory technicians, Electrical and electronics technicians, Engineering technicians, Building and civil engineering technicians, Quality assurance technicians, Planning, process and production technicians, Science, engineering and production technicians n.e.c, Architectural and town planning technicians, Draughtspersons, IT operations technicians, and IT user support technicians.

[6] I also experiment with an indicator for the presence of a university or a Russell Group (leading edge) university, but neither is significant.

A large and growing literature highlights the importance of migrant and ethnic diversity for innovation. Diversity may improve knowledge sourcing by introducing ideas from elsewhere and diverse teams may come up with a wider and better range of potential solutions than more homogenous groups (Hong and Page 2004). The variable here is diversity by country of birth, rather than ethnic group. Migrant groups tend to be self-selecting as more dynamic and entrepreneurial (Nathan, 2011) and past work has suggested that migrant diversity is a better predictor of economic success than ethnic diversity (Nathan, 2011; Lee, 2013). Evidence suggests that diverse firms are more innovative, although research on whether urban context helps this effect is less clear (Niebuhr, 2010; Nathan & Lee, 2013; Lee, 2015).

The common indicator for 'diversity' is fractionalization by country of birth. This is essentially one minus the Herfindahl index of concentration: the sum of squared percentages of each country of birth group in the local population.[7] This takes a value between 0 and 1 where 1 gives the highest 'diversity' and 0 the lowest. The highest fractionalization index is London (0.54); the lowest is Morpeth, Ashington & Alnwick (0.05).

I also experiment with regional dummies, but collinearity is a significant problem and results can be erratic. To control for potential government issues in the principality of Wales a variable is used for that, following Obschonka et al. (2015). Second, proximity to the scale of economic mass of the capital is captured through a variable for whether a TTWA is in the South East and London.

Insert table 3 around here

Table 3 gives the results of simple correlation matrix of these indicators. Of the five indicators for personality type only conscientiousness is statistically significantly associated with innovation. Agreeableness is negatively associated with diversity and

[7] Where there are 19 categories: UK, Ireland, Other European Union, North Africa, South and Eastern Africa, Central Africa, Other Africa, East Asia, South Asia, South East Asia, Middle East, Eastern Asia, Southern Asia, South-Eastern Asia, Central Asia, North American and the Caribbean, Central and South America, Antarctica and Oceania, Other.

city size. Conscientiousness is positively associated with patenting and negatively associated with historical Catholicism and city size. Neuroticism is negatively associated with the share of the population with NVQ4 +, positively associated with manufacturing, negatively with diversity and positively with historic Catholicism. Openness is positively associated with larger cities, better skilled populations but negatively with manufacturing employment.

Basic results

The basic results are given in table 4. Columns 1 - 5 consider only the personality trait variables without controls. Based on the theoretical literature, all but one of these are expected to have a positive relationship with innovation. The fifth, Neuroticism, is likely to be associated with aversion to risk and so new ideas (Digman, 1990). Two traits are statistically significant in the base regression: as expected, neuroticism is negatively associated with innovation while conscientiousness has a positive association. The other three factors - openness which accounts for creativity and tolerance, agreeableness which is a measure of trust and shared understanding, and extraversion which may signal the extent to which people are willing to put new ideas out in public – seem to have no relationship with innovation. When including all five traits together, only conscientiousness is statistically significant.

Of course, this basic finding may be explained by other factors, in particularly the qualifications of the workforce or scientific workers. To test for this, columns 7 – 12 repeat these regressions with a full set of control variables.[8] Yet the results only serve to affirm the earlier results: the only personality trait which is significantly associated with higher innovation in conscientiousness. The negative effect on neuroticism loses both magnitude and statistical significance. Openness, which is associated with creativity and desire for new experiences, does not seem to matter, in contrast to the literature on this point. Similarly, while there seemed to be links between agreeableness and factors such trust and shared understanding which help innovation, it seems unimportant in this context – perhaps because it does not sufficiently distinguish between generalised or specific trust. So while classic studies have tried to

[8] Note that collinearity is not a significant problem. The mean Variance Inflation Factor for regression 12, with the largest number of variables, is only 2.05.

account for these intangibles using proxy indicators, once considering actual data on local personality only conscientiousness remains significant.

Insert table 4 around here

The controls also provide some insight into the geography of innovation, and are consistent with the literature on this topic. The population variable is negatively associated with innovation in all models. This may be because smaller cities like Cambridge have small populations but a science-focused industrial base. In contrast, London is generally viewed as highly innovative, but patenting does not always capture the type of innovation in these larger cities (Wood, 2009). Given its scale ad this result, innovation processes in London warrant further research. The share of workers in scientific occupations is positive and statistically significant in all models but one. The share of the population with NVQ4+ is positively associated with innovation but only statistically significant in two, perhaps because the presence of human capital (measured through qualifications) is outperformed by its use (measured via the share of scientific occupations).

Diversity – proxied through fractionalization – is positively associated with innovation, but the effect is only statistically significant at the 10% level in some models. One explanation for this issue (a relatively large effect size, but with high standard errors) is the diversity of migrants in the UK and their relatively polarized skill structure. Past work has also shown that - while migrant run firms are more innovative – there is no independent 'city effect' where diverse cities are more innovative (Lee, 2015). This phenomenon may help explain the results. Moreover, there seems little difference between manufacturing and service intensive regions in terms of patenting. Again, it may be that the scientific occupations measure is a better explanatory variable.

Instrumental variable results

The results of the OLS analysis, both with and without controls, suggest one personality trait - conscientiousness - is positively associated with innovation at a local level. However, there is a clear risk of endogeneity in such a relationship leading to a spurious positive result. In this case, simultaneity is the main risk. Innovative

local economies may attract relatively hard working people who score highly on conscientiousness. The long-hours culture of places such as Silicon Valley is one example, with the need to work hard perhaps discouraging less conscientious workers from moving there. A second potential problem is omitted variable bias. An additional factor such as local culture may both increase levels of innovation but also be related to conscientiousness.

To address these challenges an instrumental variables (IV) methodology is used. The IV is the share of Roman Catholics churchgoers in 1851. Since the establishment of the Church of England some 400 years earlier, Catholicism had been a minority religion in England and Wales. The 1840s and 1850s saw the Irish potato famine which led to large scale emigration. Most of this was to North America but some was to England and Wales. This was not a normal migration as migrants were not a self-selected group of entrepreneurial workers, but forced migrants who were often less-well-educated agricultural workers and nearer the poverty line (Cousens 1960; Whelan and Maitre 2014). Importantly, the correlation table (table 3) shows that the indicator appears to measure local personality traits well being negatively correlated with Conscientiousness (-0.3, $p<0.01$). Yet it has no statistically significant relationship with population qualified to NVQ 4 + and lacks any feasible direct link with patenting today.

Why might Catholicism in the 1851 influence conscientiousness 160 years later? The obvious explanation is that Weber's (1930) idea of a Protestant work ethic may still remain in local cultures. Yet a glance at other countries suggests this is unlikely: Munich, for example, is a Catholic city, a highly innovative city and is not known for low levels of conscientiousness; moreover, cross-country studies have found little robust evidence for a link between religion, conscientiousness and economic development (e.g. Cantoni, 2015). Instead, the instrument takes advantage of the selective nature of migration in the period. The relatively more affluent Irish workers of the period may have self-selected to expensive, long-haul destinations in the New World (Ó Gráda and O'Rourke 1997). Instead, Irish Catholics settling in England and Wales at the time were seeking immediate relief from famine and so moved to areas which offered subsistence and low-skilled employment (Ó Gráda and O'Rourke 1997). They sought out areas where it was as easy as possible to make a living

without having to invest in new skills and in sectors such as manufacturing which were relatively tightly controlled and in which – while certainly hard work – workers did not require or develop the skills in task completion and self-management which they might have in other sectors. Thus, the variable is not about Catholicism per se, but about the nature of the type of communities Irish Catholics moved to in the 1850s.

The data is accessed from the Vision of Britain 1851 data at Local Authority level and then aggregated up to TTWA level. As some of the data is only available at a Local Authority basis, TTWAs are defined according to Kaplanis's (2010) method where Local Authorities are allocated to TTWAS on the basis of the greatest overlap. As this means that some smaller TTWAs cannot be identified and results in a final sample of 161 TTWAs in England and Wales.

Insert table 5 around here

Table 5 gives the results of the IV estimation, run using the same basic model as table 4. Columns 1 and 2 simply repeat the basic specifications using the reduced sample: they affirm the base result that conscientiousness has a positive relationship with patenting. However, it is only at the 10% level in columns 2, a reduction from 5% in the OLS specification. This is probably a consequence of the smaller sample size and less accurate boundaries used to ensure comparability with the Vision of Britain data.

Columns 3 and 4 give the instrumental variable results. In both columns the Cragg-Donald F test is above 10, the rule of thumb for suggesting this is not a weak instrument. The Kleibergen-Paap F tests are 14 (without controls) and just under 10 (with controls), close enough to 10 to make no difference. The relationship in both is statistically significant, suggesting a causal relationship between conscientiousness and innovation. Overall, this suggests that the relationship between conscientiousness and patenting is robust to endogeneity. However, the coefficient is considerably higher than in the OLS model: suggesting a 1 point increase in conscientiousness (a large change, given that the indicator is measured from 1 - 5 with a standard deviation of only 0.03) is associated with a 20-30 percent increase in patents. As is common with IV approaches, the standard errors are large and it is important to be cautious with the exact size of the coefficient.

A second critique of this finding comes from the psychological literature on conscientiousness, as cross-national studies using this indicator have been criticised as it may be subjective to 'reference group' issues as respondents judge their own conscientiousness relative to their peers (Wood & Rogers, 2011). Yet, as Rentfrow (2010) argues, measurement issues with conscientiousness are likely to be minimized in a national level. Moreover, as a second check, I re-run the regression in table 4 column 12 using an alternative dependent variable: log average hourly pay in the TTWA calculated using the Annual Population Survey.[9] As with patenting, conscientiousness remains the only statistically significant personality trait (β = 0.44, p>0.000.). Conscientiousness, the capacity to work hard in an organized fashion, has an independent impact on economic performance even when controlling for human capital.

[9] Results available on request.

5. Conclusions

Research in economic geography has highlighted the importance intangible factors in innovation (e.g. Florida et al., 2008; Yang & Lin, 2012; Marrocu & Paci, 2012). However, it has proven difficult to find appropriate indicators for these intangibles. At the same time, studies in psychology and management have investigated both the geographical distribution of different personality traits and begun to link this to outcomes such as entrepreneurship (Rentfrow et al., 2013; Obschonka et al., 2015; Rentfrow et al., 2015). The 'big five' personality traits long used by psychologists (e.g. Digman 1990) have close relationships to some of these concepts in economic geography. So using actual data on personality traits helps both by focusing attention on individuals, the key actors in innovation processes, and avoiding the methodological challenge of using proxy indicators for intangible constructs.

The intangible factors stressed in most innovation research have included trust, creativity and openness. Yet when focusing on individual personality, rather than wider societal factors, the key driver of innovation seems in fact to be the average value of conscientiousness in the population. In some respects, this is not surprising. It has long been recognized that technological innovation is often about mundane but significant improvements (Drucker, 1998). The focus in economic geography has been on more exiting factors, but in fact boring cities with hard working residents may outperform more exiting places. So called 'nerdistans' have been increasingly unfashionable in the literature, at least since Kotkin (1997) suggested that creative, mixed groups of geeks and tech workers were important for innovation. It might be that the balance has shifted too far and boring cities deserve more attention.

In contrast, the four other personality traits - openness, agreeableness, neuroticism and extraversion - do not seem as important. These have significant similarities with the literature on socio-institutional determinants of innovation. However, it might be that the impact of any variation is already captured in variables such as education or industrial structure. Given the emphasis on these factors in the literature, future work may want to investigate this further, possibly by breaking the 'big five' personality traits into multiple sub-traits. However, a second explanation may be methodological. The indicator used here, patenting, is the most commonly used in the field and avoids

many problems of measurement which hinder other studies of innovation. But is likely to be associated with science and technologically focused industries whereas other types of 'soft' innovation may be more important in other service focused activities. Future work should use alternative measures of innovation such as trademarks, particularly those which may capture 'soft' innovation in services. 'Openness' as a personality trait may be more associated with innovation in the arts or culture, or extraversion is associated with entrepreneurship. But future work may seek to investigate other indicators of economic competitiveness or innovation.

What do these results mean for policy? Policymakers have also often focused on schemes around creativity as a key role in driving innovation. Intervention to change local culture would be hard (Huggins & Thompson, 2014b), while interventions to change local personality traits would also raise significant ethical issues. But policy already tries to develop entrepreneurship skills through coaching, mentoring or leadership development (Brown and Mawson, 2015). Similar courses on project management, personal organization or task completion may be valuable parts of increasing conscientiousness as part of innovation strategies. Ensuring that innovative workers develop these boring skills may be a key way of ensuring that the benefits of new product development are realised.

These results also raise some potentially important avenues for future work unpacking the link between psychology and economic geography. As Rentfrow et al. (2013: 998) argue, an idiographic approach may be better suited to understanding the influence of personality, with the "configuration of traits" more important than their average shares in a population.[10] Moreover, these results provide evidence for a single point in time, yet we know that different personality traits are associated with movement. Longitudinal data might help illuminate how personality traits influence innovation at different points in time. Third, extending this analysis using alternative indicators of innovation would help address the limitations of patenting and also assess the extent to which different personality traits impacted different forms of innovation – similarly, spillovers from neighbouring TTWAs are worthy of consideration. Finally, the relationship between personality traits and firms – the intermediaries between

[10] I am grateful to an anonymous referee for raising this point.

individual level actors and innovation at a regional level – is likely to be complex, with two-way relationships and sectoral nuance. Further research unpacking this relationship would be important in clarifying the processes at work.

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Tables

Table 1. Personality traits and indicators

Personality trait	Questions used by Rentfrow et al. (2015) to identify this trait	Expected relationship with innovation
Extraversion	Tends to be quiet (-); Is talkative; Is reserved (-); Is outgoing, sociable; Is sometimes shy, inhibited (-); Has an assertive personality; Generates a lot of enthusiasm; Is full of energy	Positive - related to putting new ideas out and enthusiasm.
Conscientiousness	Does a thorough job; Does things efficiently; Perseveres until the task is finished; Tends to be disorganized (-); Makes plans and follows through with them; Is a reliable worker; Tends to be lazy (-); Is easily distracted (-); Can be somewhat careless (-)	Positive – as all characteristics of those working hard and concentrating on projects.
Openness	Is inventive; Is original, comes up with new ideas; Has an active imagination; Likes to reflect, play with ideas; Is ingenious, a deep thinker; Values artistic, aesthetic experiences; Is curious about many different things; Is sophisticated in art, music, or literature; Has few artistic interests (-); Prefers work that is routine (-)	Positive – as is associated with tolerance, openness to new ideas and creativity
Neuroticism	Worries a lot; Is relaxed, handles stress well (-); Can be tense; Is emotionally stable, not easily upset (-); Gets nervous easily; Remains calm in tense situations (-); Is depressed, blue; Can be moody	Negative – as associated with negative outcomes and tension.

Agreeableness	Is considerate and kind to almost everyone; Is sometimes rude to others (-); Has a forgiving nature; Can be cold and aloof (-); Starts quarrels with others (-); Likes to cooperate with others; Tends to find fault with others (-); Is helpful and unselfish with others; Is generally trusting	Positive – likely to be associated with trust, shared values and cooperation so may reduce incentive problems and transaction costs.

Source: Adapted from Rentfrow et al. (2015). Minus signs imply negative factor loadings.

Table 2. Summary statistics

	Source	Obs	Mean	SD	Min	Max
Patents per 100,000 (ln)	Intellectual Property Office	184	-8.88	1.09	-13.82	-5.58
Extraversion	BBC / Rentfrow et al. (2015)	184	3.23	0.05	3.06	3.34
Agreeableness	BBC / Rentfrow et al. (2015)	184	3.75	0.03	3.64	3.84
Conscientiousness	BBC / Rentfrow et al. (2015)	184	3.75	0.03	3.64	3.84
Neuroticism	BBC / Rentfrow et al. (2015)	184	3.67	0.05	3.50	3.80
Openness	BBC / Rentfrow et al. (2015)	184	2.98	0.05	2.81	3.17
Population (ln)	2011 Census	184	3.66	0.05	3.49	3.86
NVQ 4 + (%)	2011 Census	184	11.97	1.07	9.42	16.05
Scientific occupations (%)	2011 Census	184	0.25	0.05	0.13	0.37
Manufacturing (%)	2011 Census	184	0.10	0.03	0.04	0.20
Fractionalisation index	2011 Census	184	0.05	0.02	0.02	0.11
Roman catholic %, 1851	Vision of Britain	161	0.10	0.03	0.04	0.20

Source: PL2 = Intellectual Property Office, authors calculations; Personality traits = Rentfrow et al.; Population – manemp = UK Census 2001 via Nomis; sunper/rcathper = vision of Britain.

Table 3. Correlation matrix

	Patents.	*Extra.*	*Agree.*	*Consc.*	*Neuro.*	*Open.*	*Popln.*	*NVQ4+*	*Sci.*	*Man.*	*Frac.*	*Cath.*
Patents per 100,000 (ln)	1.000											
Extraversion	0.0430	1.000										
Agreeableness	0.0115	0.0965	1.000									
Conscientiousness	0.1398*	0.1800**	0.4367***	1.000								
Neuroticism	-0.1168	-0.5124***	-0.2895***	-0.3044***	1.000							
Openness	0.0986	0.1186	-0.0618	-0.0659	-0.0773	1.000						
Population (ln)	-0.1962**	0.1419*	-0.1406*	-0.1906***	0.0251	0.2546***	1.000					
NVQ 4 + (%)	0.3068***	0.3718***	-0.0840	0.0589	-0.3304***	0.4453***	0.0935	1.000				
Scientific occupations (%)	0.1820***	0.1765**	- 0.1903***	-0.0935	-0.0997	-0.0997	0.5284***	0.5509***	1.000			
Manufacturing (%)	-0.1607***	-0.2929***	0.0097	-0.0580	0.3417***	-0.3533***	0.0813	-0.4488***	0.0623	1.000		
Fractionalisation index	0.0779	0.2642***	-0.2035***	-0.0559	-0.1232*	-0.0842	0.6186***	0.3264***	0.5129***	-0.1112	1.000	
Roman catholic %, 1851	-0.3396 ***	0.0402	-0.1773**	- 0.2943***	0.1289 ***	-0.0589	0.2878***	-0.0700	0.0191	0.0528	-0.0490	1.000

Observations: 184 (161 for Roman Catholic %)

* significant at 10%; ** significant at 5%; *** significant at 1%

Table 4. Regression results (OLS)

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
DV:	Patents lodged per 100,000 population, 2009 -2011 (ln)											
Extraversion	1.028					-1.042	-1.388					-1.936
	(1.651)					(2.068)	(1.932)					(2.273)
Agreeableness		0.423				-2.856		2.196				0.453
		(3.090)				(3.111)		(2.765)				(3.107)
Conscientiousness			3.051*			3.401**			3.192**			2.942*
			(1.552)			(1.689)			(1.555)			(1.605)
Neuroticism				-2.559*		-2.329				-0.473		-0.239
				(1.374)		(1.692)				(1.237)		(1.581)
Openness					1.968	2.013					-1.909	-1.401
					(1.405)	(1.546)					(1.282)	(1.324)
Population (ln)							-0.421***	-0.426***	-0.387***	-0.422***	-0.429***	-0.386***
							(0.0829)	(0.0842)	(0.0817)	(0.0842)	(0.0830)	(0.0793)
NVQ 4 + %							3.606	3.048	2.633	3.066	4.642*	4.304*
							(2.499)	(2.221)	(2.203)	(2.259)	(2.419)	(2.537)
Scientific occupations %							13.44*	14.86**	15.95**	14.04*	11.37	13.13*
							(7.556)	(6.976)	(6.989)	(7.212)	(7.398)	(7.450)
Manufacturing %							0.0443	0.262	0.202	0.486	0.308	-0.0133
							(2.797)	(2.905)	(2.809)	(2.929)	(2.897)	(2.739)
Fractionalisation							2.243	2.329*	2.256*	2.129	2.072	2.345*
							(1.366)	(1.368)	(1.359)	(1.357)	(1.372)	(1.404)
Wales							0.302*	0.374**	0.581***	0.349**	0.366**	0.555***
							(0.176)	(0.179)	(0.180)	(0.174)	(0.170)	(0.177)
Greater South East							0.556***	0.538***	0.481**	0.550***	0.555***	0.511**
							(0.202)	(0.197)	(0.193)	(0.199)	(0.201)	(0.199)
Constant	-12.19**	-10.46	-20.07***	-1.265	-16.08***	-7.724	-1.359	-13.98	-17.88***	-4.340	1.080	-6.853
	(5.319)	(11.60)	(5.694)	(4.072)	(5.180)	(16.70)	(6.178)	(10.58)	(5.887)	(3.735)	(4.636)	(14.27)
Observations	184	184	184	184	184	184	184	184	184	184	184	184
R-squared	0.002	0.000	0.020	0.014	0.010	0.041	0.229	0.229	0.241	0.226	0.232	0.248

Robust standard errors in parenthesis. * significant at 10%; ** significant at 5%; *** significant at 1%

Table 5. Instrumental variable results (2SLS)

	(1)	(2)	(3)	(4)
DV:	Patents lodged per 100,000, 2009 – 2011 (ln)			
Estimation method	OLS	OLS	2SLS	2SLS
IV:	-	-	Roman catholic attendance, 1851 (%)	
Conscientiousness	4.644**	3.604*	29.06**	21.51*
	(2.027)	(2.032)	(11.32)	(12.90)
Population (ln)		-0.395***		-0.123
		(0.0935)		(0.227)
NVQ 4 + %		2.864		0.564
		(2.391)		(2.561)
Scientific occupations %		16.17**		23.00**
		(7.254)		(8.981)
Manufacturing %		0.379		0.170
		(2.998)		(3.305)
Fractionalisation		2.216		2.515
		(1.412)		(1.871)
Wales		0.628***		1.659*
		(0.211)		(0.850)
Greater South East		0.442**		0.0884
		(0.201)		(0.289)
Constant	-25.96***	-19.36**	-115.5***	-88.17*
	(7.439)	(7.761)	(41.54)	(49.90)
R2	0.034	0.237		
Observations	161	161	161	161
Kleibergen-Paap F statistic			13.954	9.728
Cragg-Donald F statistic			15.198	12.143

Models 1 and 2 estimated as OLS with reduced sample. 3 and 4 using 2SLS with Roman Catholic attendance in 1851 as instrumental variable. Robust standard errors in parenthesis. * significant at 10%; ** significant at 5%; *** significant at 1%

Figure 1(a) Openness to experience

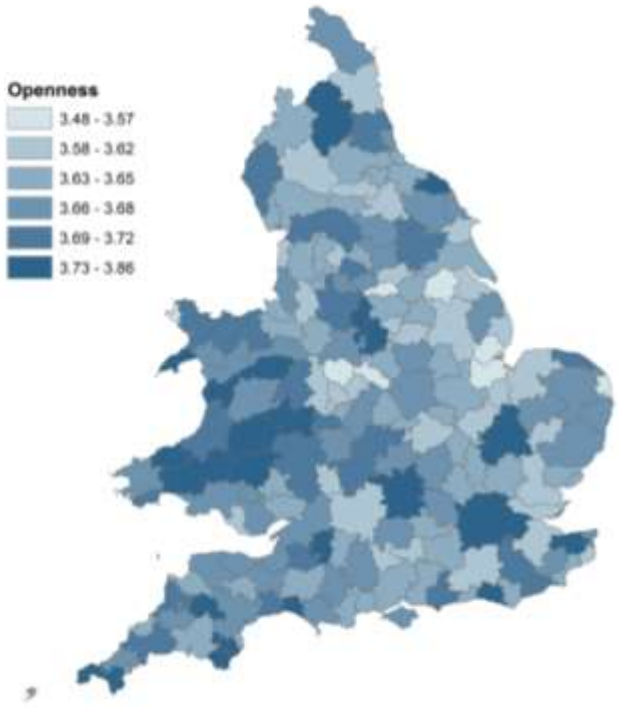

Figure 1(b) Neuroticism

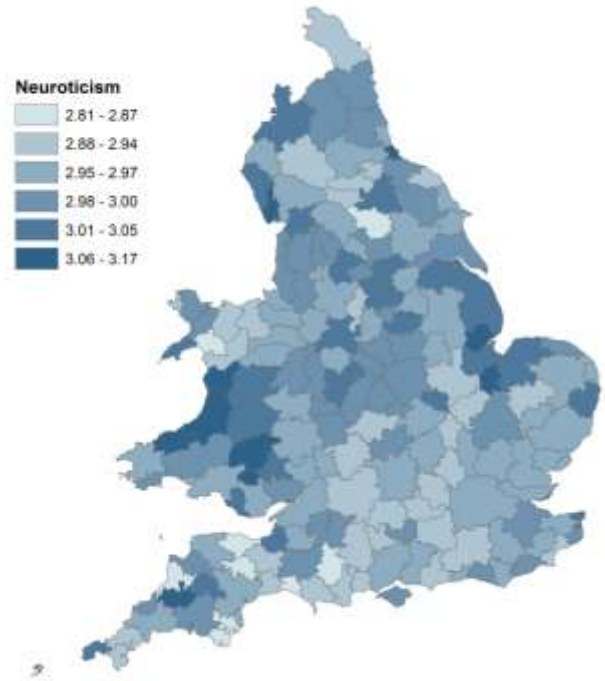

Figure 1 (c) Conscientiousness

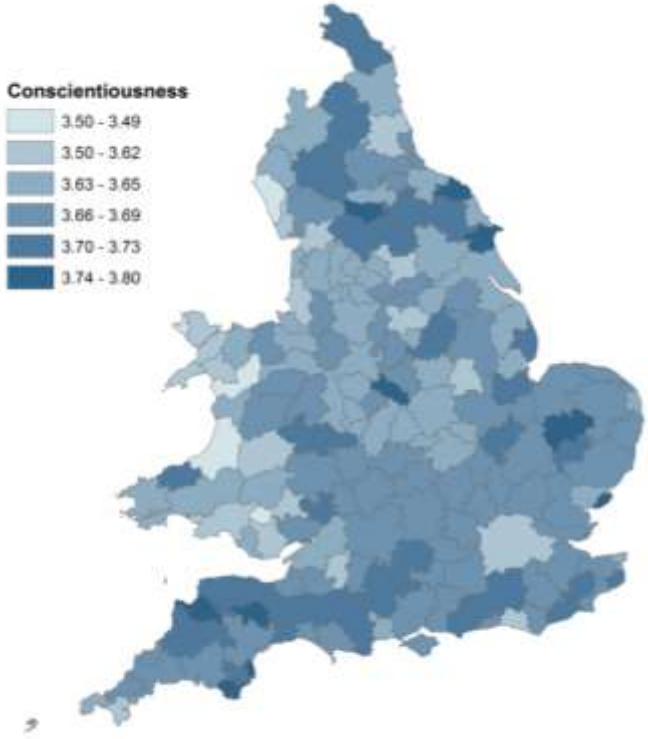

Figure 1(d) Agreeableness

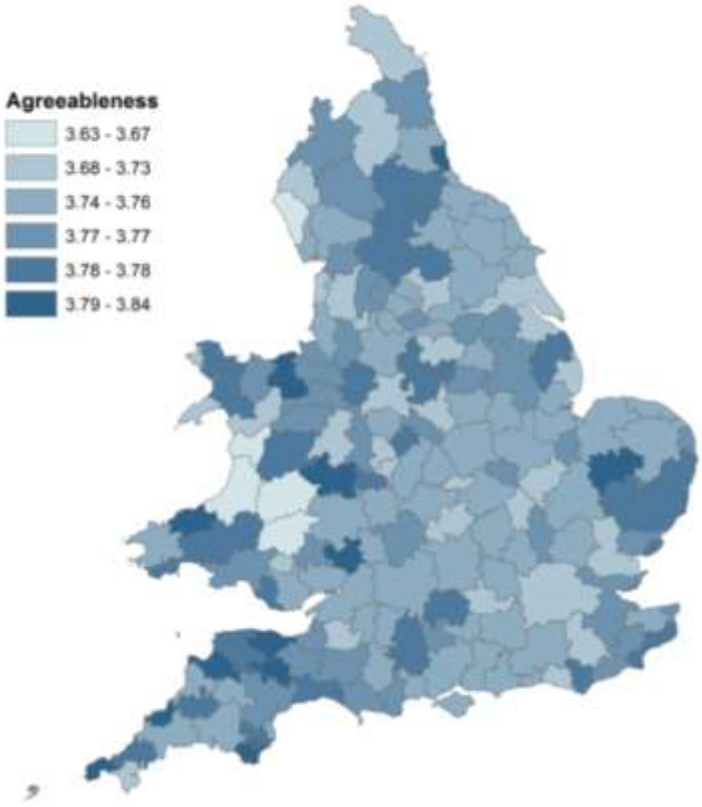

Figure 1(e) Extraversion