Human Capital, Graduate Migration and Innovation in British Regions

Alessandra Faggian[*] and Philip McCann[**]

Abstract
With the aid of a geographical information system, our paper constructs a three stage least squares simultaneous equation model to investigate the interrelationships between the interregional flows of human capital, and the innovation dynamism of a region. In order to do this, we model the interregional migration behaviour of high quality British university graduates from university into first employment, and we relate these human capital flows to both the labour market characteristics and the knowledge characteristics of the employment regions. This is done for both all industries and for just high technology industries. Our results indicate that for England and Wales there is a two-way causality between the interregional human-capital employment-migration flows of recent university graduates and the innovation performance of regions. However, the results for Great Britain as a whole depend on whether London is included and Scotland is excluded. We find little or no support that the presence of local universities or small firms promotes regional innovation.

JEL Classification: O180, R230, I230

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1. Introduction.

The contribution of higher education to economic growth has long been discussed from a variety of perspectives (OECD 2004). For regional economists of particular interest is the role higher education plays in fostering local and regional economic development (Faggian and McCann, 2008). The local existence of higher education institutions generates local direct expenditure-employment multiplier effects (Armstrong 1993; Harris 1997). More importantly, however, the provision of education and training contributes to growth in the local, regional and national stocks of human capital (Bradley and Taylor 1996). The flow of graduates into or from a region therefore indicates the extent to which a region is net recipient of newly-acquired human capital, and the greater is the net inflow, the greater are the specifically local regional returns to national higher education policies (Bennett et al. 1995). As such, although in principle all regions should benefit from the national level of human-capital growth, the regional rates of return to higher education depend crucially on the migration behaviour of university graduates.

The aim of this paper is to examine the extent to which the innovation dynamism of Britain's regions is related to the employment migration behaviour of British graduates, and in turn, to identify how graduate migration behaviour is itself related to the

[*] School of Geography, University of Southampton, Highfield, Southampton, SO17 1BJ, United Kingdom. E-mail: a.faggian@soton.ac.uk
[**] Department of Economics, University of Waikato, Private Bag 3105, Hamilton, New Zealand. E-mail: pmccann@waikato.ac.nz; and Department of Economics, University of Reading, Whiteknights, Reading, RG6 6AW, United Kingdom. E-mail: p.mccann@reading.ac.uk

innovation dynamism of British regions. In other words, our aim is to identify the extent to which the migration of graduate human capital contributes to any regional-specific cumulative learning processes, over and above any direct effects of local university-industry spillovers.

In order to do this we employ data from a large survey of British students with the aid of a Geographical Information System (from now on referred to as GIS). This allows us to observe the spatial patterns of graduate migration from higher education and into first employment. We analyse these migration flows within a three stage least squares simultaneous equation system. By combining information on these graduate migration flows with information on the labour market and knowledge characteristics of the British regions, we are able to analyse the role which the knowledge base of a region plays in attracting university graduates, and also the simultaneous role which graduate inflows play in promoting regional dynamism. Our results imply that in England and Wales, the interrelationship between regional innovation and regional human capital inflows represents an endogenous and cumulative process.

The paper is organised as follows. In section 2 we discuss the hypothesised links between industry and regional innovation performance, and in section 3 we outline the major features of British interregional migration and spatial labour markets. Section 4 describes the data and variables employed, and section 5 explains the rationale for the simultaneous equation methodology. Section 6 presents our results, while sections 7 and 8 provide a discussion, interpretation and conclusions of our findings.

2. Innovation and Regions

Over the last two decades there has been a significant growth in interest among regional economists and economic geographers regarding the relationship between innovation and regional economic performance. Following the work of key commentators (Porter 1990; Acs and Audrestch 1990 a,b; Jaffe et al. 1993), innovation is regarded as the outcome of the interaction between human capital and knowledge spillovers, which creates cumulative learning effects. From the perspective of economic growth, the basic interest in the innovation behaviour of firms comes from the fact that innovative firms and industries are generally regarded as being not only at the forefront of the technological frontier, but also responsible for advancing it. The reason is that innovations in one industry tend to spread throughout the market environment into other industries. As such, developments within innovative firms and industries appear to have much wider impacts on the economy as a whole than just within the innovative firms themselves.

Within the literature on innovation, some commentators argue that large firms play a dominant role in promoting innovations due to R&D economies of scale (Cohen and Klepper 1996) while other research suggests that innovations are increasingly being lead by the small firm sector (Acs and Audrestch 1990a,b), due to the organizational flexibility afforded by smallness. However, these two explanations might actually be consistent with each other, in that it may be both very large firms and very small firms which are the most innovative types of firms, with medium sized firms somewhat lagging behind (McCann and Simonen 2005).

A major component of innovation research has tended to focus on the characteristics, behaviour and performance of high-technology industries, such as electronics, semiconductors and biotechnology. The reason is that high technology firms are generally regarded as being at the forefront of technological developments and innovations, and techniques and practices of these sectors may act as a guide for other industries wishing to become more innovative. Moreover, the innovations made by these industries also subsequently tend to pervade all other industries, thereby driving productivity gains in the wider economy as a whole. The current evidence regarding high technology industries strongly suggests that a disproportionately high share of innovations in these sectors do indeed come from the small firms within these industries (Acs and Audrestch 1990a,b).

As well as issues of firm size and R&D, another line of research on innovation concerns questions of geography. For regional economists and economic geographers, much of the interest in innovative industries is also linked to the fact that in many cases there appears to be a very strong tendency for high technology firms to cluster in particular locations such as: in the USA, Silicon Valley (Larsen and Rogers 1984; Saxenian1994), Boston Route 128 (Castells and Hall 1994), Southern California (Scott 1993); in the UK, Cambridge (Castells and Hall 1994) and the M4 Corridor (Breheny and McQuaid 1987); Tokyo and Tsukuba in Japan (Castells and Hall 1994), and in continental Europe, Ile de France and Stuttgart (Simmie 2001). The result of this behaviour is that certain areas appear to exhibit high growth performance in these sectors, while other areas have been unable to develop any equivalent industry base. This has lead to concern among public policy planners in various countries and regions (Castells and Hall 1994) to understand the economic-environmental conditions under which such industrial clusters are fostered, in the hope of replicating these conditions elsewhere.

The reasons why innovative firms often appear to be spatially clustered are complex. Within the evolutionary economics literature (Caniels 2000), the international business literature (Cantwell and Iammarino 2003), the management literature (Porter 1990), and the economic geography literature (Scott 1988; Saxenian 1994; Acs 2002; Simmie 2001), there has been a widespread effort to understand the differences in the spatial distribution of innovative activity and knowledge-based functions. The focus of this research effort has tended to be on the role played by agglomeration economies, and in particular the role of local externalities, and specifically knowledge spillovers, in promoting clustering of innovative activities. In much of this literature it is argued that in many situations, the clustering of small and medium sized firms will guarantee the maximum levels of regional innovation (Aydalot and Keeble 1988; Saxenian 1994). Although there are other literatures which find evidence that large firms play a key role in regional innovation processes (Cohen and Klepper 1996; Cantwell and Iammarino 2003), the numbers of such papers over recent years tends to be much less than those favouring of the importance of small firm clusters.

Another line of research which has become popular recently concerns the role played by local universities in promoting regional innovation. Following the work of Anselin et al. (1997) a great deal of research has been undertaken to identify the role played by universities in national and regional innovation systems. The hypothesised link here is primarily via knowledge spillovers between universities and local industries (Abramovsky et al. 2007; OECD 2007), and the effect which such local spillovers have on the stock of regional and national human capital.

For reasons of data availability, the empirical literature on the geography of innovation tends to focus primarily on innovation as measured by either patent citations (Jaffe et al. 1993) or R&D expenditure (Acs 2002), and also focuses on mainly manufacturing innovations, with much less evidence being available concerning the service industries (Gordon and McCann 2005). Subject to these limitations, the evidence does indeed point towards the presence of local knowledge spillovers in many cases of innovative industries.

These arguments, however, generally tend to ignore the role played by the mobility of graduate human capital. Human capital migration is a well-known means by which knowledge can be transferred between regions (Faggian et al. 2007a). However, in the context of innovation studies, very little is really known about the strength of this potential knowledge transfer mechanism. The evidence supporting the role played by the mobility of local human capital in promoting innovation is still quite tentative (Angel 1991; Audrestch and Stephan 1996; Almeida and Kogut 1999; Breschi and Lissoni 2003; Franco and Filson 2000; Persson 2002; Power and Lundmark 2004). However, while other papers argue that it may be wider labour market areas rather than local ones which primarily determine innovation (Gordon and McCann 2005), there has been little research undertaken on this point. This is because, unfortunately, while empirical data on patents and R&D are readily accessible, as well as occasionally data on local labour markets, additional micro-data on interregional labour mobility is very difficult to find. Yet, without detailed data on both labour mobility as well as data on innovation, identifying the exact mechanism by which knowledge spillover effects are mediated is not entirely possible. The outcome of all of this is that very little is actually known about the extent to which highly innovative regions remain highly innovative because of the net inflow of human capital, or whether these inflows are themselves a result of the fact that some regions are more dynamic and highly innovative.

These issues appear to be very important in the case of the British regions, as there are very high levels of inter-regional mobility amongst British university graduates entering into employment. For example, in the buoyant London economy there are 40% more university graduates employed in London that are actually educated there, whereas in the economically weaker northern regions of Yorkshire and Humberside, there are 40% more graduates educated in Yorkshire and Humberside than are actually employed there (HMT-DTI 2001). The only exception is the case of Scotland where university graduates tend to be much less mobile than those in England and Wales (Faggian et al. 2007b). Moreover, increasing mobility is associated with increasing human capital (Faggian et al. 2007a,b), and graduates from better universities also exhibit greater mobility (Faggian et al. 2007a,b). The implication of these interregional flows of graduate human capital is that the migration of human capital may be a very significant form of knowledge transfer both between regions as well as within regions. Yet, in spite of the evidence regarding the scale of and nature of British graduate migration flows, analyses of regional innovation behaviour in Great Britain still tend to emphasise the role played by local informal knowledge spillovers, rather than focusing on the role of human capital mobility.

Before we can explore econometrically whether the mobility of human capital is an important issue for understanding regional innovation behaviour, it is first necessary to recall the key features of spatial labour market and migration behaviour in Great Britain. This is so that we can set up our human capital -migration model in such a way as to identify whether the interaction between the migration of graduate human-capital and regional innovation performance plays any systematic role which is distinct from the more general features of British labour markets.

3. UK Inter-Regional Labour Migration

Economists have generally built models of individual human migration based on the view that people migrate to maximise welfare. The two main approaches have been human capital theory and search-theory (Molho 1986). In the human capital model of migration (Sjaastad 1962), the likelihood that a given individual residing in a region will relocate is an increasing function of the present value of potential moves from that region. Geographic mobility is therefore necessary to bring about higher expected returns to individual human capital investments. In the spatial job-search model workers obtain employment through an optimal search practice, in which the length of search, i.e. the period of unemployment, depends on the distribution of wages that an individual perceives his services can command, as well as the cost of generating job-offers (Simpson 1992). Under this approach, the job-search process ends when a wage offer either equals or exceeds the individual's reservation wage, which is the wage which equates the marginal cost of obtaining one more job offer with the expected marginal return from continued search (Herzog et al. 1985).

Although these two approaches are distinct, they can be combined in order to understand the general determinants of individual migration propensities. Reductions in search and relocation costs generally imply that reservation wages and the duration of search will generally increase, along with the net returns to migration. In addition, the strength of all these effects and resulting migration propensities will also differ according to differences in the extent to which local wage variations reflect purely local economic conditions. The reason for this is that this will determine exactly how informative the individual's wage at a particular location will be as a benchmark for comparing alternative market opportunities (Richmond Cooper 1994) and living environments (Evans 1993; Graves 1980).

In the particular case of Great Britain, the cross-sectional dynamics of interregional migration behaviour appear to exhibit three major characteristics.

Firstly, most British evidence supports the disequilibrium model (Evans 1990, 1993) over the equilibrium approach (Gordon and Molho 1998) in that net migration flows are generally towards areas of higher nominal wages. Secondly, the returns to human capital do appear to vary across the regions (Shah and Walker 1983; Hemmings 1991), as predicted by the human capital arguments embodied in new growth theory (Romer 1986, 1987; Lucas 1988), in that nominal wage differentials between British regions are partly explained by the non-homogeneity of the regional labour force. Thirdly, and perhaps most importantly, in the case of British regions, there appears to be something of a centre-periphery phenomenon in terms of the spatial pattern of the graduate employment opportunities generated. Interregional migration flows (Gordon 1995) and interregional wage differences (Gordon and Molho 1998) appear to depend primarily on the number of job-matching opportunities available in each region, relative to the number of people seeking work. The spatial variations and constraints in the generation of such job opportunities in turn appear to be related to the rank-order of the area within the national urban hierarchy, centred on London and its hinterland regions (Fielding 1992, 1993). As such, inter-regional migration would appear to be primarily a consequence of, rather than a pre-condition for, a successful job-search (Jackman and Savouri 1992). The result is that the employment and migration patterns within Great Britain exhibit life-cycle effects according to a regional 'escalator' process (Fielding 1992, 1993; Evans 1990; Audas and McKay 1997), in which young persons and university graduates are attracted to London and the South East from other regions in order to enter employment and training, and only very much later in life move to other regions to work (Warnes and Ford 1995).

In order to estimate the interrelationships between regional innovation and graduate migration behaviour, it is necessary to control for each of these particular features of British migration and spatial labour markets. The reason is that we wish to see if graduate migration behaviour is related to regional innovation dynamics, over and above the usual labour market indicators. In addition, we also wish to see if regional innovation performance is related to graduate migration behaviour, over and above the usual innovation explanations.

In the simultaneous equation models discussed in section 4, we estimate the employment migration behaviour of human capital (students who graduated in the academic year 1999-2000) into Great Britain's regions as a function of a range of independent explanatory variables which are intended to capture the above labor market features. In addition, we also relate the employment migration behaviour of graduate human capital into Great Britain's regions to the specific innovation performance of the region. Simultaneously, we estimate regional innovation performance as a function of the types of explanatory variables normally employed in such analyses, but controlling also for flows of graduate human capital into the region. This approach allows us to identify whether the interrelationships between regional innovation and human capital migration behaviour represent a cumulative and endogenous process.

4. Data

Our graduate labour market information comes from the HESA (Higher Education Statistics Agency) student leavers' questionnaire, and provides us with data on 187,474 university graduates for the year 2000. The HESA survey includes the unit postcodes of the domicile, university and first full-time employment workplace locations of each student. There are approximately 1.78 million unit postcodes in Great Britain and our GIS system allows us to identify the geographical centre point of each of the unit postcode and therefore to map the pattern of individual and aggregate graduate migration flows. By setting this information within the GIS software MAPINFO, we are able to model the interregional geographical flows of the graduates in to employment after university and hence identify the flows of human capital into a region.

So as to make full use of the HESA data within a general migration, human capital and innovation discussion it is also necessary for us to integrate the explicitly spatial data with local labour market data, regional industrial and geographical structural data, and regional innovation data. In order to do this, we adopt as our basic spatial unit of analysis the 36 NUTS2 areas of Great Britain. These are the smallest areas of spatial disaggregation for which all of the relevant data required is available. [1] We then use the GIS system to allocate each of the student domicile, education and employment locations to the respective NUTS2 regions.

Table 1 gives a brief description of the variables used in the empirical analysis, and Table 2 provides the summary statistics.

Table 1. Variable Descriptions

Table 2 Summary Statistics

The migration component of the models are based on *HK_POP*, which is the number of university graduates who enter into full-time employment after graduation in a particular destination region *i*, which is a different area from both the domicile and the higher education area (i.e. repeat migrants), per 100,000 of regional population. As in previous analyses (Faggian and McCann 2006; Faggian et al. 2006, 2007a), in order to construct our variable *HK* we define labour mobility as a movement between two locations with a distance greater than 15 km between each other. The reason for this is that almost all individual UK urban labour markets have a radius of less than 15 km. The only real exception to this is London, but even here, from a travel time perspective, London is generally regarded as being made up of a series of distinct urban labour markets areas, each of which is less than 15 km in radius . The particular group of university graduates

[1] The 36 NUTS2 regions of Great Britain have an average population of 1.51 million, and range in population from 440,000 to 3.5million. The populations of 26 of the 36 NUTS2 areas range between 1 million and 2.6 million. Our spatial areas are therefore broadly comparable in both scale and spatial definition to the Functional Urban Regions (FURS) employed by Cheshire et al. (1988) and Cheshire and Carbonaro (1995), and are also broadly comparable with Metropolitan Statistical Areas in the USA. We exclude the Highlands and Islands NUTS2 region in this analysis, because there ILO unemployment data are not available for this particular region for this particular year. This should not affect the overall results because the flow of university graduates into this area is so tiny.

we focus on here are the highly mobile graduates who move more than 15 km away from both their domicile and university locations in order to enter employment. This definition of human capital migration is different to the three human capital definitions we employed in previous simultaneous equation models (Faggian and McCann 2006). As such, we do not include in our analysis the less mobile and less qualified graduates who enter employment either in the area of their domicile or the area of their university education, as these are discussed elsewhere (Faggian and McCann 2006).[2] As predicted by human capital theory, the cohort that we focus on here are found to be not only the most geographically mobile group of graduates but also the most highly qualified cohort of graduates (Faggian et al. 2006, 2007a). From human capital theory these are also the cohort of graduates who contribute the most to knowledge accumulation and generation.

The two measures of regional innovation performance we employ are *ALL_INN* and *HT_INN*. *ALL_INN* represents the total number of patent applications per million of population for each NUTS2 region in 2000, and *HT_INN* represents the total number of high technology patent applications made per million of population in each NUTS2 region in 2000.[3] The patent data comes from the European Patent Office. The European Patent Office (EPO) data is largely comparable both in terms of its technology characteristics (Caniels 2000) and also its spatial distribution to the US patent office data for Europe (Cantwell and Iammarino 2003). The strengths and weaknesses of using patent data as a measure of innovation have been extensively discussed elsewhere (Caniels 2000).

In our human capital migration equations, the regional labour market variables we employ are: *R_WAGE*, which represents the regional real wage, constructed as the average gross weekly salary of workers in managerial occupations in each region in 2000 divided by the unrebated average rental value; *JOBS*, which represents the total number of unfilled job vacancies in the region, standardized by dividing this by the total regional population in 1999; the regional quality of life indicator *QLIFE*, which represents the inverse of the average crime rate in 2000; *ILO*, which represent the regional

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[2] This cohort of highly mobile graduates is actually made up of two types of graduates. The first type are those graduates who move more than 15k away from the domicile location to enter university and then move gain more than 15km away from both the domicile and university locations in order to enter employment. These are the *repeat migrants* (Faggian et a. 2006, 2007a,b). The second type are the *late migrants*, who enter university within a 15km radius of the domicile, but then move more than 15km away from both the domicile and university locations in order to enter employment (Faggian et a. 2006, 2007a,b). Note that it is possible for either a repeat migrant or a late migrant to remain in the same NUTS2 region for employment as their domicile or university area.

[3] The Eurostat published patent data for the NUTS2 regions of Scotland is very incomplete. We therefore use the 2002 Eurostat (2002) provisional estimates for the relative patent scores for EU NUTS2 regions (provided on CD with the original Eurostat 2002 publication) and multiply the indices for Scottish regions by the official published values for London, in order to produce proxy patent scores for the Scottish regions. The proxy patent scores generated look far more realistic than the published scores. We then estimate the models using both the incomplete published scores and the proxy scores, and find that the results of the overall models actually change very little.

unemployment rate; *CENT*, which represents the distance between the centroid of each NUTS2 region and the centroid of London.[4]

In our regional innovation equations we employ a range of variables which theoretically ought to contribute to region's innovation performance. Our regional R&D index *RDTOT* is calculated by aggregating NUTS2 R&D expenditure data for university R&D, government R&D, and private sector R&D.[5] As well as *RDTOT*, we employ three additional measures of regional knowledge assets, which are intended to capture the effects of any possible local knowledge spillovers: *RAESTUD* represents the research quality of local universities multiplied by the number of students; *NUNIKM2* represents the density of universities in the region; *POPDENS* measures the population density of the region, and is included in our models on the basis of the arguments of Carlino et al. (2007). The regional industry structure indicators we employ are *SMAFIR*, which represents the percentage of regional firms which have less than 50 employees in 1999, and *LQMA* which reflects the region's manufacturing location quotient.

[4] Great Britain exhibits a very clear core-periphery structure in that regional rankings are highly correlated with proximity to London across a range of criteria, such as productivity, growth, activity rates, employment rates, and credit availability (HMT-DTI 2001). Increasing distance from London *CENT* is therefore a good indicator of economic as well as geographical peripherality in Britain, and can also be regarded in part as an index of the position of the region within the UK urban hierarchy.

[5] Government research and university research expenditure are provided at the NUTS2 level. Where NUTS2 level R&D data are not available, as is the case with private sector R&D, each of the NUTS2 regions are then allocated the R&D values associated with the NUTS1 regions within which they are located. The total NUTS2 regional R&D index *RDTOT* is the calculated as the sum of each of these values, divided by regional GDP. As such, the index *RDTOT* reflects the relative significance of R&D to the regional economy.

5. *Methodology*

On the basis of the arguments in sections 2-3, we can hypothesise that the ability of a destination region to attract mobile graduate human capital should be a function of the relative innovativeness of a region, while at the same time the innovativeness of a region ought to be related to the inflows of human capital. In order to capture these two way mechanisms we employ a simultaneous equation model in which we estimate the employment-migration flows of university graduates into a region as a function of the region's innovation dynamism, and at the same time estimate the region's innovation performance as a function of its graduate human capital inflows. The reason we employ such an econometric approach is that from our previous discussions, there is no obvious dominant causality between labour migration and regional innovation, in that one may lead to the other. This implies that it is necessary to explicitly estimate these relationships as simultaneous processes.

Therefore, in order to estimate the two way relationship between the flows of graduate human capital into Great Britain's regions and the regional innovation performance of Britain's regions, we employ a simultaneous equation model in which human capital inflows *HK_POP* are related to the region's innovativeness (*ALL_PAT, HT_PAT*), the number of job vacancies in a region *JOBS*, the level of regional unemployment *ILO*, the quality of life of the region *QLIFE*, the regional real wage *R_WAGE*, and the geographic peripherality of the region *CENT*. At the same time, from our arguments in section 2 regarding the innovation dynamics of a region, the innovation performance of a region (*ALL_PAT, HT_PAT*) is related to the scale of human capital inflows *HK_POP*, the number of small firms *SMAFIR* in the region, the specialisation of manufacturing in the region *LQMA*, the density of universities in the region *NUNIKM2,* the research quality *RAESTUD* of the local universities, and the regional R&D expenditure *RDTOT*.

The structural equations of the models are as follows.

When innovations in all industries are included the structural equations are:

$$HK\_POP_i = \alpha_0 + \alpha_1 ALL\_INN_i + \alpha_2 ILO_i + \alpha_3 R\_WAGE_i + \alpha_4 CENT_i + \alpha_5 JOBS_i + \alpha_6 QLIFE_i + \eta_i \quad (1)$$

$$ALL\_INN_i = \beta_0 + \beta_1 HK\_POP_i + \beta_2 RAESTUD_i + \beta_3 SMAFIR_i + \beta_4 NUNIKM2_i + \beta_5 POPDENS_i + \beta_6 LQMA_i + \beta_7 RDTOT_i + \varepsilon_i \quad (2)$$

When only innovations of high technology industries are considered the structural equations become:

$$HK\_POP_i = \gamma_0 + \gamma_1 HT\_INN_i + \gamma_2 ILO_i + \gamma_3 R\_WAGE_i + \gamma_4 CENT_i + \gamma_5 JOBS_i + \gamma_6 QLIFE_i + \xi_i \quad (3)$$

$$HT\_INN_i = \varphi_0 + \varphi_1 HK\_POP_i + \varphi_2 RAESTUD_i + \varphi_3 SMAFIR_i + \varphi_4 NUNIKM2_i + \varphi_5 POPDENS_i + \varphi_6 LQMA_i + \beta_7 RDTOT_i + \mu_i \quad (4)$$

where the subscript i refers to each NUTS2 region.

Simultaneous equation models can be estimated with either a limited or full information method (Wooldridge 2002). The most popular technique for estimating simultaneous equations is the two-stage least square method (2SLS), which belongs to the limited information family. 2SLS is easy to implement, but provides inefficient estimates of the α's and β's (γ's and φ's) if the error terms ε and η (ξ and μ) are correlated. Since there is no theoretical reason to exclude a priori the existence of such correlation in our model, a three-stage least squares (3SLS) is used. 3SLS, developed by Zellner and Theil (1962), is a full information method and can be seen as a logical extension of 2SLS to which an additional step is attached. This extra step consists of the estimation of the variance-covariance matrix of cross-equation error terms, which is then used to correct the estimates of the parameters α's and β's (γ's and φ's). 3SLS provides consistent and more efficient estimates than 2SLS since it incorporates the additional information on the structure of the error terms and is therefore also better for statistical inference. If there is no correlation or heteroscedasticity in the error terms, the 3SLS gives exactly the same results of 2SLS.

In order to examine whether the 3SLS method produces superior estimates to alternative techniques, we estimated the above model using both separate OLS regressions and also two stage least squares (2SLS). A comparison of the results of these methods indicates significant differences between each of the approaches depending on their specification. This observation suggests that the full information 3SLS method is superior to the alternative techniques. The model system is therefore estimated using the 3SLS technique, and this allows for the interrelationships between the innovation performance of a region and human-capital migration behaviour to be analysed.

The simultaneous equation models represented by equations (1)-(2) and (3)-(4) are estimated in three different settings. In Model 1, we estimate both of the equation systems represented by equations (1)-(2) and (3)-(4) across all NUTS2 regions of Great Britain. In Model 2, we estimate the same equation systems as in Model 1, but removing from the system the two London NUTS2 regions. In Model 3, we estimate the same two equation systems as in each of the two previous two models, but this time removing only the

Scottish regions (hence leaving the whole of England and Wales included). The reason for removing the London NUTS2 regions in Model 2 is in order to examine the extent to which the 'escalator' phenomenon (Fielding 1992) discussed in section 3, and also the concentration of higher education and research institutions in London, alters any of the aggregate results. The reason for removing the Scottish regions in Model 3 is based on the fact that previous evidence (Faggian et al. 2007b) suggests that human capita l mobility in Scotland is very different from the rest of Great Britain.

The results of the graduate migration equations are reported in the upper panels of Tables 3 and 4 while the results of the innovation equations are reported in the lower panels of the tables.

Table 3. 3SLS estimates: All Sectors Innovation

Table 4. 3SLS estimates: High Tech Innovation

6. Results.

For all model specifications we see that human capital in-migration is significantly related to the innovativeness of a region.

In the case of all industries reported in Table 3, for Great Britain as a whole (Model 1) and also for Britain as a whole without London (Model 2), there is no evidence of any endogenous human capital migration-innovation process, because regional innovation *ALL_INN* is not related to the scale of human capital inflows *HK_POP*. In these cases, regional innovation appears to be related only to *RDTOT* total regional R&D. However, after removing Scotland and focussing only on England and Wales together (Model 3), we see that there is clear evidence of an endogenous and cumulative process of highly graduates *HK_POP* migrating to employment in innovative regions, whose innovation performance *ALL_INN* is also positively related to such human capital inflows. In the case of England and Wales (Model 3), the two-way endogenous relationship between human capital inflows *KH_POP* and regional innovation *ALL_INN* appears to dominate all other explanatory mechanisms.

The results for high technology industries are reported in Table 4. When considering the regional innovation performance of high technology industries we see that for all model specifications there appears to be two-way relationship between human capital inflows *HK_POP* and regional innovation *HT_INN*, although the results are weaker when the London regions are removed in Model 2. In these models, there is some tentative evidence of a positive role played by local universities *RAESTUD* and *NUNIKM2*, although these results are dependent on the inclusion of London in Model 1 and Model 3. Conversely, total regional R&D *RDTOT* appears to be important for regional high technology innovation when London is not included in the model (Model 2).

The changes in results associated with the exclusion of the regions of Scotland (Model 3) are probably related to the fact that the graduate labour market of Scotland appears to function rather differently than the rest of England and Wales (Faggian et al. 2007b). Scottish students tend to exhibit much more limited mobility than students in England and Wales.

Where significant, the signs for the labour market variables are largely as expected.[6] Meanwhile, none of the variables representing small firms *SMAFIR*, population density *POPDENS*, or manufacturing specialisation *LQ*, appear to play positive any role in a region's innovation performance.

Finally, in Table 5 we report the elasticities for *HK_POP*, *ALL_INN* and *HT_INN*, calculated at the means values. As we see, for all three models, the elasticity of *HK_POP* with respect to *ALL_INN* is greater than the elasticity of *HK_POP* with respect to *ALL_INN*, whereas for all three models the elasticity of *HT_INN* with respect to *HK_POP* is greater than the elasticity of *ALL_INN* with respect to *HK_POP*. Regional

[6] Except for real wages *R_WAGE*, although this result is consistent with other findings (Faggian et al. 2007a).

high technology innovation is more sensitive to the human capital inflows than innovations across all sectors' innovation, whereas human capital inflows are relatively more sensitive to the innovation performance of all sectors than just high technology sectors.

Table 5. 3SLS Elasticities

7. Discussion

Our results demonstrating the simultaneous significance of both graduate human capital inflows and regional innovation performance provide a justification for our adoption of a 3SLS approach. Our results imply that cumulative processes do operate at the regional level, in which graduate human capital flows are an input into regional knowledge - production function (Acs 2002) which may not be subject to diminishing returns (Romer 1986, 1987; Lucas 1988).

The results reported in this paper therefore represent five new findings. Firstly, our findings regarding the endogenous and cumulative mechanism linking regional human capital inflows and regional innovation performance, imply that an *inter*-regional rather than an *intra*-regional labour market explanation is required for much of the observed variation in Great Britain's regional innovation dynamism. This cumulative mechanism has not previously been empirically demonstrated, and our results are therefore novel.

Secondly, the quality of universities is only found to be of very limited important for local regional innovation performance, and any such effect appears to be restricted to high technology sectors only, and also to models including London. As such, our findings are rather different to the observations of Anselin et al (1997). On the other hand, we find that universities have very significant impacts on regional performance via the flows of their highest quality graduates into *other* regions.

Thirdly, we find no evidence of any role played by small firms in regional innovation. Our results are in stark contrast to the 'learning regions' and 'knowledge regions' literature in which small firms are a central tenet of the hypothesised innovation mechanisms.

Fourthly, population density is always negatively related to innovation performance. This result is very different to US findings (Carlino et al. 2007), but is consistent with other European observations (Simonen and McCann 2008a,b).

Fifthly, human capital inflows are more important as an explanation of regional high technology innovation performance, than for the innovation performance of all industries.

As such, our findings provide a fundamental twist on the previous arguments regarding regional high technology innovation. Ever since the seminal works of Porter (1990) and Saxenian (1994), the potential impact of interregional labour mobility on local growth has been almost entirely ignored in favour of local cluster-type or 'learning region'-type explanations (Castells and Hall 1994; Simmie 1997, 2001; Cooke 2007). Although there have been powerful analytical critiques of the local clusters arguments (Martin and Sunley 2003) and their relationships to innovation (Iammarino and McCann 2006), a broader analytical framework has yet to emerge in the literature on the geography of innovation. Interestingly, in three of the most significant books published on the subject in recent years (Fagerberg et al. 2005; Breschi and Malerba 2007; Polenske 2007), there is not a single detailed discussion of the role played by the inter-regional mobility of human capital within a country on regional innovation. On the other hand, our results suggest that explanations of the performance of 'knowledge regions' which focus primarily on local features are likely to be miss-specified. Inter-regional, rather than intra-regional human capital mobility has recently also been found to be crucial for innovation in other contexts (Simonen and McCann 2008b). As such, where universities do play a role in regional innovation, it appears to be at least as much, if not more, related to their role as nodes within a national system of student-graduate mobility (Faggian and McCann 2006). This accords with the findings of other related empirical work (Faggian and McCann 2006; McCann and Simonen 2005). As Perrons (2004) has pointed out, some high performing regions may not necessarily be 'learning regions' but rather may simply be localities which attract learned people. Our results imply that this argument is generally applicable to the regions of Great Britain.

8. Conclusions.

In this paper we have sought to identify the interrelationships between the flows of graduate human capital and the innovation performance of the regions of Great Britain. By employing a three stage least squares procedure and controlling for regional factors, our results indicate that the innovativeness of a region is one of the major factors that encourages university graduates to seek employment in that region. At the same time, inflows of highly mobile university graduates into a region also promote regional innovation, at least within England and Wales. Our findings therefore provide evidence of a regionally-specific cumulative learning process, the primary transmission mechanism of which appears to be the interregional migration flows of highly mobile university graduates. These observations imply that explanations of regional innovation performance should look much more into inter-regional rather than intra-regional explanations than has previously been the case.

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Table 1. Variable descriptions

Name	Definition
HK_POP	Number of externally domiciled and externally educated university graduates entering into the destination region for employment after graduation (repeat plus late migrants) per 100,000 of regional population (academic year 99/00)
HT_INN	Number of high technology patent applications by NUTS2 region in 2000 per million inhabitants As registered with the International Patent Office (Source: Eurostat)
ALL_INN	Number of all sectors patent applications by NUTS2 region in 2000 per million inhabitants as registered with the International Patent Office (Source: Eurostat)
ILO	ILO regional unemployment rate 1999
R_WAGE	Nominal average gross weekly salary of managerial occupations divided by the average weekly unrebated rent (as a proxy of cost of living). (Source: New Earnings Survey 2001)
CENT	Distance between the centroid of each NUTS 2 region and the centroid of London
JOBS	Total number of vacancies over the number of vacancies filled (Source: Office for National Statistics 2000)
QLIFE	Inverse of average regional crime rate (crimes against the person) in 2000 (Source: Office for National Statistics 2001)
RAESTUD	RAE quality index by NUTS 2 area calculated as: $\sum_{i=1}^{6} iX_i$ where X_i is the percentage of staff belonging to the i-th RAE category (i = 6 equals RAE 5*) in 2000 weighted by the number of students in the region (Source: Department for Education and Employment, DFEE, 2001)
SMAFIR	Percentage of regional firms with less than 50 employees in 1999 (Source: Office for National Statistics 2000)
NUNIKM2	Number of universities in the region per squared kilometer
POPDENS	Population density (NUTS2)
RDTOT	NUTS1 regional R&D expenditure in 1999 as a % of regional GDP (Source: Eurostat)
LQMA	Regional Location Quotient for Manufacturing Industry 1999 (Source: NOMIS)

Table 2. Summary statistics

	Mean	Std. Dev	Min	Max
HK_POP	19.3094	8.5368	4.3334	37.8798
HT_INN	30.4893	38.3773	3.1438	172.3022
ALL_INN	132.4177	94.0839	19.0194	440.4988
ILO	6.5877	2.2641	2.95	12.12
R_WAGE	15.3796	2.2067	12.2638	23.7714
CENT	255.8086	166.3219	0	680
JOBS	2.0874	0.3244	1.5016	2.7889
QLIFE	-9.8576	8.6641	-55.88	-2.0167
RAESTUD	33461.87	17250.43	0	77735.74
SMAFIR	0.9109	0.0247	0.8616	0.9619
NUNIKM2	0.0012	0.0025	0	0.1398
POPDENS	604.6952	945.9111	11.3741	4685.56
LQMA	1.0751	0.2545	0.5143	1.5943
RDTOT	1.838	0.8722	0.9	3.85

Table 3. 3SLS estimates: All Sectors Innovation

	Model 1: GB	**Model 2: GB without Greater London**	**Model 3: England and Wales**
Dependent variable: *HK_POP*			
Intercept	20.3268	10.2741	8.1766
	(0.152)	(0.473)	(0.569)
ALL_INN	0.0388**	0.0521***	0.0619**
	(0.043)	(0.010)	(0.018)
ILO	-1.2112**	-1.4197**	-0.7829
	(0.030)	(0.011)	(0.167)
R_WAGE	-0.7837	-0.8514*	-0.2556
	(0.123)	(0.090)	(0.685)
CENT	-0.0005	0.0112	0.0102
	(0.957)	(0.328)	(0.460)
JOBS	6.0416	6.9071	4.5518
	(0.183)	(0.128)	(0.383)
QLIFE	-0.1425	-0.8375**	-0.1231
	(0.319)	(0.031)	(0.451)
"R-squared"	***0.5002***	***0.4795***	***0.1892***
Chi2	***44.15***	***46.44***	***24.72***
p-value	***0.0000***	***0.0000***	***0.0004***
Dependent Variable *ALL_INN*			
Intercept	945.17	1086.89	258.08
	(0.220)	(0.148)	(0.772)
HK_POP	3.4502	2.8617	7.9697**
	(0.175)	(0.261)	(0.013)
RAESTUD	0.0008	0.0006	0.0008
	(0.302)	(0.443)	(0.275)
SMAFIR	-998.20	-1150.49	-390.36
	(0.223)	(0.148)	(0.679)
NUNIKM2	26858.42	34697.17	11630.06
	(0.201)	(0.320)	(0.577)
POPDENS	-0.0669	-0.0856	-0.0261
	(0.204)	(0.210)	(0.604)
LQMA	-78.9907	-74.0362	-19.0264
	(0.197)	(0.236)	(0.737)
RDTOT	51.5836**	58.8979**	31.474
	(0.062)	(0.031)	(0.310)
"R-squared"	***0.3599***	***0.3515***	***0.2717***
Chi2	***25.73***	***25.19***	***32.75***
p-value	***0.0006***	***0.0007***	***0.0000***

p-values in parentheses
***significant at 1% level
** significant at 5% level
* significant at 10% level

Table 4. 3SLS estimates: High Tech Innovation

	Model 1: GB	**Model 2: GB without Greater London**	**Model 3: England and Wales**
Dependent variable: *HK_POP*			
Intercept	22.2313*	12.0446	14.0961
	(0.093)	(0.362)	(0.312)
HT_INN	0.0994**	0.1200***	0.1315***
	(0.014)	(0.003)	(0.004)
ILO	-1.1645**	-1.3656***	-1.0355*
	(0.030)	(0.009)	(0.066)
R_WAGE	-0.7045	-0.7317*	-0.2356
	(0.123)	(0.094)	(0.706)
CENT	-0.0003	0.0111	0.0103
	(0.976)	(0.294)	(0.427)
JOBS	5.5345	6.7670*	4.3296
	(0.184)	(0.096)	(0.324)
QLIFE	-0.1092	-0.7967**	-0.1040
	(0.432)	(0.023)	(0.487)
"R-squared"	***0.5383***	***0.5453***	***0.3386***
Chi2	***46.90***	***51.94***	***26.71***
p-value	***0.0000***	***0.0000***	***0.0002***
Dependent Variable *HT_INN*			
Intercept	212.3554	266.2085	134.502
	(0.450)	(0.335)	(0.704)
HK_POP	2.0486**	1.7654*	3.0571**
	(0.027)	(0.059)	(0.015)
RAESTUD	0.0006*	0.0005	0.0006*
	(0.060)	(0.104)	(0.071)
SMAFIR	-257.244	-317.3753	-206.7831
	(0.390)	(0.279)	(0.579)
NUNIKM2	14202.21*	13251.11	11114.84
	(0.065)	(0.303)	(0.199)
POPDENS	-0.0371*	-0.03752	-0.0277
	(0.056)	(0.138)	(0.195)
LQMA	-28.6991	-25.5730	-17.8688
	(0.199)	(0.265)	(0.445)
RDTOT	16.3514	19.8611**	14.0832
	(0.102)	(0.046)	(0.233)
"R-squared"	***0.4763***	***0.4605***	***0.4180***
Chi2	***38.75***	***37.04***	***39.07***
p-value	***0.0000***	***0.0000***	***0.0000***

p-values in parentheses
***significant at 1% level
** significant at 5% level
* significant at 10% level

Table 5: Elasticities

a. All Sectors Innovation

	Model 1: GB	**Model 2: GB without Greater London**	**Model 3: England and Wales**
Dependent variable: *HK_POP*			
ALL_INN	0.2661**	0.3559**	0.3919**
Average ALL_INN	132.42	131.08	131.64
Dependent Variable *ALL_INN*			
HK_POP	0.5031	0.4194	1.2603**
Average HK_POP	19.31	19.21	20.81

b. High Tech Innovation

	Model 1: GB	**Model 2: GB without Greater London**	**Model 3: England and Wales**
Dependent variable: *HK_POP*			
HT_INN	0.1569**	0.1839*	0.2007**
Average HT_INN	30.48	29.43	31.78
Dependent Variable *HT_INN*			
HK_POP	1.2974**	1.1521***	2.0023***
Average HK_POP	19.31	19.21	20.81

***significant at 1% level
** significant at 5% level
* significant at 10% level