

Faggian, Alessandra; McCann, Philip

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Human Capital Flows and Regional Knowledge Assets: A Simultaneous Equation Approach

Alessandra Faggian and Philip McCann

Department of Economics
The University of Reading UK

Abstract

Our paper constructs a simultaneous equation model in order to investigate the relationship between interregional human capital knowledge flows and regional knowledge assets. In particular, with the aid of a GIS system, we model the simultaneous relationship between the interregional migration behaviour of UK students and graduates to and from university, the knowledge assets of the regions, and the regions of employment of the graduates. Our results indicate that the innovativeness of a region encourages university graduates to seek employment in that region. However, there is little or no evidence in favour of direct spillovers between university research and regional innovation. Rather, the primary role of universities appears to be as a conduit for bringing potential high quality undergraduate human capital into a region. Many of these migrants will remain in the university region for employment after graduation, thereby subsequently contributing to the innovative performance of the region. We argue therefore that the spillovers of embodied human capital appear far more important than informal spillovers between universities and local firms.

1. Introduction

The contribution of higher education to both individual welfare and aggregate economic growth has long been discussed from a variety of perspectives. These perspectives include, an assessment of the real private returns to investments in human capital acquired in higher education (Blundell et al. 1997), a discussion of the cost-efficient structure of a publicly funded higher education system (Johnes 1997), the problem of the how higher education is to be funded (Chapman 1997; Dolton et al. 1997), and the contribution of higher education to national development (Chatterji 1998; Blundell et al. 1999). For regional economists, however, of particular interest is the role higher education plays in fostering specifically local economic development. Over and above the local direct expenditure-employment multiplier effects of higher education (Armstrong 1993; Brownrigg 1973; Harris 1997), the local provision of education and training may also contribute to a growth in the local stock of human capital (Bradley and Taylor 1996; Bennett et al. 1995). The net flow of graduates into or from a region will indicate the extent to which a region is net recipient of newly-acquired human capital, and the greater is the net inflow of newly-acquired human capital, the greater will be the specifically local regional returns to higher education. Moreover, iff local agglomerative forces are at work, the local growth in human-capital fostered by the local higher education institutions may engender further local growth in both public and private investments. On the other hand, if no local agglomerative behaviour is evident, then many of the gains to productive capacity may be lost to other areas, dependent on the subsequent migration behaviour of the student body. Although all regions should benefit from national human-capital growth, the regional rates of return to higher education will depend crucially on the migration behaviour of the students both prior, and subsequent, to higher education.

The object of this paper is to examine how the employment migration behaviour of UK students is related to the knowledge capabilities of the region, and in

turn, to identify how the knowledge capabilities of the region are related to the higher education infrastructure of the region. In other words, our aim is to identify the contribution made by human capital migration to regional knowledge production.

In order to do this we employ data from a large survey of UK students, and with the aid of a Geographical Information System (GIS) we can identify the domicile, education and employment locations of the individual student. This allows us to observe the spatial patterns of student migration from domicile locations to higher education locations on leaving secondary school, and the subsequent spatial patterns of graduate migration from higher education to first employment. By combining information on these two migration flows with information about the knowledge and innovative capacity of the region, we can identify the role which the knowledge base of a region plays in attracting university graduates into local employment. At the same time, we are able to identify the role which the regional university system plays in fostering the growth in the local regional knowledge base. In order to do this we employ a three stage least squares simultaneous equation system. Controlling for the characteristics of UK interregional migration flows and regional labour markets, conclude that the university graduates are encouraged to remain in their region of education for employment purposes in regions where the innovative performance, quality of life and demand conditions in the region are high. At the same time, the innovative performance of the region is directly related to the number of graduates remaining the region. Meanwhile, we find that the flows of students into university is largely independent of the economic or innovative characteristics of the region. Students flows into a region depend primarily on the quality and availability of universities in a region. However, the universities appear to play no direct research or information spillover role in improving the innovative performance of the region. Rather, the local hysteresis effects associated with the production of a large locally-educated high quality graduate workforce appear to be the major regional effects of universities.

The paper is organised as follows. In the next section we will discuss the links between innovation performance and regional characteristics. These major features of these hypothesised links will inform our choice of variables in section 5. In section 3 we will outline the major features of UK interregional migration behaviour and spatial labour markets behaviour. These features will then also be controlled for in our subsequent models in section 5. Section 4 will outline the data we employ, and section 5 will explain our econometric methodology. Section 6 presents our results and section 7 provides a discussion and interpretation of our results. Section 8 ends with some conclusions.

2. Innovation and Regions

Discussions of regional growth associated with agglomeration economies are somewhat complicated by a range of alternative notions of the various ways in which cities or regions might generate economies of scale and growth. In particular, although the simple Marshallian (Marshall 1890) description of agglomeration allows for information spillovers, no discussion of the specific types of information which spills over or the specific role played by such information spillovers is provided. In response to this, a series of models have been developed which attempt to relate the role of the city or the region to the generation of particular types of information, and

also relate the role of the city or the region to the specific function of particular types of information spillovers. These models focus on the local generation within the region of information related to new ideas and techniques, under the general broad heading of 'innovation', and attempt to explain why there often appear to be systematic spatial variations in the 'knowledge base' of different regions.

Within the evolutionary economics literature (Caniels 2000), the international business literature (Cantwell and Iammarino 2003), the management science literature (Porter 1990), the literature on the economic geography of innovation (Simmie 2001; Saxenian 1994; Acs 2002; Acs et al. 2002), and the literature on new industrial areas (Scott 1988; Piore and Sabel 1984; Saxenian 1994) there has developed a widespread effort to understand the reasons for the differences in the spatial distribution of innovative activity and knowledge-based functions. For reasons of data availability, the empirical literature on innovation tends to focus primarily on innovation as measured by either patent citations (Jaffe et al. 1993) or R&D expenditure (Acz 2002), and also on mainly manufacturing innovations, with much less evidence being available concerning the service industries (Gordon and McCann 2000). Additional research, however, has also focused on the geography of creativity and entrepreneurship, in the sense of the various ways in which the knowledge assets of certain places and their characteristics appear to favour the development and commercial launching of potentially successful new or improved products, either through established or new business organisations. The emphasis of this line of research is therefore on the factors which stimulate and enable novel developments while also facilitating the selection of those with real competitive potential.

From all of these literatures there appear to be three key sets of factors which generally appear to characterise innovative regions.

(i) Firstly, innovative regions exhibiting significant regional knowledge assets tend to exhibit a rich soup of skills, ideas and technologies, as well as a permissive business and cultural environment enabling unconventional initiatives to be brought to the marketplace. Such skills, ideas and technologies are embodied both within the human capital of the region's labour force and also within the physical capital of the region's industrial base and system of firms.

(ii) Secondly, however, in order for such features to flourish, it is also necessary for innovative regions to exhibit a vigorously competitive economic environment operating selection criteria which anticipate and shape those of wider future markets. In some circumstances, particularly when the driver is patentable scientific knowledge which can be profitably produced and exploited in-house, the ideal environment for fostering innovation may be primarily that of a global business corporation. More typically, however, it is argued that the ideal environment for fostering innovation is likely to be a place with the "unique buzz, unique fizz (and) special kind of energy"¹ coupled with sufficient levels of discretionary spending power (Hall 1999).

(iii) Thirdly, the existence of specific regional knowledge assets knowledge such as local universities and research institutes is often argued to provide a reason why some regions are more innovative than others (Fischer and Varga 2002; Caniels 2000;

¹ Hall 1999, 963

Simmie 2002). The argument here, is that in regions with research universities, the local research undertaken within the universities will tend to spill over to local business via university-industry links, and also via the local generation of a skilled workforce.

From the arguments outlined in (i) and (ii) above, it is often argued that highly diversified regions, particularly associated with small and medium sized firms, tend to be the focal points of much innovative activity. These arguments would suggest that major densely populated cities exhibiting widespread urbanization economies will be ideal environments for innovation and entrepreneurial behaviour based on the prevalence of local information spillovers from local knowledge-based assets (Chinitz 1961; Duranton and Puga 2001) However, combining the argument outlined in (iii) with (i) above, also suggests that major urban centres may not be the only highly innovative and entrepreneurial regions. Due to the presence of specific types of educational and social infrastructure assets, some regions with small urban concentrations may also be ideal environments for innovation and entrepreneurial behaviour, based on the prevalence of local information spillovers.

What these literatures rarely do however, is specifically define the nature of any local information spillovers which take place, or indicate whether there will be any differences between the nature of the information spillovers which will predominate in major urban innovative centres from those which will predominate in smaller less concentrated innovative regions. This is important, because there are two ways in which the nature of the spillovers will vary according to the mechanism of the spillover. Local spillovers may be primarily informal tacit information spillovers from face-to-face conversations between employees of different firms, or alternatively they may be primarily the spillovers associated with the transfer of embodied human capital due to the local movement of employees into or between local firms.² It can safely be assumed that these are two rather different information spillover mechanisms, in that for an individual person, the potential frequency of face-to-face interaction between business executives is much greater than the potential frequency of job changes. Moreover, the transfer of employees between firms allows the recipient firm to capture all of their embodied human capital, whereas the informal tacit information spillovers will allow only limited information on certain topics to be transferred from one firm to another. In general, although the individual informal tacit information spillovers will represent smaller individual quantities of information transfer than (human-capital embodied) employment transfers, the frequency of the former will be much greater than the latter. The total quantity of information spillovers in the local economy will therefore depend both on the quantities of information which spill over in each individual information transfer and also the frequency with which such spillovers take place. What is not clear, however, is which particular type of information spillover mechanism is dominant in different types of regions.

² The first of these mechanisms corresponds to Marshall's (1890) first source of agglomeration economies, while the second of these mechanisms, corresponds to the labour pool argument, the third of Marshall's (1890) sources of agglomeration economies.

This raises the issue of the extent to which information spillover mechanisms are themselves the product of labour migration behaviour, or that the performance of regions also depends on such migration behaviour. In the case of the UK, there is evidence that localised regional learning effects may be very significantly affected by interregional flows of human capital. For example, in the buoyant London economy there are 40% more university graduates employed in London that are actually educated in London, whereas in a economically weaker northern region of Yorkshire and Humberside, there are 40% more graduates educated in Yorkshire and Humberside than are actually employed there (HMT-DTI 2003). This suggests that there are major flows of university graduates away from regions such as Yorkshire and Humberside and into regions such as London. These interregional flows of university graduate human capital therefore suggest that the migration of human capital may be a very significant form of information transfer both between regions as well as within regions.

Very little research, however, has been undertaken in order to determine the extent to which labour migration plays a role in determining the extent to which a region is a so-called 'learning region'. Some commentators have argued that local labour hysteresis in the job hiring arena may actually be a far more powerful explanation of local growth of many so-called 'learning' regions than informal tacit information spillovers (Angel 1991; Arita and McCann 2000). On the other hand, very little is known about the extent to which highly innovative regions remain highly innovative in part because of the net inflow of highly skilled and entrepreneurial workers, or whether these inflows are themselves a result of the fact that some regions are dynamic and highly innovative

The interaction between UK regional innovation performance and the migration of graduate human capital is therefore the issue on which this paper seeks to throw light. However, before we can explore this issue econometrically, it is first necessary to identify the key features of the UK's spatial labour market and migration behaviour. This is so that we 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 knowledge assets plays any systematic role which is distinct from the more general features of UK labour markets.

3. Interregional Migration and the Characteristics of UK Regional Labour Markets

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 (Hertzog 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.³ Yet, the self-selection characteristics of migrants may also influence the relationship between information, search costs and migration, with migration propensities generally being positively related to education (Schwartz 1973; Bartel 1979), previous migration (DaVanzo 1976, 1983; DaVanzo and Morrison 1981; Vanderkamp 1971), and unemployment⁴ (DaVanzo 1978) and negatively related to age (Becker 1964).⁵ 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, 1983; Graves and Linneman 1979).

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

(a) Firstly, most UK evidence supports the disequilibrium model over the equilibrium approach (Gordon and Molho 1998; Molho 1995) in that net migration flows are generally towards areas of higher nominal wages. However, although the UK consistently exhibits interregional nominal wage differences and income per household differences of the order of some 40% between the lowest and highest wage regions, and unemployment and productivity differences of over 100% of the lowest

³ However, these models do not always suggest effects which work in the same direction. For highly educated individuals the human capital model will tend to predict high migration propensities (Bartel 1979). Yet, at the same time, given that the reservation wage will depend on both the human capital characteristics of the individual, as well as attributes of local labour market which affect wage distributions, if these highly educated workers are also highly paid, the job-search model suggests that they will also incur high opportunity costs of leaving their current employment location, and thereby exhibit a lower propensity to migrate (Bartel 1979). The actual migration propensity of the individual will depend on the balance between these two effects.

⁴ The strength of the relationship between local unemployment and job-search appears to increase with the mean distance of potential moves, union membership and the severity of local cyclical downturns, and to decrease with search duration (Hertzog et al. 1993) and public-sector housing tenure (Hughes and McCormick 1981).

⁵ The relationship between migration, re-employment and the duration of the search process, however, is not entirely clear (Hertzog et al. 1985). The expansion of the search area increases the number of available jobs within a given field (Schwartz 1976) thereby reducing the time to find an acceptable wage offer. Yet, this expansion of the search area from a purely local labour market will itself increase the duration of the search process (Seater 1979). Moreover, the increase in the spatial area of the job-search will increase the expected distance of potential migration, and may thus lead to an increase in the reservation wage, thereby further prolonging the search process. Once again, the search duration and the migration propensity of the individual will depend on the balance between these different effects.

level regions (ONS 1999), UK interregional the migratory flows are too slow and weak to eliminate inter-regional wage and unemployment differentials (Armstrong and Taylor 1985; Blackaby and Manning 1990a), although they are in the correct direction according to the disequilibrium model.

(b) Secondly, although the returns to human capital do appear to vary across UK regions (Shah and Walker 1983; Hemmings 1991), the relationship between nominal and real earnings is somewhat conflicting, and if anything, is the reverse of what would be expected from the simple neo-classical adjustment mechanism. Nominal wage differentials between UK regions are only partly explained by the non-homogeneity of the labour force, although these factors become much more important when we take into account the costs of living (Blackaby and Manning 1987). Real wages for non-manual workers are about equal in the north and south for many occupations (Blackaby and Murphy 1995), whereas manual real wages are lower in the south, thereby discouraging north-south migration. At the same time, increases in regional unemployment, relative to the national average, reduce regional earnings (Blackaby and Manning 1990 a,b,c), and this effect is strengthened by the cohort of long-term unemployed, a result which is consistent with the insider-outsider model of Lindbeck and Snower (1988). Nominal UK interregional wage differences appear to reflect variations and constraints in the spatial pattern of the graduate employment opportunities, which themselves appear to be related to the rank-order of the area within the national urban hierarchy, centred around London and its hinterland (Fielding 1992, 1993). In other words, the behaviour of UK regional labour markets appears broadly inconsistent with the pure neo-classical hedonic wage model of the labour market, and appears to support a Keynesian view of spatial employment quantity constraints.⁶

(c) Thirdly, there appears to be something of a centre-periphery phenomenon in terms of UK employment. While it may be that the generation of employment opportunities is related to the position of an area within the UK urban hierarchy, the evidence on this point (Gordon and Molho 1998) implies that if any such effect is evident it is more likely to be primarily related to the performance of London and its hinterland economy. Following this argument, it appears that UK employment and migration patterns exhibit life-cycle effects according to a regional 'escalator' process (Fielding 1992, 1993; Evans 1990; Audas and McKay 1997), in which young persons are attracted to London and the south east from other regions in order to enter employment and training and only later in life move to other regions to work (Boyle 1994; Warnes and Ford 1995). Urban systems theory (Fujita et al. 1999) would suggest that this process will continue as long local agglomeration economies continue to be prevalent within the London area (Gordon and McCann 2000). This would also imply that UK inter-regional migration flows may be rather more heterogeneous across both space and time, depending on the current circumstances, than the simple centre-periphery model would suggest.

⁶ The reasons for these spatial constraints may be connected with the structure of the regulated housing market (Minford et al. 1987, 1988; Hughes and McCormick 1981, 1985, 1987) or the real wage effects of interregional house price differentials on nominal wage signals (Bover et al. 1989; Hughes and McCormick 1987) and the exacerbating impacts of the UK land-use planning system (Evans 1985). Although each of these features is likely to contribute to the particular low levels of UK interregional migration, there is as yet no clear consensus as to which of these effects is dominant (Fielding 1993).

The foregoing description of the UK labour markets suggests that UK inter-regional migration flows appear to depend primarily on the number of job-matching opportunities available in each region (Gordon 1995), relative to the number of people seeking work. 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 1992b), except where travel-to-work areas straddle more than one region (Jackman and Savouri 1992a). UK migration-location behaviour is therefore largely consistent with predictions of the human capital and search theory combination discussed earlier (Hughes and McCormick 1985) when set within a disequilibrium model of inter-regional migration, in which migration moves are also subject to the constraints imposed by spatial variations in regional employment opportunities (Gordon and Molho 1998). Moreover, these constraints in the spatial pattern of employment opportunities appear to be largely related to the dominance of the London economy within the national urban hierarchy.

We need to control for each of these particular features of UK migration and spatial labour market behaviour in the models we develop estimating the interaction between regional innovation and graduate migration behaviour.

4. The Data

Our student and graduate information comes from the HESA (Higher Education Statistics Agency) student leavers' questionnaire, and provides us with data on 190,000 students for the year 2000. The HESA survey provides us with the postcode district details of the domicile, university and first full-time employment workplace locations of each student. There are 2700 postcode districts in Great Britain⁷, and our GIS system allows us to identify the geographical centre point of each of the postcode districts and therefore to map the pattern of individual and aggregate graduate migration flows.

In order to make use of this HESA data within a general migration, human capital and innovation discussion it is 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 35 NUTS2 areas of the UK. Ideally, we would have liked to use smaller areas of analysis, but these are the smallest areas of spatial disaggregation for which all of the relevant data required is available.

In our simultaneous equation models discussed in the next section, we estimate the employment migration behaviour of graduate human capital into and out from the UK regions in the academic year 1999-2000, as a function of a range of independent explanatory variables relating to specific knowledge base indicators of the region, regional labour market indicators, industry structure indicators, quality of life indicators, and geographical indicators.

⁷ The postcode districts have an average area of 84.9 sq. km and an average population of 21162

We construct two different human capital dependent variables. Firstly, we employ a variable HK which represents the number of locally-educated university graduates who enter into full-time employment after graduation in the same region as their university. Our second human capital dependent variable is HK2, which represents the net flows of university students into a region in order to study. As we have already indicated, in some regions this net flow is negative.

Table 1 gives a brief description of the variables used in the empirical analysis.

Table 1: Variable description

Name of variable	Definition
HK	Number of locally educated university graduates remaining in their university region for employment after graduation during the academic year 1999-00
HK2	Net inflow of students into the region to study during the academic year 1999-00
INN	Number of patent applications by NUTS2 region in 1999 (Eurostat 2003) ⁸
WAGE	Average gross weekly salary of managerial occupations in each region in 2000 (NES 2003) ⁹
QLIFE	Average regional crime rate (crimes against the person) in 2000 (ONS 2003) ¹⁰
KNOW	Index of employment in knowledge-intensive services (Eurostat 2003) ¹¹
NETSTU	Net flows (in-migration minus out-migration) of university students into each region 1999-2000 (HEFCE 2003; SHEFCE 2003)
JOBS	Number of vacancies filled over total number of vacancies by region in 1999 (ONS 2003)
CENT	Distance between the centroid of each NUTS 2 region and the centroid of London
RAE1	Percentage of full academic staff belonging to RAE 1 departments by region in 2000 (HEFCE 2003; SHEFCE 2003)
RAE5	Percentage of full academic staff belonging to RAE 5 and 5* by region in 2000 (HEFCE 2003; SHEFCE 2003)
RAEIND	RAE quality index by NUTS2 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*)
SMAFIR	Percentage of regional firms with less than 50 employees in 1999 (ONS 2003)
PEER	Percentage of population with tertiary level education in each region in 1999 (Eurostat 2003)
DSCO	Dummy variable for domicile in Scotland

⁸ As registered with the International Patent Office

⁹ Data comes from NES the New Earnings Survey

¹⁰ Office for National Statistics, London

¹¹ The European Union classifies 'knowledge-intensive activities' as NACE industrial classifications 61, 62, 64-67, 70-74, 80, 85, 92.

INMIG	Total population in-migration rate in 2000 (ONS 2003)
POP	Population density per squared kilometer in 2000 (ONS 2003)
NUNI	Total number of universities in the region (HEFCE 2003; SHEFCE 2003)

The knowledge base indicators of the region are: INN, which represents the total number of patents applications made per head by each NUTS2 region in 1999; KNOW, which represents the proportion of the regional labour force employed in knowledge-intensive services, as defined by the European Union; RAE1, which represents the percentage in 2000 of full time academic staff belonging to (Research Assessment Exercise) RAE 1 graded departments within each region¹²; RAE5, which represents the percentage in 2000 of full time academic staff belonging to RAE 5 graded departments within each region; PEER, which represents the proportion of the regional population with tertiary level education.

The regional labour market indicators we employ are: WAGE, which represents the average gross weekly salary of workers in managerial occupations in each region in 2000; NETSTU, which represents the net student flow (in-migration minus out-migration) into or out of the region in order to attend university between 1999 and 2000; JOBS, which represents the total number of vacancies filled over the total number of vacancies in each region in 1999; INMIG, which represents the total population in-migration rate into each region in 2000;

The regional industry structure indicator we employ is SMAFIR, which represents the percentage of regional firms which have less than 50 employees in 1999, and the regional quality of life indicator we employ is QLIFE, which represents the average crime rate (crimes against the person) in 2000.

Finally, the regional geographical indicators we employ are: CENT, which represents the distance between the centroid of each NUTS 2 region and the centroid of London; POP, which represents the regional population density per squared kilometer in 2000; DSCO, which is a dummy variable for Scotland. Both CENT and POP can be regarded as indices of the position of the region within the UK urban hierarchy.

The data for the variables WAGE, QLIFE, POP, SMAFIR, PEER, INMIG, NETSTU, JOBS all come from the UK Office for National Statistics. The data for the variables WAGE and JOBS come from NOMIS, the UK National On-line Manpower Information System, the RAE data comes from the UK government Department for Education and Skills, and the data for the variables INN and KNOW comes from the European Union.

5. Methodology

From our HESA data of just under 190,000 UK university graduates, for each graduate we are able to identify the exact location of where a student was domiciled

¹² In the UK, a Research Assessment Exercise (RAE) ranking of 5 or 5* are the highest scores representing departments and universities producing world-class research outputs, whereas 1 is the lowest score, indicator little or no research output.

prior to entering university, where a student studied, and finally where a student entered full-time employment after graduating from university. By setting this information within a Geographical Information System MAPINFO, we are able to model the geographical flows of the students both prior to entering and after university. This allows us to identify both the retained stocks of graduate human capital within a region, and also the net flows of human capital into and out from a region.

In order to estimate the relationship between the knowledge-base of UK regions and the contribution of both the retained stocks and the net flows of graduate human capital to regional variations in these knowledge assets, in this paper we employ two different types of simultaneous equation models.

In the first simultaneous equation model, Model 1, we estimate the dynamic inter-relationships between the university region' stock of graduate human capital which is retained within the region, and the stock of the region's knowledge assets and its innovation performance.

The structural equations of the first model, Model 1, are¹³:

$$HK_i = \alpha_{0i} + \alpha_{1i}INN + \alpha_{2i}WAGE + \alpha_{3i}QLIFE + \alpha_{4i}KNOW + \alpha_{5i}NETSTU + \alpha_{6i}JOBS + \alpha_{7i}CENT + \eta_i \quad (1)$$

$$INN_i = \beta_{0i} + \beta_{1i}HK + \beta_{2i}RAE1 + \beta_{3i}RAE5 + \beta_{4i}SMAFIR + \beta_{5i}PEER + \beta_{6i}DSCO + \beta_{7i}POP + \varepsilon_i \quad (2)$$

The HK sample on which our model is based is that of 45,747 graduates migrating between 35 regions. From our discussion in section 2 of the various arguments about information spillovers and innovation, in equation (1) of Model 1 we can hypothesize that the ability of a university region to retain its locally educated university graduates HK should be a function of the level of knowledge-based activities in the region, as captured here by the variables KNOW and INN. However, following our discussion in section 3 of the characteristics of UK labour markets, we must control for the other more general features of UK regional labour markets which may influence graduate migration behaviour, represented here by WAGE, QLIFE, and JOBS. In addition from our discussion in section 3, it is also necessary to control for the centre-periphery features of UK interregional migration behaviour CENT, and also for any student immigration scale effects, represented here by NETSTU.

Simultaneously in equation (2) of Model 1, from our discussion in section 2 we can argue that the level of regional innovation INN, should be itself a function of the regional stock of locally retained knowledge assets, represented by HK, PEER, the performance of the local university sector, as represented by RAE1 and RAE5, and the importance of the small firm sector in the region SMAFIR. In addition, from our discussion in section 2, we must also control for any variations in the geographical structure and location of the region, which may influence the level of information spillovers, represented here by POP. Finally, we include a dummy variable for Scotland, DSCO, in order to see whether there any cultural or institutional differences between Scotland and the rest of the UK which may affect the ability of Scottish university regions to retain graduates in local employment.

¹³ where the subscript $i=1, \dots, 35$ identifies the NUTS2 regions in the U.K.

In the second simultaneous equation model, Model 2, we estimate the dynamic inter-relationships between the region's innovation performance, and its net inflows of students studying in the region's universities, and the stock of the region's knowledge assets.

The structural equations of the second model, Model 2, are:

$$HK2_i = \gamma_{0i} + \gamma_{1i}INN + \gamma_{2i}WAGE + \gamma_{3i}QLIFE + \gamma_{4i}NUNI + \gamma_{5i}RAEIND + \gamma_{6i}JOBS + \gamma_{7i}INMIG + \xi_i \quad (3)$$

$$INN_i = \delta_{0i} + \delta_{1i}HK2 + \delta_{2i}RAE1 + \delta_{3i}RAE5 + \delta_{4i}SMAFIR + \delta_{5i}PEER + \delta_{6i}POP + \psi_i \quad (4)$$

The HK sample on which our model is based is that of 187,474 graduates migrating between 35 regions. From our discussion in section 2 of the various arguments about information spillovers and innovation, in equation (3) of Model 2 we can hypothesize that the ability of a region to attract net inflows of university students from other regions to study locally should be a function of the number of universities in the region NUNI, plus an index of the overall performance of the regions university sector RAEIND. From our discussion in section 3, we must also control for the general features of UK interregional migration and labour market behaviour, represented here by WAGE and QLIFE, plus a scaling factor INMIG. Finally, we also include the variables JOBS and INN, which capture the dynamism of the local industry, in order to see if the dynamism of the region plays any additional role in determining the patterns of student flows into tertiary education.

Simultaneously in equation (4) of Model 2, from our discussion in section 2 we can argue that the level of regional innovation INN may itself be a function of these inflows of potential human capital, represented by HK2, plus the same knowledge base and structural assets PEER, POP, RAE1, RAE5, SMAFIR, as in equation (2) above.

The two models represented by equations (1) and (2) and equations (3) and (4) 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 if the error terms ε and η are correlated. Since there is no theoretical reason to exclude a priori the existence of such correlation in our model, we estimated our equation using three-stage least squares (3SLS). 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. 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.

6. Results

The 3SLS estimates for Model 1 are given in Tables 2a and 2b, and the 3SLS estimates for Model 2 are given in Tables 3a and 3b. In addition to the coefficient estimates, the p-values and R-squared are also given.

For Model 1 equation 1, we see that the ability of a region to retain locally-educated university graduates HK in local employment is positively related to INN, QLIFE, NETSTU and CENT, and negatively related to JOBS. The variables WAGE and KNOW are insignificant. Meanwhile, for Model 1 equation 2, we see that the innovation performance of a region INN, is positively related to HK, SMAFIR, PEER, and negatively related to RAE1 and POP. The variable RAE5 is insignificant.

Table 2: 3SLS Results
a) Equation (1) - *Dependent variable: HK*

Variable	Coefficient
Intercept	-2038.05** (0.00)
INN	60.74** (0.02)
WAGE	0.31 (0.71)
QLIFE	51.92** (0.00)
KNOW	21.88 (0.11)
NETSTU	0.08** (0.00)
JOBS	-951.74** (0.02)
DSCO	0.61 (0.66)
CENT	1.54** (0.00)
Chi squared	167.25
p-value	0.0000
R-squared	0.82

Table 2b Equation (2) - *Dependent variable: INN*

Variable	Coefficient
Intercept	-5.77 (0.71)
HK	0.002** (0.05)
RAE1	-45.93** (0.00)
RAE5	3.19 (0.17)

SMAFIR	56.82** (0.02)
PEER	0.26** (0.00)
POP	-0.001* (0.05)
<i>Chi squared</i>	25.30
<i>p-value</i>	0.0007
<i>R-squared</i>	0.38

For Model 2 equation 3, we see that the ability of a region to attract net inflows of university students into local employment HK2 is positively related to NUNI and RAEIND, and negatively related to INMIG. The variables WAGE, QLIFE, JOBS and INN are all insignificant. Meanwhile, for Model 2 equation 4, we see that the innovation performance of a region INN, is positively related to HK2, SMAFIR, PEER, and negatively related to RAE1 and POP. Once again, the variable RAE5 is insignificant.

Table 3a: 3SLS Results
Equation (3) - *Dependent variable: HK2*

Variable	Coefficient
Intercept	-2780.77 (0.75)
INN	244.57 (0.34)
NUNI	555.71** (0.03)
RAEIND	1769.00** (0.02)
INMIG	-53.69** (0.00)
WAGE	-9.41 (0.18)
QLIFE	-40.59 (0.70)
JOBS	-2630.21 (0.37)
<i>Chi squared</i>	35.20
<i>p-value</i>	0.0000
<i>R-squared</i>	0.54

Table 3b Equation (4) - *Dependent variable: INN*

Variable	Coefficient
Intercept	-33.18 (0.13)
HK2	0.001**

	(0.00)
RAE1	-57.97** (0.00)
RAE5	-0.17 (0.94)
SMAFIR	56.82** (0.02)
PEER	0.26** (0.00)
POP	-0.001* (0.05)
Chi squared	22.34
p-value	0.0010
R-squared	0.22

7. Discussion

If we consider the determinants of both the retained stocks of human capital within a region and also the net flows of human capital into a region, we see from equations (1) and (3) that in both cases, the WAGE appears insignificant. The reason for this is that the effects of wages on UK graduate migration are very complex, and appear to depend primarily on the specific spatial pattern of a student's sequential migration behaviour to and from university. Given that students exhibit a whole range of different spatial patterns in their sequential migration behaviour to and from university, the overall effect of regional wages as an indicator of migration behaviour appears to be largely cancelled out, irrespective of whether the wages are specified in nominal or real terms (McCann and Sheppard 2001).

Meanwhile, the significant explanatory factors appear to be rather different between our two different measures of regional human capital.

In the case of HK, from Model 1 equation 1, we see that the ability of a region to retain locally educated university graduates in local employment is positively related to the innovative potential INN of the region, the quality of life of the region QLIFE, the size of the net flows of students into the region NETSTU, geographic peripherality CENT of the region¹⁴, and negatively related to the weakness in the local job market JOBS. The knowledge base KNOW of the region appears to play no role, such that there is no distinction between regions with either a large or small share of knowledge based activities, in terms of their ability to retain graduate employees.

If we consider HK2, we see from Model 2 equation 3, we see that the ability of a region to attract net inflows of university students into local education is positively related to the number of universities in the region NUNI and the average research performance of the local universities RAEIND, and negatively related to the total net inflows of people into the region INMIG. The results on the first two variables suggest that regions with a large scale and high quality tertiary education sector act as

¹⁴ The positive result on CENT reflects the fact that students both domiciled and educated in many geographical peripheral areas tend to stay in these regions for employment (McCann and Sheppard 2001).

a magnet for students, irrespective of the local wage, the quality of life, the tightness of the local labour market, or the innovation performance of the region. These findings are consistent with the fact that most students choose where to study largely for reasons connected with the quality of the university, rather than on the basis of the local environmental or economic issues in the vicinity of the university. The negative sign on INMIG suggest that the only exception to this is that the congestion effects of large population inflows into a region, for example via increasing housing prices, will encourage students to move elsewhere for education.

Having controlled for both the regional retention of human capital and also the interregional flows of students, we can now also begin to reconsider the material covered in section 2, namely the issues which determine the level of innovation in the region.

From equations (2) and (4), which estimate the innovation performance of the region INN, in Model 1 and Model 2, respectively, the variables which are significant and the signs of their coefficients are almost exactly the same. In both cases, the innovation performance of the region INN, is positively related to the respective human capital variables HK or HK2, as well to both SMAFIR and PEER, and negatively related to RAE1 and POP. In both cases, the variable RAE5 is insignificant. As such, the proportion of people in the region with tertiary education, and the number of small firms do appear to contribute significantly to the region's innovation performance, as do both the retained stocks and net inflows of university graduates into the region. These findings support the general argument that a high quality local labour force, combined with a significant presence of small and medium sized firms within the local industry, will together imply that the region has a high level of innovation performance.

On the other hand, however, there is little or no evidence of local information spillovers contributing to such innovation performance. The population density variable, which we treat as a proxy for the level of urbanization economies and the position of the region within the UK urban hierarchy, is negatively related to innovation.¹⁵ Similarly, in terms of the contributions of universities to regional innovation performance, our results suggest that while the proportion of non research-active university staff appears to limit the regional innovation performance, the proportion of internationally renowned research staff appears to have no bearing whatsoever on the region's innovation performance. This suggest that in regions with universities with some level of research activity, the level of local information spillovers between these universities and local industry is not significantly affected by the quality of the university research.

Far more important than informal information spillovers between universities and local industry, appears to be the role of universities in attracting potential high quality human capital into a region in the form of undergraduate students, many of whom remain in the region of their education for employment. As such, all of the information spillover effect of universities on local regions appear to be related to

¹⁵ The negative relationship between INN and POP is consistent with the fact that much UK innovation actually takes place outside of the major cities and often in rather smaller urban centres (Simmie 2002).

issues of local labour hysteresis, in which regions with an extensive infrastructure of high quality universities tend to foster a local labour pool of skilled workers. The existence of such a skilled labour pool then contributes to the innovative performance of the region. Importantly, however, once we control for the flows of graduates between regions, there is no evidence either of a direct link between universities and local innovation performance, nor is there any evidence of a direct feedback from local innovation to the net inflows of students. All our evidence points to a direct link between the regional availability of high quality universities, and the level of inflows of students, a number of whom will subsequently remain in the region after graduation in order to enter employment in the same region, thereby contributing to the innovative performance of the region.

8. Conclusions

In this paper we have sought to identify the interrelationships between the spatial flows of student and graduate human capital and the performance of the regional knowledge base. By employing a three stage least squares procedure, our results indicate that the innovativeness of a region encourages university graduates to seek employment in that region. However, there is little or no evidence in favour of direct spillovers between university research and regional innovation. Rather, the primary role of universities appears to be as a conduit for bringing potential high quality undergraduate human capital into a region. Many of these migrants will remain in the university region for employment after graduation, thereby subsequently contributing to the innovative performance of the region. We argue therefore that the primary link between universities and regional innovation appears to be in the form of spillovers of embodied human capital, rather than informal tacit information spillovers between universities and local firms.

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