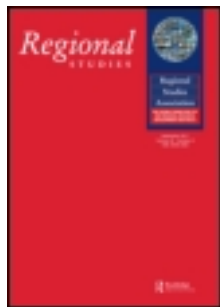


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Factors Affecting Regional Productivity and Innovation in Israel: Some Empirical Evidence

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Factors Affecting Regional Productivity and Innovation in Israel: Some Empirical Evidence

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FELSENSTEIN D. Factors affecting regional productivity and innovation in Israel: some empirical evidence, *Regional Studies*. The role of human capital and physical capital in determining regional productivity and innovation is examined. Two specific mechanisms through which knowledge becomes an inherently regional asset are investigated: the generation of local externalities (a stock mechanism) and human capital accumulation and mobility (a flow mechanism). Empirically, this connection is investigated using recent advances in spatial panel data analysis applied to regions in Israel. Panel co-integration is used to entangle issues of spurious relationships. Results show that human capital stock has large and relatively consistent effects on both regional earnings and regional innovation levels. Human capital mobility is inversely related to innovation. This is interpreted as reflecting the 'conduit' role of the region in the innovation process. Regional capital-to-labour ratios are also inversely related to innovation, implying that physical capital substitutes rather than complements human capital.

Productivity Innovation Panel data Research and development (R&D) Human capital

FELSENSTEIN D. 影响以色列的区域生产力及创新的因素：部分的经验证据，区域研究。本文检视人力资本与实质资本在决定区域生产力及创新中所扮演的角色。本文将分析使知识成为区域内资产的两个特别机制：在地外部性的产生（存量机制）以及人类资本积累与流动（流动机制）。就经验上而言，本文将使用应用至以色列区域的空间面板资料分析的近期发展，探讨此一连结。我将使用面板协整来涉入伪关系的议题。研究结果显示，人力资本存量同时对区域所得与区域创新程度而言，有着大幅且相对一致的影响。人力资本流动则反之与创新有关，此则可解释为反映区域在创新过程中所扮演的“导管”角色。区域的资本—劳动比率亦反之与创新有关，意味着实质资本取代、而非补充人力资本。

生产力 创新 面板资料 研究发展 (R&D) 人力资本

FELSENSTEIN D. Les facteurs qui influent sur la productivité et l'innovation régionales en Israël: des preuves empiriques, *Regional Studies*. On examine le rôle du capital humain et physique dans la détermination de la productivité et de l'innovation régionale. On étudie deux mécanismes spécifiques au moyen desquels la connaissance devient un atout d'envergure régionale: la production d'externalités locales (un dispositif pour développer le stock) et l'accumulation et la mobilité du capital humain (un dispositif pour développer le flux). Du point de vue empirique, on étudie cette connexion à partir des progrès récents en ce qui concerne l'analyse des données à échantillon constant spatiales appliquées à des régions en Israël. On emploie le principe de cointégration des échantillons constants pour démystifier la question des faux rapports. Les résultats laissent voir que le stock de capital humain a des effets importants et relativement constants à la fois sur le niveau des gains régionaux et sur la capacité d'innovation régionale. La mobilité du capital humain est inversement proportionnelle à l'innovation. Cela est interprété comme une réflexion du rôle de 'conduit' de la région dans le processus d'innovation. Le rapport capital/travail régional est aussi inversement proportionnel à l'innovation, ce qui laisse supposer que le capital physique se substitue au capital humain plutôt que de le compléter.

Productivité Innovation Données à échantillon constant Recherche et Développement (R et D) Capital humain

FELSENSTEIN D. Faktoren mit Auswirkung auf die regionale Produktivität und Innovation in Israel: empirische Belege, *Regional Studies*. In diesem Beitrag analysieren wir die Rolle von Humankapital und physischem Kapital für die Festlegung von regionaler Produktivität und Innovation. Hierfür untersuchen wir zwei spezifische Mechanismen, durch die Wissen zu einem inhärent regionalen Gut wird: die Erzeugung von lokalen Externalitäten (ein Bestandsmechanismus) und die Ansammlung und Mobilität von Humankapital (ein Flussmechanismus). Anschließend untersuchen wir diese Verbindung in empirischer Hinsicht unter Nutzung der aktuellen Fortschritte bei der räumlichen Paneldatenanalyse, die auf Regionen in Israel angewandt wird. Mit Hilfe einer Panel-Kointegration erfassen wir Probleme mit Scheinbeziehungen. Aus den Ergebnissen geht hervor, dass der Bestand an Humankapital einen großen und relativ gleichmäßigen Einfluss auf das regionale Einkommen und die regionale Innovation ausübt. Die Mobilität des Humankapitals steht im umgekehrten Verhältnis zur Innovation. Dies wird als Anzeichen der 'übermittelnden' Rolle der Region im Innovationsprozess interpretiert. Auch die regionalen Kapital-Arbeitskraft-Quotienten

stehen in einem umgekehrten Verhältnis zur Innovation, was darauf schließen lässt, dass das physische Kapital das Humankapital nicht ergänzt, sondern ersetzt.

Produktivität Innovation Paneldaten Forschung und Entwicklung (F&E) Humankapital

FELSENSTEIN D. Factores que afectan a la productividad regional y la innovación en Israel: algunas evidencias empíricas, *Regional Studies*. En este artículo se analiza el papel del capital humano y el capital físico a la hora de determinar la productividad y la innovación regionales. Se examinan dos mecanismos específicos a través de los cuales el conocimiento se convierte en un activo regional inherente: la generación de efectos externos locales (un mecanismo de reservas) y la acumulación y movilidad de capital humano (un mecanismo de flujo). Desde un punto de vista empírico, se analiza esta conexión mediante los recientes avances en el análisis de datos de panel espaciales aplicados a regiones en Israel. Mediante la cointegración de panel abordamos cuestiones de relaciones engañosas. Los resultados indican que las reservas de capital humano tienen efectos importantes y relativamente constantes en los salarios regionales y los niveles de innovación regional. La movilidad de capital humano está inversamente relacionada con la innovación. Esto se interpreta como un reflejo del papel 'conductor' de la región en el proceso de innovación. La relación entre el capital y la mano de obra regional también está inversamente relacionada con la innovación, lo que supone que el capital físico, en lugar de servir de complemento, sustituye al capital humano.

Productividad Innovación Datos de panel Investigación y Desarrollo (I+D) Capital humano

JEL classifications: R11, R12, R58

INTRODUCTION

This paper examines the factors driving regional productivity and innovation. Knowledge is the bedrock of innovation. Two mechanisms underpin the process by which knowledge becomes a regional asset. The first is the externality effect whereby a region embellishes its stock of knowledge based on contagion effects between workers in different places. Through the generation of externalities within a given region total factor productivity will rise, as will the average level of regional productivity. Similar workers will therefore be more productive and receive higher wages if they operate in regions with large stocks of human and physical capital externalities (RAUCH, 1993). Externality effects for physical capital can also be observed as the accumulation of capital stock increases the productivity of existing stock (CHANG, 1997; WEBER and DOMAZLICKY, 2006). The second mechanism relates to the human capital mobility effect and the way knowledge transfers to the region through the agency of individual migration decisions (SJASTAAD, 1962). Obviously innovation, productivity and human capital do not necessarily work in tandem and disentangling these interdependencies is a challenging task. This paper presents empirical evidence relating to these mechanisms and the way regional human and physical stocks are reflected in higher levels of regional wages and innovation levels.

Two classic traditions relate innovation to regional growth. The Marshallian tradition assumes local knowledge spillovers to be a central factor in the formation of agglomeration in space, supplemented by local labour pooling and non-traded local inputs (MARSHALL, 1890). The Jacobian tradition similarly sees knowledge transfer as an important input to local growth, although its source is somewhat different, emanating from outside the local production environment and grounded in

scope and diversified economic activity rather than scale and concentrated production (JACOBS, 1969).

The advent of the New Growth Theory (NGT) has highlighted the active role played by innovation in understanding regional growth (ROMER 1986, 1994). Prior to the NGT, the region was understood as the arena in which knowledge creation took place. Within this environment, tacit and implicit knowledge was produced and exchanged and the demarcation of the region expressed the territorial limits in which growth could be expected. NGT posits that growth is the result of increasing returns associated with new knowledge or technology. In contrast to previous theory, NGT internalizes (endogenizes) technological progress and knowledge into a model of how markets function. When individuals accumulate new skills and know-how they impact on the productivity and human capital levels of others. A similar effect occurs with new investment in physical capital. As such, the production of technological progress becomes endogenized. The increasing returns and spillovers from human and physical capital become the glue that holds cities and regions together. The 'region' thus progresses from being the context in which innovation takes place to a central component in this change.

The main contribution of this paper is to test hypotheses about the determination of regional productivity and the roles of human and physical capital in this process using a unique regional panel dataset. A secondary contribution is methodological. Since the data are non-stationary, recent advances in panel co-integration are used to test these hypotheses.

The paper is structured as follows. The next section examines the two specific mechanisms through which knowledge becomes an inherently regional asset. The first is a 'stock' mechanism and relates to the generation of local externalities. The second is a 'flow' mechanism and concerns human capital mobility and the individual

decisions of workers and households. While each of these issues is treated separately, their interdependence is highlighted. The paper then presents the empirical analysis that attempts to tie these notions together in a systematic framework by estimating the way the human and physical capital drive regional productivity and innovation. Previous work has shown that higher compensation is paid in cities and regions with higher levels of human and physical capital (GLAESER and MARE, 2001; WEBER and DOMAZLICKY, 2006; ECHEVERRI-CARROLL and AYALA, 2008; LOPEZ-BAZO and MOTELLON, 2012). In contrast to previous cross-sectional analyses, an attempt is made to investigate this connection using spatial panel data for Israeli regions. The dataset and its construction are described. Given the non-stationary nature of the key variables, spatial panel estimation methods are used in order to entangle issues of spurious relationships.

DRIVERS OF REGIONAL PRODUCTIVITY AND INNOVATION.

A *sine qua non* of the innovation literature is that knowledge is distributed unequally across space and that it exhibits 'sticky' properties in which it is not always easily transferable (MARKUSEN, 1996). While knowledge spillovers are unanimously recognized as agents for the generation of clusters of activity, differences exist in conceptualizing this process. The original New Economic Geography (NEG) perspective on agglomeration sees these clusters purely as a product of labour market pooling behaviour. In this growth model, firms and workers find it profitable to seek out locations where each is found in abundance (the market size effect), leading them to converge on locations that have an early lead in a particular industry (KRUGMAN, 1991). The theoretical spatial outcome of this NEG approach is the formation of exaggerated 'catastrophic' agglomerations of economic activity in a given region and the 'desertification' of activity in its vicinity. To prevent this from happening, the NEG modelling strategy introduces technical fixes that allow for the existence of workers and firms in peripheral regions. These include distributing low-wage labour across the region and manipulating transport costs to allow firms to cluster and produce under increasing returns. Whatever the cause, the logical conclusion of the NEG approach leads to over-concentration, which is only prevented via technical rather than structural reasons. Much intellectual effort has been exerted in extending the original NEG conception in order to accommodate more realistic outcomes (TABUCHI and THISSE, 2002; MURATA, 2003; NOCCO, 2009). In contrast, the NGT view is that local externalities do not just stem from market size effects or pecuniary externalities, but also from knowledge and technological externalities. Thus, while regional agglomeration is the outcome of NEG

modelling efforts, under the NGT approach regional agglomeration is an endogenously determined cause of growth (MCCANN and VAN OORT, 2009).

The place of the region in this process is also debated. FAGGIAN and MCCANN (2009a) have posited two main processes by which knowledge becomes embodied in the region and becomes part of the regional innovation infrastructure. The first relates to spatially grounded externalities that accompany the production of knowledge, and the second to human capital decisions (with respect to residential location and migration) that lead to a reallocation of production factors as people move in response to economic opportunity.

Marshallian externalities are the natural springboard for any discussion of spatial spillovers. Marshall highlighted local knowledge spillovers, non-traded local inputs and specialized local labour pools in his speculations on the causes of spatial clustering in economic activity. For Marshall:

if one man starts as idea, it is taken up by others and combined with suggestions of their own; and thus it becomes the source of further ideas.

(MARSHALL, 1920, p. 271)

In identifying the causes of agglomeration, Marshall distinguished between the roles of 'first' and 'second' nature in economic development (KRUGMAN, 1993). He saw knowledge spillovers and externalities as key second-nature determinants of external returns to scale which accounted for spatial agglomerations. Subsequently, the micro-economic foundations of local spillovers and externalities have been developed. STORPER and VENABLES (2004) have shown how face-to-face contact amongst economic agents improves coordination, increases productivity and mitigates the incentives problem, leading to spillovers and greater innovative activity. For them, it is the 'buzz' of the agglomeration (that is, the accidental and non-scheduled spillovers) that give places an edge. Several commentators point to the importance of externality effects (CHARLOT and DURANTON, 2004; FU, 2007) where important information is released randomly in both time and space leading to agglomeration as a strategic response. The more concentrated the agents, the more 'luck' in accessing information and the more rapid the diffusion and growth of this knowledge. As knowledge percolates, total factor productivity grows. Scale is an important issue here. The larger the agglomeration or the region, the greater the probability of meeting an information-rich contact so that total factor productivity will vary directly with scale. Conversely, scale may also impose a communication cost. As the agglomeration overheats, total factor productivity will become reduced.

In this externality-driven world, knowledge becomes embodied in the region through a cumulative growth process that is internally (endogenously) driven (GLAESER and MARE, 2001). The stock of regional knowledge accumulates as the level of average human

and physical capital rises and as scale increases. The regional knowledge base is not embellished on the basis of transfers or redistribution from other places (via migration) which represents regional accrual via a flow mechanism. Instead, it grows on the basis of spillovers that are spatially bounded. These are generally intense, frequent and short-term transactions that only add to the importance of proximity and territorial compactness.

The fact that knowledge has spillover effects is non-controversial. It is well accepted that knowledge generates externalities due to its public-good nature characterized by non-rivalry in consumption and non-exclusivity in production (ARROW, 1962). It is also unchallenged that the marginal cost of transmitting tacit knowledge across space diminishes as frequency of contact increases. FELDMAN (1994) has added a further twist to this logic by pointing out that proximity reduces the uncertainty and risk inherent in innovative activity. This has been formalized in empirical studies that estimate knowledge production functions with specific reference to spatial units of observation (JAFJE, 1989). From there only a short leap is needed to estimate empirically the spatial extent of innovation spillovers and the break-points beyond which spatial effects are no longer felt (ANSELIN *et al.*, 1997).

The second major theme in the regional innovation literature is the role of human capital and labour mobility in making innovation 'stick' in certain places. At a general economy-wide level, LUCAS (1988) has identified human capital as an endogenous source of economic growth. Human capital accumulation affects the productivity of the individual worker and also that of the economy as a whole. However, a key element of human capital in regional growth terms is its mobility in response to economic opportunity. This mobility can occur over short distances (commuting) or long distances (migration). The former is generally in response to short-term disequilibria between supply and demand, while the latter represents a reallocation of factors of production. In fact, neoclassical theory predicts that labour migration should lower the rate of economic growth. However, if migrants are highly skilled, their propensity to migrate will increase and their effect on the growth of their destinations will be positive (DAVANZO, 1976).

The collective behaviour of migrants is therefore a mechanism for conveying knowledge across regions through the collective decisions of migrants. The seminal work of SJASTAAD (1962) looks at migration as a human capital investment decision with both costs and returns. The utility to individual i from migrating to region j is a function of personal characteristics, such as age, family size, etc., and destination characteristics, such as wage rates, cost of living, etc. The return to personal characteristics varies by person and region. Generally, higher skilled workers will have lower costs and higher returns from migration due to lower

information costs, more perfect information, and lower psychological costs of attachment to place of origin and its social networks (DAVANZO and MORRISON, 1981). High-skilled labour expects more compensation for its investment in education and has higher expected net benefits from migration than non-skilled labour.

While labour mobility is a mechanism for raising the knowledge and innovation level of a region, confusion exists as to the exact causality of this relationship. Is the regional knowledge base the result of labour mobility or does labour move in response to regional knowledge opportunities? This in itself is tied up with the role of regions in generating human capital (that is, the 'learning region' thesis; for example, RUTTEN and BOEKEMA, 2007). As noted above, regions have traditionally been considered the territorial unit in which the exchange and production of tacit knowledge takes place and spatially based externalities then ensue. Another view, however, is that the region functions as a conduit for the flow of highly skilled and mobile labour that replaces similar sized outflows of other (skilled and non-skilled) labour (FAGGIAN and MCCANN, 2009b). This is a labour market 'churning' mechanism in which the stock of labour may not grow but its knowledge base will be continually upgraded (SCHETTKAT, 1996). Regions that include a large concentration of knowledge centres and institutions such as corporate and government research and development (R&D) centres, research universities and technological incubators are clear magnets for this kind of 'escalator' effect (FIELDING, 1992). The Greater London metropolitan region has filled this role for some time with education in the region playing a key role in the career paths of young people seeking to accumulate human capital and job experience. Over time, this skilled labour tends to disperse from the London area as their life cycle pattern changes and they can capitalize on the housing market gains and human capital accumulation that they have amassed over their period in the region. The region therefore becomes an active element in the inter-regional or even international flows of mobile labour. Other evidence shows that for generating new innovations, mobile human capital attracted from other regions is more of a potent force than locally bred human capital (SIMONEN and MCCANN, 2010).

Increasingly, human capital mobility is international and not just inter-regional. While international labour mobility movement may be too small to be detected at the economy-wide level, at the regional level there is a wealth of evidence that immigrants do have a positive effect on wages and innovation levels measured by R&D activity and patents (HUNT and GAUTHIER-LOISELLE, 2008; PISCHKE and VELLING, 1997; NIEBHUR, 2010). To test the hypothesis distinguishing between economy-wide and regional effects of human capital mobility, a suitable context needs to be chosen.

Israel provides an appropriate laboratory setting for natural experiments in this area. Mass immigration in the 1990s boosted the population by 15% and began to have an economy-wide effect in the early 2000s. At the national level evidence shows that mass immigration did not have had any adverse effect on manufacturing productivity (PASERMAN, 2008), employment or wages (FRIEDBERG, 2001). At the regional level the picture is more equivocal. BEENSTOCK and PELEG (2000) found that regional unemployment and wage rates are not sensitive to immigration. Their explanation was that in a small country like Israel, employment is sufficiently mobile between regions to diffuse the effects of immigrants in the local labour market to the national labour market.

METHOD AND DATA

Estimation strategy

The stock and flow factors influencing earnings and innovation are estimated using estimable generalized least squares (EGLS) with seemingly unrelated regressions (SUR) cross-section dependence. In the EGLS model, the error variance-covariance matrix is estimated, not assumed. As serial cross-sectional correlation is likely across the regions, applying ordinary least squares (OLS) estimation to each cross-section is inefficient. SUR weighting takes into account information about possible correlations between the errors (ZELLNER, 1962) correcting for both cross-section heteroskedasticity and contemporaneous correlation. In the present case, $N < T$ ($6 < 9$) and therefore SUR can be used. A system of equations formulated in general terms as follows therefore can be considered:

$$Y_{jt} = X_{jt}B_{jt} + e_{jt}, \quad (1)$$

$$j = 1, \dots, 6, \quad t = 1, \dots, 9$$

where Y_{jt} is an $N \times 1$ vector of observations on the dependent variable; e_{jt} is an $N \times 1$ vector of random errors with $E(e_{jt}) = 0$; X_{jt} is an $N \times n_{jt}$ matrix of observations on n_{jt} non-stochastic explanatory variables including a constant term; N is the number of observations per equation; and n_{jt} is the number of rows in the vector B_{jt} .

When estimating the above, Y_{jt} represents average annual regional earnings or innovation levels in a given year. The matrix X_{jt} denotes the human capital, physical capital and mobility variables hypothesized to be driving the dependent variables. The estimation strategy is derived from human capital theory and relates human capital, mobility, and capital stock to productivity and innovation. Specifically the focus is on knowing whether regions endowed with a larger stock of human and physical capital make for greater productivity as a positive process of cumulative

causation starts to set in. To test this proposition, productivity by average wage in the region, human capital by the educational level (average years of schooling), physical capital by the capital-labour ratio, and mobility by the share of highly educated foreign immigrants out of the total regional population are measured. Specifically, it is posited that:

$$\ln w_{jt} = \alpha_j + \theta_t + \gamma \ln k_{jt} + \delta e_{jt} + \rho m_{jt} + u_{jt} \quad (2)$$

where subscripts j and t are region and year, respectively; α and θ are the two-way fixed effects for the six regions and nine years of data; $\ln w$ is wages deflated by national consumer prices; $\ln k$ is the capital-labour ratio; e is the regional share of human capital; m is the regional share of highly educated immigrants; and μ is the residual error.

Echoing the ‘externalities’ perspective of regional growth, it is anticipated that workers of similar productivity will attain higher wages if they operate in regions with larger stocks of human and physical capital (RAUCH, 1993; WEBER and DOMAZLICKY, 2006). It is therefore hypothesized that regional productivity varies directly with human and physical capital, hence γ and $\delta > 0$. Additionally, it is expected that highly educated immigrants will have the same productivity effects as accumulated local human capital and therefore it is posited that $\rho > 0$.

Regional innovation is similarly estimated and regional productivity is added as a right-hand-side variable as follows:

$$\ln i_{jt} = \alpha_j + \theta_t + \gamma \ln k_{jt} + \delta e_{jt} + \rho m_{jt} + \tau \ln w_{jt} + u_{jt} \quad (3)$$

where $\ln i$ is innovation measured by regional expenditure on civilian R&D. The hypothesized impacts of both capital stock (γ) and human capital represented by highly skilled migrants (ρ) are more ambiguous. If physical capital substitutes for human capital in the innovation process, it is anticipated that γ will be negative. If, on the other hand, it is complementary, then γ is expected to be positive. The impacts of ρ are contingent on the perception of role of the region in generating regional innovation. If the region is hypothesized as a ‘conduit’ for human capital accumulation, ρ would not be expected to be positive. Alternatively, if the region is seen as actively enhancing human capital, ρ is likely to be positive.

The structure of the data (six regions and nine time periods) means that equations (2) and (3) call for panel data estimation. The short panel, however, limits the use of lags of greater than one year. There is also an issue of finite sample bias in small panels as raised by TAYLOR (1980). In small panels there is always a concern with serial and spatial correlation in the data

that can induce bias. A check of the residuals in the current data allays that fear. The use of nine time periods discounts the issue of asymptotics and the fact that the six regions cover the total national area prevents any spatial bias.

Given the use of panel data, non-stationarity needs to be tested.¹ The heterogeneous panel unit root test proposed by IM *et al.* (2003) (hereafter IPS, for Im, Pesaran and Shin) is used, assuming no spatial dependence between the panels in the data. This test is chosen as it allows for heterogeneity in the roots of each panel unit. Since some of the variables in equations (2) and (3) are non-stationary (see below) but are stationary in first differences, the equations are panel co-integrated if the residuals (μ) are stationary. If the residuals are not stationary, this indicates that they might be spuriously correlated and may make any assumptions about independence untenable (PHILLIPS and MOON, 1999). The equations in first differences are therefore estimated and panel co-integration is used.

Description of the regional panel data

The data used have largely been regionalized from microdata from national surveys conducted annually by the Israel Central Bureau of Statistics (CBS). Times-series for key variables are assembled by creating regional averages for data based on individual observations. The spatial units of analysis are the six districts (regions) defined by the CBS (Fig. 1). It should be noted that Israel is a small country of 7 million people and an occupied land area of about 20 000 km². As a result, Israeli regions are small and exhibit great variation in population densities. Within the regions used in this study there is an inverse relationship between physical size and population size; small regions with large populations; and the reverse for large regions. In this respect, Israel is similar to other small developed countries such as Denmark (42 300 km² and 5.3 million people), Switzerland (40 000 km² and 7.2 million people) and Belgium (30 000 km² and 10.2 million people).

Microdata from national institutional sources are used: the Household Income Surveys (HIS) for earnings and schooling; the Labor Force Survey (LFS) for calculating regional shares of highly educated immigrants; and the annual Survey of civilian R&D (RDS) for constructing a regional innovation (inputs) from firm-level data. The HIS is an annual survey of about 15 000 respondents which is conducted in conjunction with the more comprehensive annual LFS. The latter uses a rolling panel approach surveying 25 000 respondents each quarter with respondent overlaps to ensure continuity. While small sample bias can be an issue when using these data at a high level of spatial resolution (small cities, for example), at the aggregate level of the district representativeness is not an issue. The RDS is an annual survey based on the Community Innovation Survey (CIS) used in European Union and Organisation

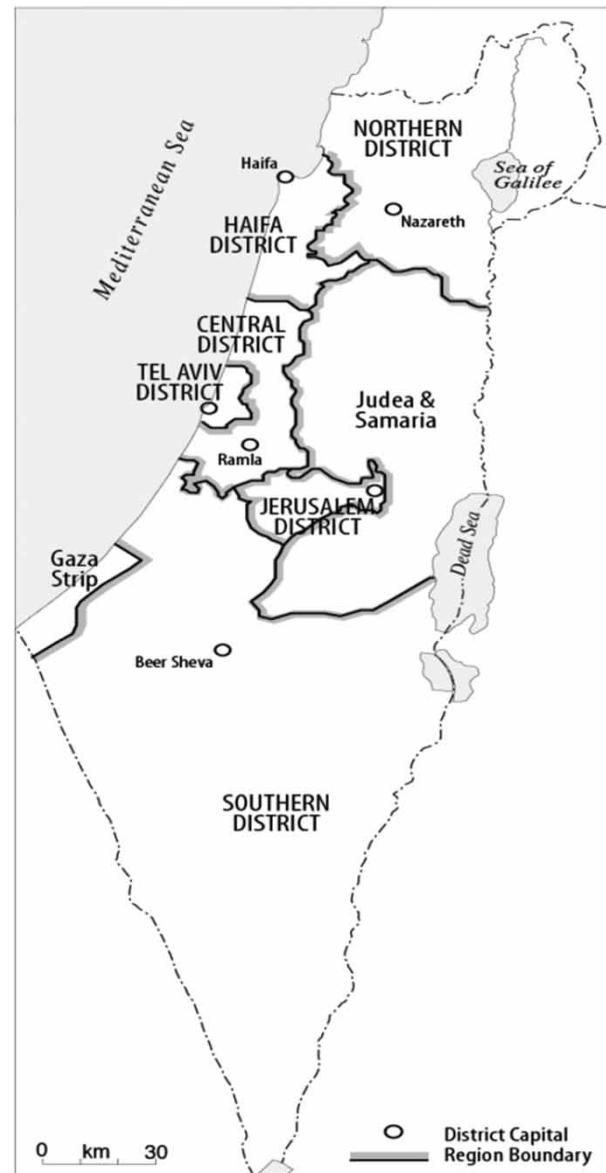


Fig. 1. Israeli regions (districts)

for Economic Co-operation and Development (OECD) countries. It samples annually some 3000 firms engaged in R&D including all the large companies (250 or more employees) and covers some 60 000 employees working in civilian R&D. Given this level of coverage, spatial bias at the district level is negligible.

The variables used and their method of construction are outlined in Table 1. HIS data yield regional averages related to real earnings (deflated by the national consumer price index) and years of education representing human capital stock. The LFS data are used to construct regional shares of highly skilled immigrants by first calculating immigrants (fewer than ten years in Israel) as a share of population and then educated immigrants as a share of all immigrants. Data on physical capital (capital-labour ratios) are constructed from recent regional estimates of capital stock reported elsewhere (BEENSTOCK *et al.*, 2011). Essentially a mixture of the

Table 1. Variables used in the analysis

Variable	Sources ^a	Method of construction
Earnings (monthly value)	HIS (CBS)	Regional totals and averages created from micro-data
Physical capital (capital-labour ratio)	BEENSTOCK <i>et al.</i> (2011), LFS (CBS)	Regional capital-labour ratios constructed from capital stock estimates (perpetual inventory and apportioning methods)
Human capital (years of schooling)	HIS (CBS)	Regional averages created from micro-data
Educated migrants (sixteen or more years of schooling)	LFS (CBS)	Regional shares created from shares of immigrants in the total population and the share of educated immigrants from all immigrants
Innovation inputs – (ln R&D expenditure)	RDS (CBS)	Regional totals created from reported firm data (special CBS data processing)

Notes: ^aHIS (CBS) is Household Income Survey (Central Bureau of Statistics), Annual Surveys 2002–2010; LFS (CBS) is Labor Force Survey (Central Bureau of Statistics), Annual Survey, 2002–2010; and RDS (CBS) is R&D Survey (Central Bureau of Statistics), Annual Survey, 2002–2010.

R&D, research and development.

perpetual inventory method for estimating regional plant values and top-down apportioning for estimating regional machinery and equipment values is used. These data represent the physical capital base of the region and reflect the region's knowledge assets, skills and technologies. For innovation levels the work of MAIRESSE and MOHNEN (2005) in using expenditure on R&D (an R&D input measure) is followed. These include costs of labour, raw materials and third-party expenditures.

To describe the regional panel data, relative regional shares for innovation, wages and capital-labour ratios along with regional percentages for years of schooling and educated immigrants are plotted (Fig. 2). Each variable portrays a very different regional pattern. Regional innovation levels (Fig. 2a) seem bifurcated with low, stable shares of R&D activity in the peripheral North and South districts and in the metropolitan regions of Haifa and Jerusalem and high sustained levels in the Central and Tel Aviv districts that function as a single labour market. With respect to regional real wages (Fig. 2b), the Central and Tel Aviv districts slightly increase shares throughout the study period. While there is some shifting in the ranks of the other regions, the overall impression is one of regional stability. The North and South regions' shares of real wages are consistently low with some negative convergence for Jerusalem from 2006 onwards.

Regional human capital is clearly non-stationary (Fig. 2c) with Jerusalem consistently top ranked over the period followed by a group of regions that comprises the Central, Tel Aviv and Haifa districts. At the other end of the spectrum, the North and South retain their rank with the former growing faster than the latter. In terms of regional physical capital (Fig. 2d), the traditional heavy industry base in Haifa has a consistently larger share of capital investment than the South and North. The latter are traditionally favoured target regions by government regional policy and publicly subsidized investment (SCHWARTZ and KEREN, 2006). However, since the mid-1980s, the map of regional

assistance has been progressively rolled back and government policy has changed its emphasis. As a result, greater weight has been placed on supporting market forces in trade policy, labour market policy, and on more selective regional assistance to R&D and incubator projects (AVNIMELECH *et al.*, 2007). Finally, the spatial choices of educated immigrants seem to reflect housing rather than economic opportunities (Fig. 2e). The popularity of the Southern district as an immigrant destination has reduced over time and flattened out since 2007. In the context of regional human capital agglomeration, this might indicate support for the 'regions-as-conduits' perspective of innovative activity, facilitating the flow of innovation embodied in highly skilled immigrants but not always enabling its accumulation.

RESULTS

Panel unit root tests

In order to show patterns of divergence/convergence, most of the variables in Fig. 2 are charted as relative shares. When these same data are plotted in levels, the variables all show clear trending tendencies. Trending variables cannot be stationary since their means and variances must grow over time. Classical statistical tests based on the normal distribution are not valid for non-stationary data. Using non-stationary data containing spatial roots can lead to spurious regression (FINGLETON, 1999), as even if variables trend together, this still does not mean they are causally related. This paper tests for panel unit roots using the IPS test (see above), which allows for heterogeneity across regions in the panel (Table 1). This is the average of the first-order augmented Dickey-Fuller (ADF) statistics for each variable in the six regions.² From Table 1 it can be seen that physical capital, human capital and innovation when measured in levels ($d = 0$) are clearly non-stationary. The values of the IPS statistics are below their critical values. When $d = 1$, all variables become difference stationary. Therefore, in order to avoid spurious

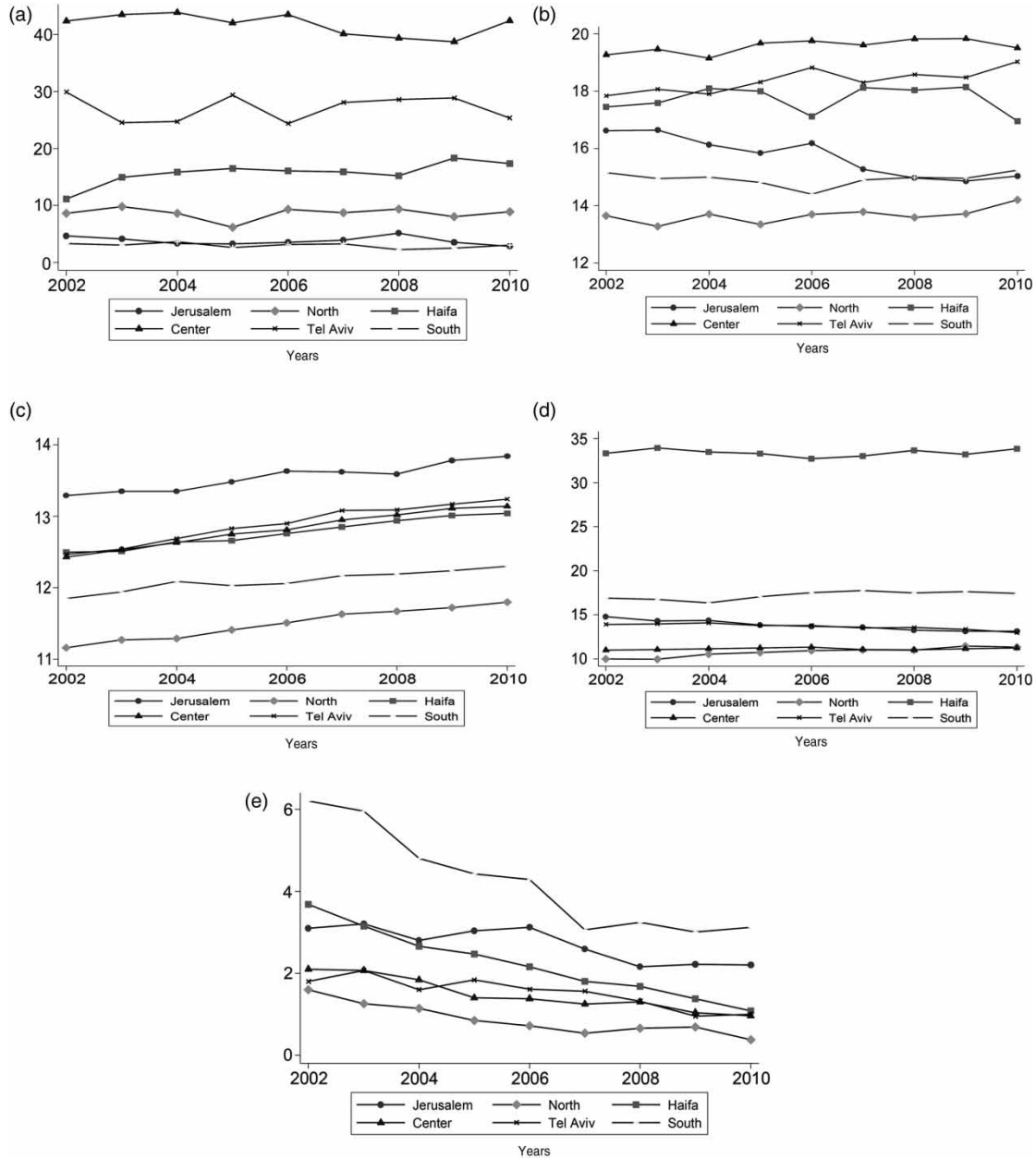


Fig. 2. Data trends over time: (a) relative regional innovation inputs (research and development (R&D) expenditure); (b) relative regional real wages; (c) regional human capital (percentage years of schooling); (d) relative regional capital-labour ratios; and (e) regional percentage of educated immigrants (out of the total population)

Table 2. Panel unit root tests

Variables	IPS statistic	
	$d = 0$	$d = 1$
Earnings (ln)	-2.473	-6.049
Physical capital (ln)	-1.706	-2.291
Human capital	-2.164	-5.520
Educated immigrants	-2.900	-5.059
Innovation inputs - (ln) R&D expenditure	-0.133	-2.298

Note: Critical value of the Im, Pesaran and Shin (IPS) statistic when $N = 6$ and $T = 9$ is -2.21 ($p < 0.05$) (Im *et al.*, 2003, p. 61).

correlation between the non-stationary variables, equations (2) and (3) need to be estimated using panel co-integration methods.

Determinants of regional productivity and innovation

Table 3 presents the panel co-integration tests for the effect of human and physical capital stocks on regional earnings. Three specifications varying in their level of heterogeneity are presented. Model 1 presents the most homogenous specification. It is estimated without

Table 3. Effect of regional human and physical capital on productivity: spatial panel regressions for Israeli regions, 2002–2010 (dependent variable = \ln earnings)

	Model 1: Homogeneity in regional human capital	Model 2: Heterogeneity in regional human capital	Model 3: Heterogeneity in regional human capital
Regional fixed effects	No	No	Yes (2.66–17.05)
Educated immigrants	0.032	0.048	0.097
Capital–labour	0.035	0.329	0.177
Human capital	0.135	–	–
Centre – human capital	–	0.773	1.894
Haifa – human capital	–	0.586	2.487
Jerusalem – human capital	–	0.633	2.600
North – human capital	–	0.676	3.093
South – human capital	–	0.605	2.849
Tel Aviv – human capital	–	0.719	1.743
Adjusted R^2	0.920	0.976	0.986
DW statistic	1.732	1.929	2.390
<i>Co-integration tests</i>			
Group ADF test	–0.354	–1.259	–1.672
Group PP test	–0.886	–1.490	–1.980

Notes: All coefficients are significant.

Values were estimated using estimable generalized least squares (EGLS) with seemingly unrelated regressions (SUR) cross-section dependence.

ADF, augmented Dickey–Fuller test; DW, Durbin–Watson statistic; PP, Phillips–Perron co-integration test (null hypotheses of no co-integration) based on PEDRONI (2004).

regional fixed effects and assumes human capital is homogenous across regions. Model 3 is the most heterogeneous where human and physical capital are assumed to vary by region and there are regional fixed effects. Model 2 represents an intermediate position. As the data are non-stationary, parameter estimates have non-standard distributions. Standard errors or t -tests for individual parameters are therefore not reported. The R^2 values are all very high and not a guide to co-integration. A better (if somewhat crude) measure is the Durbin–Watson (DW) statistic with a critical value of 1.8.

To contend with potentially spurious correlation, the determinants of regional productivity and innovation are tested using the average ADF statistic of the residuals estimated from the different cross-section units and the residual-based panel co-integration method (PP) introduced by PEDRONI (1999). This accounts for both heterogeneity induced by fixed effects and heterogeneity in the co-integrating vectors. If the estimated residuals in equations (2) and (3) are stationary, the models are panel co-integrated and the relationship between innovation, productivity and the independent variables is not spurious. These tests are suitable for studies such as the present where T is small.

Table 3 shows that the return to human capital is estimated as quite high: 13.5% for an extra year of education. The elasticity of earnings with respect to the capital–labour ratio is rather small and is estimated as 0.032 and significant. Skilled immigrants have a small and positive effect on productivity. Collectively these results might offer support for the externalities' view of regional productivity growth. However, the co-integration test statistics are far from significant³ and cannot support the contention that the non-

stationary variables are co-integrated. The DW statistic, however, does offer some support as it is close to the critical value of 1.8.

Model 2 allows human capital to vary by region but it does not specify regional fixed effects. The mobility effect of skilled immigrants grows slightly, but is still small. The elasticity of real wages with respect to the capital–labour ratio grows significantly to 0.32. When returns to human capital are allowed to vary by region, the result is large estimated coefficients ranging from 0.77 and 0.71 in the Central and Tel Aviv districts, respectively, to 0.58 and 0.60 in the Haifa and Southern districts, respectively. The DW statistic grows slightly, but the other co-integration test statistics do not indicate that the model is co-integrated and that the estimated coefficients are not spurious. This is important as the concerns that self-selection of more educated workers in the higher wage regions produces the observed productivity effect still cannot be discounted. If the non-stationary regressors in the model could be shown to be co-integrated, one could be more confident that they are not correlated with the residual (an indication of selection bias).

In the most homogenous form of estimation (model 3), both regional fixed effects are specified and human capital is also allowed to vary by region. The test statistics for panel co-integration improve (become more negative), but the DW statistic is over its critical value. The effect of immigrant human capital continues to grow, but the capital–labour parameter declines in comparison with model 2. Some of this effect may be picked up in a wide range of regional fixed effects. Human capital effects seem to change ranking in comparison with model 2. The largest effects are registered in the weaker districts (North and South). In sum, the

Table 4. *Effect of regional physical and human capital and earnings on innovation: spatial panel regressions for Israeli regions, 2002–2010 (dependent variable = ln R&D expenditure)*

	Model 1: Homogeneity in regional earnings	Model 2: Heterogeneity in regional earnings	Model 3: Heterogeneity in regional earnings
Regional fixed effects	No	No	Yes (0.324–20.67)
Immigrants	-0.093	-0.051	-0.061
Capital–labour	0.068 ⁺	-1.135	-1.181
Human capital	0.312	0.291	0.116 ⁺
Earnings	0.682	–	–
Centre – earnings	–	0.708	0.121
Haifa – earnings	–	0.759	1.122 ⁺
Jerusalem – earnings	–	0.506	-0.397 ⁺
North – earnings	–	0.555	0.033 ⁺
South – earnings	–	0.578	-1.368
Tel Aviv – earnings	–	0.697	3.175
Adjusted R ²	0.984	0.995	0.995
DW Statistic	1.92	1.95	1.99
<i>Co-integration tests</i>			
Group ADF test	-1.287	-1.604	-1.546
Group PP test	-1.491	-2.174	-2.237

Notes: All coefficients are significant $p < 0.01$, except for those marked with a ⁺.

Values were estimable using estimable generalized least squares (EGLS) with seemingly unrelated regressions (SUR) cross-section dependence.

ADF, augmented Dickey–Fuller test; DW, Durbin–Watson statistic; PP, Phillips–Perron co-integration test (null hypotheses of no co-integration) based on PEDRONI (2004).

hypothesized positive effects of human and physical capital on regional productivity are supported, but there is not unambiguous support that the residuals are stationary. Thus, there may be spurious correlation in the data-series making assumptions about independence untenable.

Table 4 shows the results relating to the drivers of regional innovation. Three specifications for the effects of human and physical capital with the addition of earnings on regional innovation are again presented. At one extreme all parameters are homogenous and there are no fixed effects (model 1). At the other, regional fixed effects are specified and earnings are assumed to vary by region (model 3). Under the most homogenous specification (model 1), the returns to education are very large whereas the human capital impact of highly skilled immigrants is negative. In addition, the homogenous earnings coefficient is also very large. In contrast, the coefficient for capital–labour is very small and non-significant. Together these results suggest inappropriate specification. The panel co-integration statistics are not significant and the DW statistic is slightly over its critical value.

When heterogeneity in regional earning is introduced into the specification (model 2), parameter effects change considerably. While the effects of highly skilled immigrants continue to be small (and negative), the physical capital effect grows dramatically and is negative and significant. The elasticity of earnings with respect to innovation ranges across the different regions with the Central, Haifa and Tel Aviv districts having the largest coefficients. The DW statistic is below its critical value and the PP co-integration test indicates that the estimated coefficients are not spurious. When the same model is estimated with regional fixed effects (model 3), the

human capital effect becomes non-significant as do some of the regional earnings coefficients. The PP co-integration test statistic improves (become more negative) and the ADF statistic remains short of its critical value. In sum, the results from models 2 and 3 provide two insights into the determinants of regional innovation. The first relates to the role of capital stock. The negative coefficient on capital–labour suggests that physical capital substitutes rather than complements human capital in the innovation process. Second, in terms of human capital flow, it is found that skilled immigrants regionally have a negative impact on innovation. This finding can be used to support the ‘conduit’ role ascribed to regions in the innovation process.

CONCLUSIONS

This paper has highlighted the role played by human capital in generating the regional knowledge base and the stock and flow mechanisms through which this human capital effect is expressed: spatial externalities and labour mobility. While there is ostensibly a causality issue in this relationship (does human capital accumulation spawn innovation or do innovative places attract skilled labour?), in reality both situations occur, and from a dynamic perspective the causation is circular.

The results have discussed whether the human and physical capital characteristics of a region contribute to productivity and innovation. This paper has tested for the possibility of spurious correlation in this relationship in that more skilled workers self-select better paying and more innovative regions. As expected, human capital has consistently large and significant effects on both

regional earning and innovation levels. In contrast, labour mobility as measured by the import of highly skilled immigrant human capital has a positive effect on productivity but a negative effect on innovation, suggesting a conduit-like function for regions in the innovation process. It has also been shown that regional physical capital is more consistent and less volatile in determining productivity than innovation, suggesting that physical capital substitutes for human capital in the innovation process. Finally, regional earnings are highest and most significant in generating innovation in the established core locations of the Israel (Tel Aviv, Central and Haifa districts), but this effect is confounded when regional fixed effects are considered.

Of the above findings, probably the most surprising relates to immigrant human capital effects. It would seem that inter-regional mobility in a small country such as Israel is strong enough to dissipate any effects of immigrants on innovation levels. Ideally, the impact of immigrants on regional economic performance would be tested in a model in which this effect was jointly determined with their location using regional house prices. As housing is an immobile (non-traded) good, this factor is likely to be much more sensitive to the regional distribution of immigrants' innovation levels. This is an extension that could be considered in future.

The results seem to indicate that while knowledge spillovers are notoriously difficult to track, it would seem that knowledge externalities are a prime source of regional productivity and innovation gains probably more so than labour market processes of migration and mobility. Thus, while one might be sceptical of much of the promotional hype that glorifies 'high-technology regions', the basic story that these accounts tell is not that far from reality. Innovative activity tends to cluster in relatively few choice regions and attract further activity. This self-entrenching process is at the base of the observed productivity and innovation premia and

makes it difficult for regions not caught up in this spiral ever to close the gap.

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NOTES

1. Because of the non-stationary nature of the data, simultaneous estimation – two-stage least squares (2SLS) – is not possible. If equations (2) and (3) are panel co-integrated, the parameter estimates are 'super consistent'. This means that if k , e and m are jointly determined with w in equation (2), these variables are asymptotically independent of u . Had the data been stationary, this would have induced inconsistency in the parameter estimates and instrumental variable (IV) estimation or generalized method of moments (GMM) would have been necessary to identify the parameters.
2. The unit root test assumes independence between regions. However, dependence between regions may be induced by common factors (such as interest rates) that affect all cross-section units and by spatial dependence such as commuting flows. Given the self-contained nature of regional labour markets in Israel, it is assumed that spatial autocorrelation is not very pronounced and the IPS test is used.
3. The more negative the statistic, the stronger the co-integration. Following PEDRONI (1999), these test statistics are transformed into the standard normal variable z with a critical value of -1.96 :

$$z_k = \frac{\sqrt{N}[S_k - E(S_k)]}{sd(S_k)} \Rightarrow N(0, 1)$$

where S_k labels the particular statistic (such as ADF, PP); and $E(S)$ and $sd(S)$ are, respectively, the expected value and standard deviation of S obtained by Monte Carlo simulation under the assumption that the panel units are independent.

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