Parallel Session 1.1. Knowledge-Based Urban Development

REGIONAL EVOLUTION AND WAVES OF GROWTH: A KNOWLEDGE-BASED PERSPECTIVE

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The evolution of a regional economy and its competitiveness capacity may involve multiple independent trajectories, through which different sets of resources and capabilities evolve together. However, there is a dearth of evidence concerning how these trends are occurring across the globe. This paper seeks to present evidence in relation to the recent development of the globe's most productive regions from the viewpoint of their growth trajectories, and the particular form of growth they are experiencing. The aim is to uncover the underlying structure of the changes in knowledge-based resources, capabilities and outputs across regions, and offer an analysis of these regions according to an uncovered set of key trends. The analysis identifies three key trends by which the economic evolution and growth patterns of these regions are differentiated—namely the Fifth Wave Growth, the Third & Fourth Wave Growth, and Government-led Third Wave Growth. Overall, spectacular knowledge-based growth of leading Chinese regions is evident, highlighting a continued shift of knowledge-based resources to Asia. In addition, a superstructure is observed at the global scale, consisting of two separate continuums that explicitly distinguish Chinese regions from the rest in terms of regional growth trajectories.

Keywords
Competitiveness, Regional Economic Development, Innovation, Knowledge-Based View

1. Introduction

The evolution of a regional economy and its competitiveness capacity may involve multiple independent trajectories, through which different sets of resources and capabilities evolve together. However, there is a dearth of evidence concerning how these trends are occurring across the globe. This paper seeks to present evidence in relation to the recent development of the globe's most productive regions from the viewpoint of their growth trajectories, and the particular form of growth they are experiencing. The aim is to uncover the underlying structure of the changes in knowledge-based resources, capabilities and outputs across regions, and offer an analysis of these regions according to an uncovered set of key trends. From these trends the paper identifies that regions are experiencing differing 'waves of growth' related to their overall economic evolution.

A number of theories, including agglomeration, industrial districts and clusters, as well as innovation systems, attempt to explain the way in which productive resources are combined and productivity is enhanced within a regional economy. In general, these concepts suggest a number of factors, such as industry and industry structure, firm type and the geographical range of external economies, to explain regional economic evolution, with them all highlighting the multiple trajectories that regions may follow in their development [1], [2], [3]. Yet, while a large number of extant empirical studies resting on these theories are informative and useful in their own right, they are not always without shortcomings in light of the aim of uncovering an underlying structure of economic evolution and development across regions. For instance, a significant number of studies are designed to account for a specific dependent variable, such as gross

domestic product (GDP) as a measure of economic output, or patents as a measure of innovation. This is typically achieved through the identification of a linear combination of other variables which maximises the proportion of the variance of the dependent variable they seek to explain. However, such accounting is different in its purpose and result from approaches which seek to identify a set of commonalities across variables. When variables represent the growth of resources, capabilities and outputs of regional innovation systems and economies, the commonalities identified across these variables may suggest processes of co-evolution across regions.

A further limitation of many extant studies is the lack of a common framework and dataset that is applicable to an analysis of regions across the globe. Empirical findings on innovation systems are typically initially generated on the basis of regions selected from a particular nation or continental bloc, rather than a fuller global coverage, resulting in a lack of harmony in terms of the frameworks employed, or the capability to provide regional comparisons that uncover regional trends across the globe [4]. This chapter seeks to go some way to overcoming this particular shortcoming by examining the globe's most productive regions. This facilitates a better understanding of the connections between knowledge-based development and the fundamentals of economic development, such as job creation, at a regional level [5], [6].

2. The Co-Evolution of Resources, Capabilities and Outputs

Based on the view of a region as an interlinked system, innovation systems theory proposes the co-evolution of its components [7], [8], [9]. However, there is little evidence concerning the key dimensions through which a region's resources, capabilities and outputs evolve together. Doloreux and Parto [4] find that studies of regional innovation systems are typically designed either to offer 'snapshots' of individual regional innovation systems, or to specify desirable factors and mechanisms for promoting innovation through a comparison of regions. Surveying approximately 200 studies of regional innovation systems, Carlsson [10] finds that slightly more than half are empirically oriented, focusing mostly on a particular region or multiple regions, with more than half of the empirical studies focusing solely on regions within Europe. A significant proportion of early studies are qualitative case studies as they aim to provide a narrative on the intangible dimension of the knowledge circulation and learning [4]. More recently, a growing body of literature takes a quantitative approach, such as a knowledge production function model, to investigate regional innovation systems [11], [12], [13], [14], [15], [16].

The aim of these studies is to account for a specific variable selected *a priori*, such as patents or GDP, and to examine the effects of variables representing innovation system characteristics. In these studies, variables are often measured only at one point in time, thus failing to show change over time. Such analyses are different in their aims and findings from approaches seeking to identify the co-evolution of the key components of regional economic systems. An exception to this is a recent study of four selected knowledge-based sectors across German regions by Buerger et al. [17], who investigate the co-evolution of patents, R&D and employment, analysing panel data for these three variables with a vector autoregression model. The study finds that past innovation growth, as measured by patents, is associated with the subsequent growth of employment in certain sectors, suggesting that, in these sectors: the employment gains of innovators are greater than the losses of non-innovators; and, the labour-saving effects of process innovations are compensated for by other positive effects resulting from these innovations. However, the study focuses on a relatively small number of variables in selected knowledge-based sectors, leaving their relationships with other less knowledge-intensive sectors unexplored. Furthermore, the study concerns regions in a single nation. This latter point of limited regional coverage is shared by most qualitative case studies examining a single or only a few regions, as well as econometric studies which examine regions in a single nation [13], in Europe [11], [12], [15], [16] or in Europe and the US [14].

There is, therefore, a gap in the literature in terms of identifying the co-evolution of regional economic system components at a global level. In order to achieve this, the analysis presented here seeks to

combine theories of knowledge production and innovation systems [11], [18], [13], [16] with the wider economic systems underlying the production of goods and services, allowing an examination of the interrelationships among these components at a regional level. In particular, the impact of knowledge-based sectors upon the rest of their regional economy is likely to be influenced by how closely the former is tied to more traditional, less knowledge-intensive economic activity within the region through knowledge spillovers, as well as through input–output linkages and the multiplier effects of demand creation [3], [15].

3. Data and Analysis

The analysis reported in this chapter covers a subset of 117 regions covered by the World Competitiveness Index of Regions (WCIR), developed by the authors of this paper, for which data are available for the 19 WCIR indicators plus GDP per capita at two time points, 2000/01 and 2010/11, or equivalent years [19]. The analysis utilises the compound annual growth rates across these two time periods. Of the 117 regions contained in the dataset there are 54 representatives from North America, 41 from Europe, and 22 from Asia and Pacific. Of the North American regions, 48 are US and 6 are Canadian. Among the Asian and Pacific regions, there are 7 Chinese regions (Taiwan is also included separately), 9 Japanese regions, and 3 Australian regions, as well as New Zealand and Singapore.

As the annual compound growth rates of the 20 indicators may overlap with one another, factor analysis is utilized to reduce the original set of variables into a smaller number of composite variables called ‘factors’. Each factor is a latent dimension underlying the original set of variables, presented as a condensed statement of the relationships between them. Furthermore, the position of a region in each dimension is given as a score called a factor score. The factors identified are orthogonal with one another and accordingly factor scores are uncorrelated across factors. With the use of the Anderson–Rubin method of estimation, factor scores have a mean of zero and a standard deviation of one. As for the extraction of factors and rotation of a factor matrix, the maximum likelihood method and the varimax method are utilized. The maximum likelihood method provides the best statistical procedure as a goodness-of-fit test of the factor model [20].

In the factor analysis, four variables—the growth rates for gross domestic product per capita, public expenditures on primary and secondary education, secure servers, and broadband access—are dropped as they are found to conform to Heywood case variables. In factor analysis, the variance of each variable is divided into the variable’s unique variance and the rest explained by latent factors. A Heywood case refers to the appearance of a negative estimate of the unique variance or the convergence of an estimate to zero, which is practically implausible. This computational anomaly often arises from the presence of one or more high correlations of variables and the attempt to extract more factors than are present [21, p. 62–63].

After these variables are removed, a reliable set of factors is obtained using the Schwarz [22] method to determine the number of factors. A goodness-of-fit test of the factor model obtains the chi-squared value of 196.06 and the significance value of 0.00, showing a highly satisfactory level. Utilising the factor score of each region, cluster analysis is then undertaken to establish a grouping of regions. Cluster analysis is the most commonly used technique for identifying groups of homogeneous objects within the population. This is achieved by maximising the homogeneity of objects within the clusters, while also maximising the heterogeneity between the clusters. Similarity between regions is defined by the Euclidian distance using their factors scores as co-ordinates. For a hierarchical clustering algorithm the average linkage procedure is adopted. The number of clusters is decided by examining changes in the agglomerative coefficients [23].

4. Growth Rates

The average growth rates of 117 regions for the 20 indicators and their averages by nation or continental bloc—the US, Europe, Canada, Australia, Japan, and China—are shown in Table 1. When the averages of 117 regions are examined, per capita gross domestic product hits an annual growth rate of 4.18 per cent. The majority of this growth comes from the growth of labour productivity, which shows an annual growth of 2.95 per cent, whilst the rest derives from the growth of labour force participation relative to the total population. Economic activity rates grew at an annual rate of 1.25 per cent. In contrast, the employment rate dropped by 0.24 per cent on average. Thanks to the growth of labour productivity, mean gross monthly earnings grew at an annual rate of 5.67 per cent. However, the number of managers per 1,000 employees declined by 1.30 per cent annually, most likely due to the reduction of middle managers through the delayering of corporate hierarchies.

In terms of knowledge creation, the number of patents registered per 1,000 inhabitants grew by 11.39 per cent annually, which is an indication of a number of factors including changes made in the regime of patenting in the 1990s and tactics of patent harvesting employed by a growing number of corporations, as well as a deepening of the knowledge economy. As for the inputs of knowledge creation, per capita expenditures on R&D performed by government dropped by 9.20 per cent annually, reflecting recent austerity measures taken by governments in many nations and regions. By contrast, per capita expenditures on R&D performed by business continued to grow, with an average annual growth rate of 7.13 per cent.

Changes in employment in high-technology industries vary significantly across the five sectors examined. The growth of employment in instrumentation and electrical machinery was the fastest, showing an annual growth rate of 4.78 per cent, followed by 2.77 per cent for high-tech services. By contrast, the other three sectors exhibit a decline in their employment per 1,000 employees. IT and computer manufacturing was hit the hardest with a decline of 5.55 per cent annually. This was followed by biotech and chemicals which declined by 2.05 per cent and automotive and mechanical engineering by 0.53 per cent.

As for public educational expenditures per inhabitant, expenditures on higher education grew by 5.75 per cent, whilst expenditures on primary and secondary education showed a more modest growth of 2.77 per cent annually. The amount of private equity investment, or venture capital, per inhabitant grew by 12.71 per cent annually, second only to the three ICT infrastructure indicators—Internet hosts, secure servers, and broadband access—which showed the fastest rates of growth, 39.44 per cent, 42.55 per cent, and 21.47 per cent respectively.

Table 1 Average compound annual growth rates of 20 variables from 2000/01 to 2010/11 or equivalent (percentage)

	US regions	Canadian regions	European regions	Australian regions	Japanese regions	Chinese regions	All regions
Gross domestic product per inhabitant	3.64	4.18	4.15	4.35	3.66	7.60	4.18
Labour productivity	2.39	2.63	3.46	3.07	1.88	4.89	2.95
Mean gross monthly earnings	7.20	4.68	5.53	1.62	6.97	–2.40	5.67
Economic activity rate	0.99	–0.04	0.21	0.42	1.92	10.09	1.25
Employment rate	–0.50	0.04	–0.15	0.14	0.07	0.06	–0.24
Number of managers per 1,000 employees	–2.57	–6.52	2.00	5.17	–1.32	–11.89	–1.30
Number of patents registered per one million inhabitants	2.00	5.09	10.78	13.66	26.88	59.84	11.39
Per capita expenditures on R&D performed by Government	–30.31	–9.17	8.41	–1.22	13.95	–7.13	–9.20
Per capita expenditures on R&D performed by Business	6.43	5.51	5.63	19.93	5.97	15.14	7.13
Employment in Instrumentation and Electrical Machinery per 1,000 employees	–5.79	0.70	17.22	–0.81	–1.72	19.13	4.78
Employment in Automotive and Mechanical Engineering per 1,000 employees	–8.49	–4.96	6.54	3.65	–2.13	16.60	–0.53
Employment in Biotech & Chemicals per 1,000 employees	–4.07	0.90	–1.40	–12.50	–1.50	10.67	–2.05
Employment in IT and Computer Manufacturing per 1,000 employees	–9.66	–20.94	–3.90	0.44	–2.82	16.64	–5.55
Employment in High-Tech Services per 1,000 employees	–0.72	4.97	2.25	14.50	–2.31	29.17	2.77
Per capita public Expenditures on Primary and Secondary Education	7.36	2.69	6.23	6.91	–5.34	7.18	5.75
Per capita public Expenditures on Higher Education	8.03	11.24	6.17	5.22	2.56	35.78	8.76
Venture Capital ($ per capita)	–9.72	5.38	8.14	36.41	2.59	193.05	12.71
Internet Hosts per 1000 inhabitants	10.45	15.80	31.11	27.07	27.90	337.03	39.44
Secure Servers per 1,000,000 inhabitants	15.70	18.76	35.19	27.84	28.96	317.60	42.55
Broadband Access per 1000 inhabitants	19.12	12.75	24.69	26.14	12.66	37.98	21.47

Against this overall picture, regions in the US, Europe, Canada, Australia, Japan, and China present differentiated patterns of growth. In terms of per capita GDP, the growth performance of Chinese regions is spectacular with an average rate of 7.60 per cent, which is in stark contrast to the rest of the regions analysed. Five Chinese regions—Beijing, Jiangsu, Tianjin, Shandong, and Guangdong— are in the top 10 of the fastest growing economies along with Singapore, British Columbia, Bratislavsky, Ontario, and Estonia. In contrast, regions in the US, Canada, Europe, Australia, and Japan on average grew at nearly half of the average rate achieved by Chinese regions. The slowest-growing regions are predominantly US, with six regions (Buffalo-Niagara Falls, Rochester, Grand Rapids-Wyoming, Richmond, Louisville, and Sacramento—Arden-Arcade—Roseville) ranking in the bottom 10, along with Alberta, Quebec,

Saskatchewan, and Emilia-Romagna. Of these, Buffalo-Niagara Falls, Rochester, and Alberta have shown a fall in per capita GDP.

5. Productivity, Earnings, and Activity Rates

Labour productivity growth has also been most pronounced among Chinese regions, showing an average rate of 4.89 per cent. However, the gaps with the rest of the regions and particularly European regions are smaller than the gaps observed in per capita GDP growth. This is in large part due to a significant proportion of GDP growth in Chinese regions deriving from the inflow of labour from other parts of the nation, which is shown in the fast pace of growth in Chinese economic participation rates. Of the rest of the regions analysed, European and Australian regions have shown relatively fast growth rates, whilst Japanese regions showed the slowest pace. The fastest rate of labour productivity growth was recorded by Bratislavsky and Praha, two East European regions, with the rest of the top 10 regions consisting of Tianjin, Région de Bruxelles-Capitale, Singapore, London, Beijing, Shandong, Tokyo, and Estonia. By contrast, the bottom 10 regions include seven US regions (Buffalo-Niagara Falls, Rochester, Hartford-West Hartford-East Hartford, Richmond, Grand Rapids-Wyoming, San Antonio, and Sacramento—Arden-Arcade—Roseville), two Dutch regions (Noord-Nederland and Zuid-Nederland), and one Japanese region (Kanagawa).

Earnings growth shows a significantly different pattern from those of per capita GDP and labour productivity growth. The Chinese regions have experienced a decline by 2.40 per cent annually, whilst the other nations or continental blocs have shown a positive growth on average, with the US and Japanese regions in particular showing a strong performance. Latvia and Estonia are the best performers in this indicator, followed by five US regions (Salt Lake City, Houston-Sugar Land-Baytown, Nashville-Davidson—Murfreesboro, Milwaukee-Waukesha-West Allis, and Virginia Beach-Norfolk-Newport News), two Japanese regions (Kanagawa and Kyoto), and Etelä-Suomi. The bottom 10 regions are dominated by Chinese regions (Beijing, Guangdong, Tianjin, Shanghai, and Zhejing), along with Israel, Taiwan, Sydsverige (Sweden), and two Australian regions (Victoria and New South Wales).

Changes observed in economic activity rates are relatively small with the exception of the Chinese regions. As mentioned earlier, the strong performance of the Chinese regions in GDP growth comes from the influx of labour force into the regions from others part of the nation, leading to a significant increase in economic activity rates in these regions. All seven Chinese regions are ranked in the top 10, followed by three US regions (Virginia Beach-Norfolk-Newport News, Miami-Fort Lauderdale-Miami Beach, and San Antonio). The Canadian and European regions are weak performers on average in this indicator.

Of the 117 regions analysed, 20 regions suffered a fall in economic activity rate, with a great majority of them being located in Europe and Canada. In particular, six regions in the Nordic nations (Västsverige, Stockholm, Småland med Öarna, and Sydsverige in Sweden, Etelä-Suomi in Finland, and Norway) rank in the bottom 10 regions, along with Ontario and three US regions (Cleveland-Elyria-Mentor, Salt Lake City, and Milwaukee-Waukesha-West Allis).

Across the 20 indicators, employment rates shows the smallest change in percentage terms. The annual rate of change ranges from 0.14 per cent in the Australian regions to –0.50 per cent in the US regions. The largest improvement in this indicator is made by Israel (0.55 per cent), with Berlin (0.52 per cent) and Bratislavsky (0.34 per cent) being the second and third best performers. They are followed by Singapore, Schleswig-Holstein, Quebec, Osaka, Niedersachsen, Zhejing, and Western (Australia). The bottom 10 regions on this indicator are seven US regions (Las Vegas-Paradise, Detroit-Warren-Livonia, Sacramento—Arden-Arcade—Roseville, Tampa-St. Petersburg-Clearwater, Hartford-West Hartford-East Hartford, Charlotte-Gastonia-Concord, and Jacksonville), two Spanish regions (Comunidad de Madrid and Noreste), and Southern and Eastern in Ireland. Las Vegas-Paradise, Comunidad de Madrid, and Southern and Eastern (Ireland) suffered an annual rate lower than –1.00 per cent.

6. Human Capital and Innovation

The number of managers per 1,000 employees is another indicator in which the Chinese regions showed the weakest performance. On average, the Chinese regions showed the biggest fall on this indicator, followed by the Canadian, US, and Japanese regions. The fall in the Chinese regions is most likely due to the massive inflow of labour force across regions, which filled newly-created low-level, non-managerial positions. By contrast, the fall in the Canadian, US, and Japanese regions appears to derive from the flattening of corporate organisational hierarchies, which cut back middle management positions. Against the trend, the European and Australian regions exhibit an increase overall, with the top 10 regions being predominantly European, including Saarland, Schleswig-Holstein, Nordrhein-Westfalen, and Niedersachsen in Germany, Lazio and Emilia-Romagna in Italy, Småland med Öarna (Sweden), Switzerland, Région de Bruxelles-Capitale, and Lithuania. The bottom 10 regions include four Chinese regions (Tianjin, Shanghai, Guangdong, and Jiangsu) along with West-Nederland, Bratislavsky, Közép-Magyarország, Île de France, and Noreste and Comunidad de Madrid.

Growth rates for patent registrations show that Chinese regions have seen the greatest improvement. The fastest ten growth rates include seven Chinese regions, followed by three Japanese regions, Aichi, Toyama, and Tochigi. In contrast, North American regions, on average, achieved the slowest growth. With the exception of London, which suffered the fastest pace of decline (–3.72 per cent), the bottom 10 regions are dominated by North American regions, including Memphis, Nashville-Davidson—Murfreesboro, Indianapolis, Columbus, Cincinnati-Middletown, Cleveland-Elyria-Mentor, and Milwaukee-Waukesha-West Allis in the US, and Manitoba and British Columbia in Canada, all of which have seen a fall on this indicator.

In terms of R&D expenditures, those regions in receipt of the biggest increases in R&D expenditures performed by government are regions in Japan and Europe. The top three regions are Swedish (Småland med Öarna, Sydsverige, and Västsverige), followed by four Japanese regions (Shiga, Kyoto, Toyama, and Shizuoka), Zuid-Nederland in Netherlands, Noreste in Spain, and Singapore. Conversely, US, Canadian, and Australian regions have seen a dilution of government R&D investment. In particular, the drop in government R&D investment was high in the US regions, which occupy the bottom 10 positions (Hartford-West Hartford-East Hartford, Kansas City, Buffalo-Niagara Falls, Rochester, Minneapolis-St. Paul-Bloomington, St. Louis, Pittsburgh, Seattle-Tacoma-Bellevue, Louisville, and Las Vegas-Paradise).

As for R&D investment by businesses, the Australian and Chinese regions have seen by far the strongest growth on the whole, with the biggest growth occurring in Western and Victoria in the former, and Shandong, Jiangsu, Zhejing, and Tianjin in the latter. The other top 10 regions are Estonia, Singapore, Raleigh-Cary, and Alberta. Of the 117 regions, eight regions have seen a drop in business R&D investment, including Baltimore-Towson and Seattle-Tacoma-Bellevue in the US, Ontario and Manitoba in Canada, Kanagawa and Osaka in Japan, Bratislavsky in Slovak Republic, and Beijing in China. Västsverige and Stockholm in Sweden are the other two in the bottom 10 regions, showing a marginal increase.

7. Industrial Development

As shown by Table 1, there is significant volatility in employment change across the so-called knowledge-based sectors. In instrumentation and electrical machinery, Chinese and European regions have seen strong growth, with the top 10 spots occupied by Jiangsu, Zhejing, and Shandong (China), Estonia, Ostösterreich (Austria), Lazio (Italy), Stockholm (Sweden), Région de Bruxelles-Capitale (Belgium), Etelä-Suomi (Finland), and Zuid-Nederland (Netherlands). In contrast, a significant proportion of US and Japanese regions have seen a decline in these sectors. With the exception of Switzerland, all the bottom 10 regions are located in the US, including Memphis, Louisville, Baltimore-Towson, Nashville-Davidson—Murfreesboro, St. Louis, Atlanta-Sandy Springs-Marietta, Charlotte-Gastonia-Concord, San Antonio, and Kansas City.

In automotive and mechanical engineering sector, a majority of the regions have seen a decline of employment as a proportion of total employment. Those regions showing a growth are predominantly European and Chinese, with the top 10 regions including Zhejing, Jiangsu, Shandong, and Guangdong in China, as well as Bratislavsky, Stockholm, Västsverige, Région de Bruxelles-Capitale, Saarland, and Norway. As for the regions which have been hit hardest, Beijing is the worst with an annual change of –23.54 per cent. Aside from the Chinese capital, those regions suffering the fastest pace of decline are predominantly US, including Washington-Arlington-Alexandria, Nashville-Davidson—Murfreesboro, Louisville, Atlanta-Sandy Springs-Marietta, St. Louis, San Jose-Sunnyvale-Santa Clara, Columbus, Buffalo-Niagara Falls, and Kansas City.

In a similar vein, less than one third of the regions have seen a growth of employment in biotechnology and chemicals. Chinese regions are best performers in the sectors, with Jiangsu, Shandong, Zhejing, and Guangdong ranking in the top 10. Canadian regions also gain in these sectors, with Saskatchewan and Manitoba in the top 10 positions. Although the average of the US and European regions is negative, some have performed well, with Région de Bruxelles-Capitale, Saarland, Minneapolis-St. Paul-Bloomington, and Île de France occupying the other top 10 spots. Of those regions which have seen a fall of employment in the sectors, the worst 10 include seven US regions (Richmond, Virginia Beach-Norfolk-Newport News, Charlotte-Gastonia-Concord, Columbus, Nashville-Davidson—Murfreesboro, Rochester, and San Antonio), two Australian (New South Wales and Victoria), and New Zealand.

As mentioned earlier, of the five knowledge-based sectors, IT and computer manufacturing was hit hardest in terms of the share of employment, with only 24 regions showing positive growth rates. Regions in China gained most, which gives a strong indication of the extent to which employment has become increasingly concentrated in key locations. The top 10 regions include four Chinese regions (Jiangsu, Shandong, Zhejing, and Guangdong) along with Jacksonville and Louisville, Saarland, Switzerland, Taiwan, and Praha. Over 30 regions have witnessed a double-digit fall of employment share in percentage terms annually. Of these, those hit hardest include Virginia Beach-Norfolk-Newport News, Nashville-Davidson—Murfreesboro, Baltimore-Towson, Sacramento—Arden-Arcade—Roseville, Charlotte-Gastonia-Concord, Houston-Sugar Land-Baytown, and San Antonio in the US, as well as Saskatchewan, Manitoba, and Zuid-Nederland.

As for high-tech services, the regions analysed are relatively evenly split into those 57 regions which have gained and those 60 which have lost in terms of employment share. The pattern is somewhat surprising, as one might expect a more widely spread growth resulting from the increased deindustrialisation of advanced regional economies. However, the growth in the offshoring of high-technology services in many advanced regions appears to have dampened employment growth. Of the former group, 13 regions have made a double-digit growth annually. The top 10 includes five Chinese regions (Zhejing, Shandong, Tianjin, Shanghai, and Guangdong) and three Australian regions (New South Wales, Western, and Victoria), as well as Région de Bruxelles-Capitale and Switzerland. The worst performing regions are Vlaams Gewest, Shiga, and Kanagawa, followed by two Dutch regions (Noord-Nederland and West-Nederland), four US regions (Chicago-Naperville-Joliet, San Antonio, Atlanta-Sandy Springs-Marietta, and Houston-Sugar Land-Baytown), and Lombardia.

8. Knowledge Sustainability and Finance

In terms of growth in public expenditure on primary and secondary education, the great majority of the analysed regions recorded an increase, led by Irish, Chinese, and US regions. The top 10 regions include Southern and Eastern (Ireland), Shandong, Jiangsu, Zhejing, Orlando-Kissimmee, Washington-Arlington-Alexandria, Phoenix-Mesa-Scottsdale, and Las Vegas-Paradise, as well as Latvia and Singapore, which all have recorded double-digit annual growth rates. By contrast, only 12 regions have seen a fall in this indicator, including three Chinese regions (Beijing, Tianjin, and Guangdong) and all nine Japanese regions analysed. In a similar vein, except for five regions, all analysed regions recorded an increase in

the expenditure on higher education. The fastest growths have been shown by Chinese and Canadian regions, with all seven Chinese regions and Ontario ranking in the top 10, along with Southern and Eastern (Ireland) and Praha. As for those regions experiencing falls in expenditure, they include Buffalo-Niagara Falls, Rochester, Scotland, Israel, and Latvia. These regions are followed by Switzerland, New York-Northern New Jersey-Long Island, Seattle-Tacoma-Bellevue, Westösterreich (Australia), and Emilia-Romagna, which have shown a marginal increase in expenditure. Growth in private equity investment shows a significant contrast between Chinese regions and US regions. It is clear that the biggest growth has occurred in Chinese regions, which occupy the top 7 spots in the rankings, followed by Taiwan, New South Wales, and Victoria in Australia. In the US, the traditional heartland of venture capital, most regions have seen a fall in levels of such capital investment. Of the all regions analysed, 30 regions have shown a double-digit decline in percentage terms, with only two regions (Latvia and Bratislavsky) being outside the US. Those US regions which have seen the largest falls include Hartford-West Hartford-East Hartford, Louisville, Orlando-Kissimmee, Jacksonville, Tampa-St. Petersburg-Clearwater, Miami-Fort Lauderdale-Miami Beach, Memphis, Phoenix-Mesa-Scottsdale, Milwaukee-Waukesha-West Allis, and Las Vegas-Paradise.

Finally, for the three ICT infrastructure indicators, Chinese regions have made the greatest strides in ICT development. In particular, the Chinese regions have achieved a three-digit growth in percentage terms in Internet host per capita and secure servers per capita, dominating the top 10 rankings. They are followed by Bratislavsky, Praha, and Lithuania in the growth of Internet hosts, and by Bratislavsky, Praha, and Taiwan in the growth of secure servers. European, Australian, and Japanese regions have shown a modest growth in both Internet hosts and secure servers, occupying middle positions in the rankings. In contrast, US and Canadian regions lag behind in the pace of their development. The bottom 10 regions include two Canadian regions (Manitoba and Saskatchewan) and eight US regions (San Antonio, Buffalo-Niagara Falls, Tampa-St. Petersburg-Clearwater, Grand Rapids-Wyoming, Rochester, Detroit-Warren-Livonia, Jacksonville, and Louisville).

The growth of broadband access is led by the Chinese regions, although their rates of growth are more comparable with those shown by European and Australian regions. The top 10 spots are populated by Chinese and European (mostly East European) regions, including Beijing, Shanghai, Guangdong, and Zhejing in China, and Bratislavsky, Praha, Southern and Eastern (Ireland), Közép-Magyarország, and Lithuania in Europe, as well as Ontario. In Europe, Swedish regions are anomalies to this trend, with Småland med Öarna, Sydsverige, and Västsverige occupying three of the bottom 10 spots. In addition, Japanese and Canadian regions have shown weak growth in the diffusion of broadband access. Aside from the three Swedish regions, Manitoba, Saskatchewan, Kanagawa, and Kyoto enter the list of the bottom 10 regions. Taiwan, Israel, and Singapore are also in the bottom 10 list.

9. Waves of Growth: Factor Analysis

Utilising the results of the factor analysis, the original variables are reduced to three factors, each of which represents a unique combination of the original variables. The three identified factors explain 64.50 per cent of the total variance, a satisfactory level, given the fact that more than 100 regions are included, with the subsequent analysis focusing on those variables with a loading greater than ±0.40 [20].

Table 2 Factor loadings of the variables

	1 (Fifth Wave Growth)	2 (Third and Fourth Wave Growth)	3 (Government-led Third Wave Growth)
Labour productivity	0.20	0.22	0.20
Mean gross monthly earnings	***–0.69***	0.11	–0.24
Economic activity rate	***0.80***	***0.45***	–0.18
Employment rate	0.20	0.14	***0.52***
Number of managers per 1000 employees	–0.33	–0.11	0.33
Number of patents registered per one million inhabitants	***0.65***	***0.53***	0.20
Per capita expenditures on R&D performed by Government	0.00	0.12	***0.73***
Per capita expenditures on R&D performed by Business	0.22	0.34	0.03
Employment in Instrumentation and Electrical Machinery per 1000 employees	0.06	***0.54***	***0.64***
Employment in Automotive and Mechanical Engineering per 1000 employees	0.12	***0.68***	***0.60***
Employment in Biotech & Chemicals per 1000 employees	0.12	***0.75***	0.11
Employment in IT and Computer Manufacturing per 1000 employees	0.29	***0.50***	0.21
Employment in High Tech Services per 1000 employees	***0.57***	0.36	0.21
Per capita public Expenditures on Higher Education	***0.73***	0.36	–0.15
Venture Capital ($ per capita)	***0.93***	0.13	0.19
Internet Hosts per 1000 inhabitants	***0.90***	***0.42***	0.08

Note: Factor loadings greater than 0.40 are shown in bold and italics.

As shown by Table 2, Factor 1 indicates a close association between the growth of high-tech services employment, Internet hosts, venture capital, patent registration, and public expenditures on higher education. Growth in economic activity rates and falls in mean gross monthly earnings rates are also significantly loaded on this factor. This factor is labelled 'Fifth Wave Growth' as it indicates a close association between ICT-based service growth, growth in knowledge outputs, and growth in key knowledge-based investments.

Based on Nikolai Kondratieff's work [24], [25] on the cycle of major economic crises at approximately half-century intervals, Joseph Schumpeter [26] wrote that each of the 'long waves' of economic development started with a new group of innovations, which resulted in the creation of new industries. According to this long wave theory, the first Kondratieff wave was based on iron and cotton industries, spanning the period of 1785–1842. This is followed by the second wave (1843–1897) with steel, machine tools, and ships as its key industries. The twentieth century includes two waves: the third wave (1896–1947) based on automotive, electrical engineering, and chemicals; and the fourth wave (1948–) for which growth was propelled by electronics, computers, communications, aerospace, and producer services [27]. Whilst the timing of the fourth wave's end and the fifth wave's beginning remains open to debate, ranging from the early 1990s to around the turn of the century, there is much agreement as to the central role played by

digital revolution and the Internet as the enabling innovation underpinning the fifth wave, creating a large increase in informational service jobs, as well as a demand for new infrastructural network development [27], [28], [29], [30].

The close association identified between employment in high-tech services and Internet hosts, as well as private equity investment capital, signifies the newest wave of economic development. Furthermore, the factor's association with patents, which is found to grow during an upswing of a long wave [31], further strengthens its representation as a fifth wave. Of course, our analysis cannot be said to infer causality, but at an exploratory level it does suggest that across this cohort of leading regions in both established and emerging economies the trajectory of knowledge-based service sectors and patents generally moves in the same direction as growth in venture capital, as well as investment in ICT infrastructure and higher education, chiming with the propositions of innovation systems theory.

The second factor mainly represents growth of employment in the four knowledge-intensive manufacturing sectors and growth in patent registration, with growth in Internet hosts and economic activity rate also marginally loaded. We label this factor 'Third & Fourth Wave Growth', as those manufacturing sectors represent leading industries in the third and fourth waves. As for the third factor, highly loaded variables include growth in R&D expenditures performed by business and employment in automotive and mechanical engineering, as well as instrumentation and electrical machinery. Growth in employment rates (namely, decline in the unemployment rate) is also significantly loaded on this factor. We call this factor 'Government-led Third Wave Growth', suggesting a close association between public R&D spending growth and growth in third wave manufacturing sectors. The loading of employment rate growth may also be interpreted as a sign of an interventionist approach taken by government in job creation and its association with the older generation of knowledge-intensive manufacturing sectors.

10. Waves of Growth: Cluster Analysis

Following the factor analysis, cluster analysis is undertaken to identify groups of regions. Regions within a group are close to one another according to the distance defined by their factor scores. Figures 1 (a and b) and 2 show the identified 13 groups of regions in three-dimensional space consisting of the three factors. Chinese regions are clearly set apart from the rest of the regions in terms of their extremely high values for Fifth Wave Growth. Furthermore, the Chinese regions show much wider variations in their values for the Third & Fourth Wave Growth than the rest of the regions. As a result, each of the seven Chinese regions forms a cluster of its own.

By construct, the Fifth Wave Growth and the Third & Fourth Wave Growth are necessarily orthogonal, with their values showing no correlation. However, in Figure 1a, the Chinese regions show a pattern of negative association between the Fifth Wave Growth and the Third & Fourth Wave Growth. In a similar vein, the negative association is replicated among the rest of the regions as well, meaning that those regions showing faster growth in high-tech service employment, venture capital, and public expenditures on higher education tend to exhibit slower growth, or even falls, in employment in the four knowledge-intensive manufacturing industries.

In the close-up section of Figure 1b, which focuses on the distribution of non-Chinese regions, a few clusters are identified at the opposite corners, with a three-region cluster of New South Wales, Victoria, and Taiwan and a single-region cluster of Nashville-Davidson—Murfreesboro in the right-hand bottom, and a two-region cluster of Estonia and Latvia in the left-hand top. As for the rest of the non-Chinese regions, although there is a significant overlap, US regions tend to be situated in the right-hand bottom, whilst European regions in the left-hand top, with Japanese regions occupying the middle ground.

The US and European regions are clearly separated in terms of the Government-led Third Wave Growth, as shown by Figure 2. All US regions, except for Nashville-Davidson—Murfreesboro and Salt Lake City, form a cluster situated at the bottom, along with Saskatchewan (Canada) and Kanagawa (Japan). There

is an independent cluster of three Swedish regions (Småland med Öarna, Västsverige, and Sydsverige) situated at the top, with the rest of the regions forming another large cluster, consisting mainly of European, Japanese, and Canadian regions. Clearly the two large clusters are differentiated in the Government-led Third Wave Growth, with the European cluster showing faster growth than the US cluster.

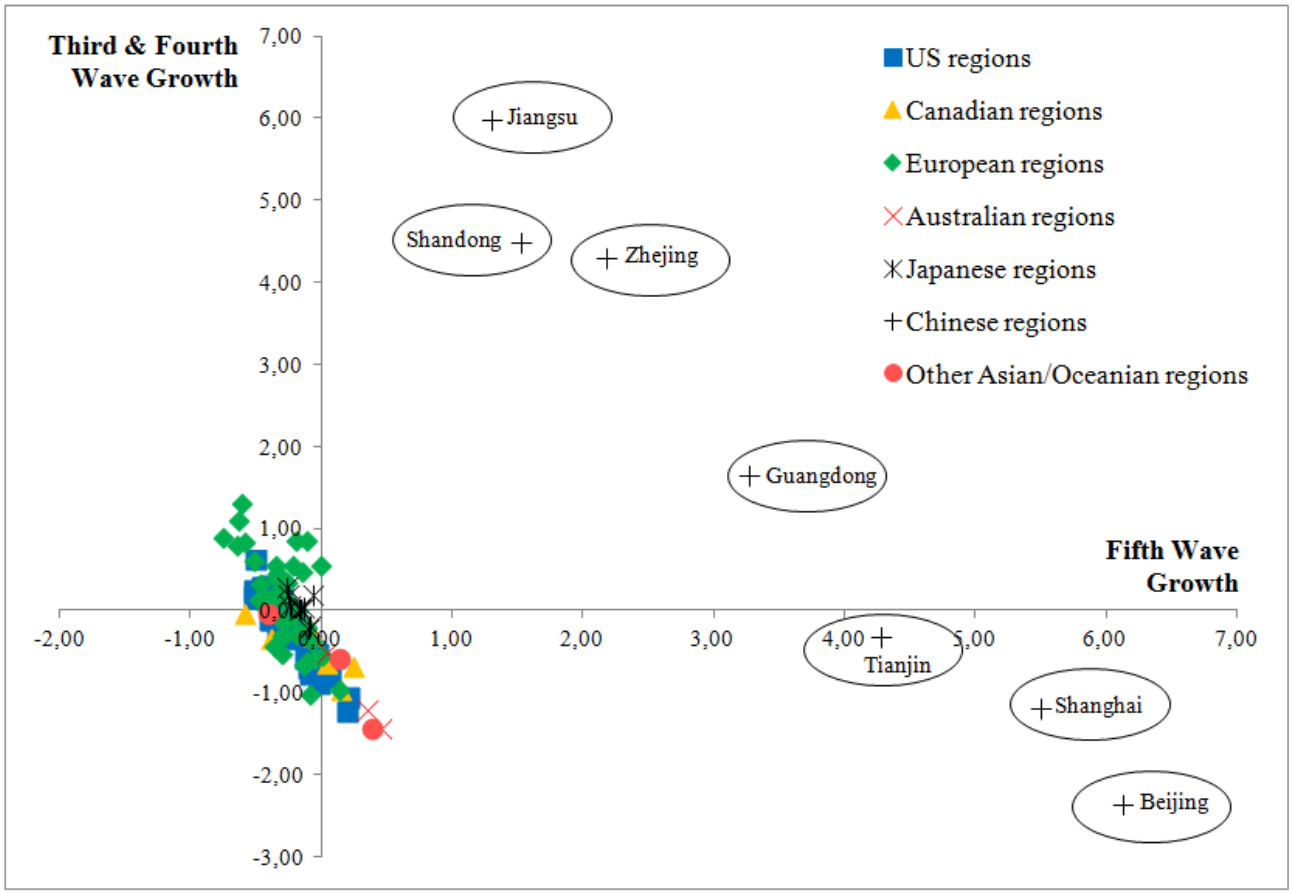

Figure 1a Regions and Waves Growth of Growth

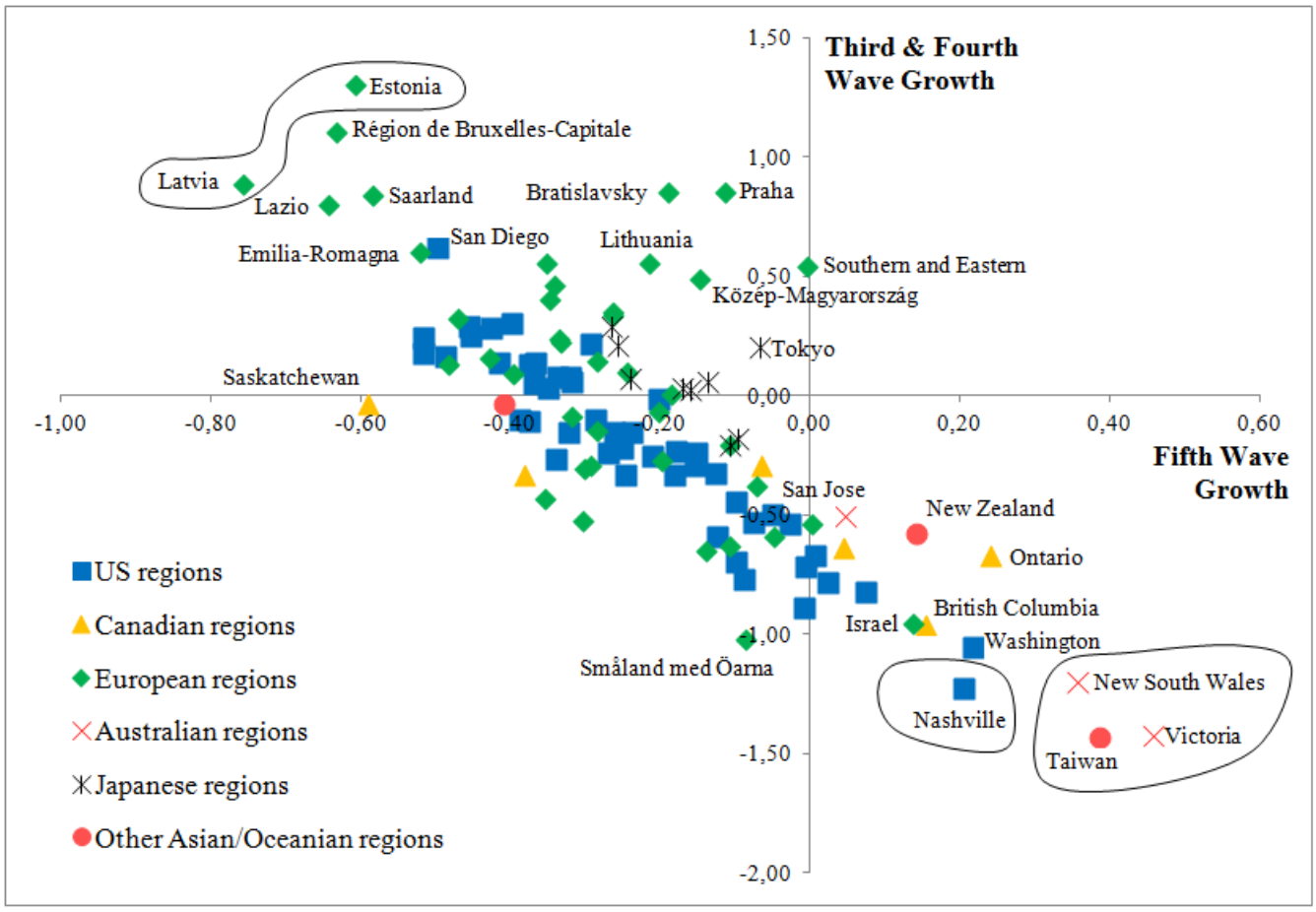

Figure 1b Regions and Waves Growth of Growth

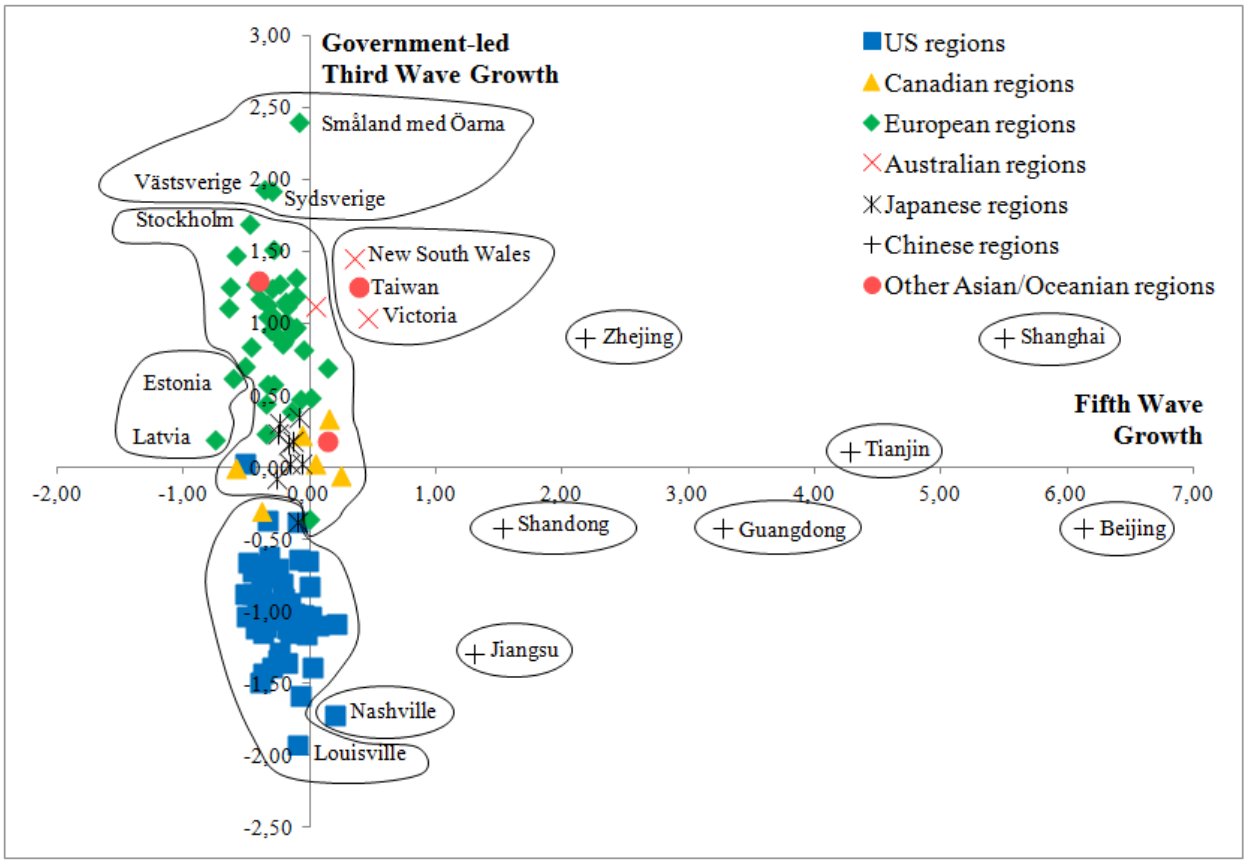

Figure 2 Fifth Wave Growth and Government-led Third Wave Growth

Cluster 1: Beijing
Cluster 2: Shanghai
Cluster 3: Tianjin
Cluster 4: Guangdong
Cluster 5: Zhejing
Cluster 6: Shanghai
Cluster 7: Shandong
Cluster 8: New South Wales, Victoria (Australia), Taiwan
Cluster 9: Nashville-Davidson—Murfreesboro (US)
Cluster 10: Atlanta-Sandy Springs-Marietta, Austin-Round Rock, Baltimore-Towson, Boston-Cambridge-Quincy, Buffalo-Niagara Falls, Charlotte-Gastonia-Concord, Chicago-Naperville-Joliet, Cincinnati-Middletown, Cleveland-Elyria-Mentor, Columbus, Dallas-Fort Worth-Arlington, Denver-Aurora, Detroit-Warren-Livonia, Grand Rapids-Wyoming, Greensboro-High Point, Hartford-West Hartford-East Hartford, Houston-Sugar Land-Baytown, Indianapolis, Jacksonville, Kansas City, Las Vegas-Paradise, Los Angeles-Long Beach-Santa Ana, Louisville, Memphis, Miami-Fort Lauderdale-Miami Beach, Milwaukee-Waukesha-West Allis, Minneapolis-St. Paul-Bloomington, New York-Northern New Jersey-Long Island, Orlando-Kissimmee, Philadelphia-Camden-Wilmington, Phoenix-Mesa-Scottsdale, Pittsburgh, Portland-Vancouver-Beaverton, Raleigh-Cary, Richmond, Rochester, Sacramento—Arden-Arcade—Roseville, San Antonio, San Diego-Carlsbad-San Marcos, San Francisco-Oakland-Fremont, San Jose-Sunnyvale-Santa Clara, Seattle-Tacoma-Bellevue, St. Louis, Tampa-St. Petersburg-Clearwater, Virginia Beach-Norfolk-Newport News, Washington-Arlington-Alexandria (US), Saskatchewan (Canada), Kanagawa (Japan)

Cluster 11: Salt Lake City (US), Alberta, British Columbia, Manitoba, Ontario, Quebec (Canada), Région de Bruxelles-Capitale, Vlaams Gewest (Belgium), Baden-Württemberg, Bayern, Berlin, Hessen, Niedersachsen, Nordrhein-Westfalen, Saarland, Schleswig-Holstein (Germany), Noreste, Comunidad de Madrid (Spain), Île de France, Centre-Est (France), Southern and Eastern (Ireland), Emilia-Romagna, Lazio, Lombardia (Italy), Noord-Nederland, West-Nederland, Zuid-Nederland (Netherlands), Ostösterreich, Westösterreich (Austria), Etelä-Suomi (Finland), Stockholm (Sweden), Eastern, London, Scotland, South East (UK), Bratislavsky (Slovak Republic), Közép-Magyarország (Hungary), Praha (Czech Republic), Lithuania, Norway, Switzerland, Israel, Western (Australia), Aichi, Kyoto, Osaka, Shiga, Shizuoka, Tochigi, Tokyo, Toyama (Japan), New Zealand, Singapore

Cluster 12: Sydsverige, Västsverige, Småland med Öarna (Sweden)

Cluster 13: Estonia, Latvia

Four key findings emerge from the results. First, there is a spread of knowledge-based resources in the form of human capital formation, knowledge production, and entrepreneurial investment, as well as overall economic growth in GDP and labour productivity, in regional economies within China. In the three key growth trends identified, the Chinese regions stand out of the rest in Fifth Wave and Third & Fourth Wave Growth. In terms of the Fifth Wave Growth, all the seven Chinese regions grew at a faster pace than the rest of the regions analysed.

Among the more established regions, many of those showing relatively strong performance in terms of Fifth Wave Growth are located around the Pacific Rim, such as Victoria, New South Wales, Taiwan, Washington, British Columbia, and New Zealand, indicating that they enjoy an opportunity for the offshoring of labour-intensive operations to China, as well as robust demand from within the Chinese economy. As for the Third & Fourth Wave Growth, again, four of the seven Chinese regions (Jiangsu, Shandong, Zhejing, and Guangdong) grew faster than all the non-Chinese regions. Across the non-Chinese regions, those showing strong performance are to a large extent concentrated in Eastern Europe, including Estonia, Latvia, Bratislavsky, Praha, Lithuania, and Közép-Magyarország. Overall, a continued shift of knowledge-based resources and capabilities to the East can be observed, or what can be termed the globalisation of knowledge-based development.

Second, a bipolar development can be observed regard to Fifth Wave Growth on the one hand and the Third & Fourth Wave Growth on the other. As mentioned earlier, by construct of factor analysis, the Fifth Wave Growth and the Third & Fourth Wave Growth are orthogonal, with their values showing no association at all. This means that, at the global scale, a region's position on the Fifth Wave Growth shows no indication of its position on the Third & Fourth Wave growth, and vice versa. However, as shown in Figure 1a, when the Chinese regions and the non-Chinese regions are divided into two separate groups, we observe in each of the groups a close negative association between the values for the Fifth Wave Growth and the Third & Fourth Wave Growth, meaning that a region with faster growth in high-tech service employment and venture capital formation tends to show a slower growth (or a faster fall) in knowledge-intensive manufacturing employment, and vice versa. Whilst the speed at which this development has taken place is much faster within the Chinese regions, what is common between the two groups of regions is a growing sector specialisation in either high-tech services accompanied by venture capital formation, or knowledge-intensive manufacturing.

Third, sector specialisation emerges as one of the three key trends by which the economic evolution and growth patterns of leading regions across the globe are differentiated. In addition to the first two factors, the third factor concerns employment change in the Third Wave manufacturing industries, automotive and mechanical engineering, as well as instrumentation and electrical machinery. Within this Government-led Third Wave Growth, two large clusters—the US-centric cluster and the Europe-centric cluster—are identified, along with a few much smaller clusters at the fringe.

Fundamentally the superstructure identified by the analysis is based on sector specialisation, and is

in contrast to an observation from an earlier period at the turn of the new century. In an earlier study of the period from 2001/02 to 2004/05 [32], it is found that the key trends differentiating the globe's most productive regions are not sector employment change but a commonality among the growth of GDP, gross monthly earnings, and business R&D, as well as labour market growth. This change in the identified factors may indicate that leading regions have been in the process of repositioning themselves in the global value chain through sector specialisation, in response to the major shocks including the burst of the dotcom bubble in 2001 and the more recent Lehman shock in 2008.

Last, but not least, the factor analysis presented above does not indicate the insignificance of labour productivity growth as an indicator of knowledge-based growth. In Table 2, labour productivity is conspicuously not loaded on any of the three factors strongly. However, this means that labour productivity growth is not associated with any one of the three diverging sector employment changes alone, but it is to a great extent evenly associated with all three sector employment changes. Technical progress appears to have taken place at each of the sectors associated with the three factors, and by design the factor analysis identifies commonalities orthogonal to, or independent of, each other, resulting in labour productivity not being strongly loaded on any of the factors. In similar vein, the growth of private R&D expenditure is not loaded strongly on any of the three factors, although an analysis regressing labour productivity growth shows that it is closely associated with the growth of private R&D expenditure.

11. Concluding Remarks

It is widely observed that the global geography of innovation is rapidly evolving. This paper presents evidence concerning the contemporary evolution of the globe's most productive regions, uncovering the underlying structure and coevolution of knowledge-based resources, capabilities and outputs across these regions. The analysis identifies three key trends by which the economic evolution and growth patterns of these regions are differentiated—namely the Fifth Wave Growth, the Third & Fourth Wave Growth, and Government-led Third Wave Growth. Overall, spectacular knowledge-based growth of leading Chinese regions is evident, highlighting a continued shift of knowledge-based resources to Asia. In addition, a superstructure is observed at the global scale, consisting of two separate continuums that explicitly distinguish Chinese regions from the rest in terms of regional growth trajectories.

References

1 Markusen, A. (1996) Sticky places in slippery spaces: a typology of industrial districts, *Economic Geography*, 72(3), pp. 293–313.

2 Phelps, N.A. and Ozawa, T. (2003) Contrasts in agglomeration: proto-industrial, industrial and post-industrial forms compared, *Progress in Human Geography*, 27(5), pp. 583–604.

3 Adams, J.D. (1990) Fundamental stocks of knowledge and productivity growth, *Journal of Political Economy*, 98(4), pp. 673–702.

4 Doloreux, D. and Parto, S. (2005) Regional innovation systems: current discourse and unresolved issues, *Technology in Society*, 27(2), pp. 133–153.

5 Vivarelli. M and Pianta, M. (eds.) (2000) *The Employment Impact of Innovation: Evidence and Policy*, London: Routledge.

6 Döpke, J. (2001) The 'employment intensity" of growth in Europe, Kiel Working Paper No. 1021, Kiel Institute of World Economics, Kiel Germany).

7 Freeman, C. (2002) Continental, national and sub-national innovation systems —complementarity and economic growth, *Research Policy*, 31(2), pp. 191–211.

8 Borrás, S. (2004) System of innovation theory and the European Union, *Science and Public Policy*, 31(6), pp. 425–433.

9 Heidenreich, M. (2004) The dilemmas of regional innovation systems, in: P. Cooke, M. Heidenreich, and H.-J. Braczyk (Eds.) *Regional Innovation Systems*, 2nd ed. pp. 363–389. London: Routledge.

10 Carlsson, B. (2003) Innovation systems: a survey of the literature from a Schumpeterian perspective. Paper for the Elgar Companion to Neo-Schumpeterian Economics, June.

11 Fritsch, M. (2002) Measuring the quality of regional innovation systems: a knowledge production function approach, *International Regional Science Review*, 25(1), pp. 86–101.

12 Bilbao-Osorio, B. and Rodríguez-Pose, A. (2004) From R&D to innovation and economic growth in the EU, *Growth and Change*, 35(4), pp. 434–455.

13 Buesa, M., Heijs, J., Pellitero, M.M., and Baumert, T. (2006) Regional systems of innovation and the knowledge production function: the Spanish case, *Technovation*, 26(4), p. 463–472.

14 Crescenzi, R., Rodríguez-Pose, A., and Storper. M. (2007) The territorial dynamics of innovation: a Europe–United States comparative analysis, *Journal of Economic Geography*, 7(6), pp. 673–709.

15 Rodríguez-Pose, A. and Crescenzi, R. (2008) Research and development, spillovers, innovation systems, and the genesis of regional growth in Europe, *Regional Studies*, 42(1), pp. 51–67.

16 Buesa, M., Heijs, J., and Baumert, T. (2010) The determinants of regional innovation in Europe: A combined factorial and regression knowledge production function approach, *Research Policy*, 39(6), pp. 722–735.

17 Buerger, M., Broekel, T., and Coad, A. (2010) Regional dynamics of innovation: investigating the co-evolution of patents, research and development (R&D), and employment, *Regional Studies*, DOI:10.1080/00343404.2010.520693.

18 Cooke, P. (2004) Regional innovation systems: an evolutionary approach, in: P. Cooke, M. Heidenreich, and H.-J. Braczyk (Eds.) *Regional Innovation Systems*, 2nd ed. pp. 1–18. London: Routledge.

19 Huggins, R., Izushi, H., Prokop, D. and Thompson, P. (2014) The Global Competitiveness of Regions, London: Routledge.

20 Gorsuch, R.L. (1983) *Factor Analysis*, 2nd ed. Hills Dale, NJ: Lawrence Erlbaum Associates.

21 Bartholomew, D.J. and Knott, M. (1999) *Latent Variable Models and Factor Analysis*, 2nd ed. London: Arnold.

22 Schwarz, G. (1978) Estimating the dimension of a model, *Annals of Statistics*, 6(2), pp. 461–464.

23 Hair, Jr., J.F., Black, W.C., Babin, B.J., and Anderson, R.E. (2010) *Multivariate Data Analysis*, 7th ed., Upper Saddle River, NJ: Pearson.

24 Kondratieff, N.D. (1926) 'Die langen Wellen der konjunktur', *Archiv für Sozialwissenschaft*, 56, 573–609.

25 Kondratieff, N.D. (1935) 'The long waves in economic life', *Review of Economic Statistics*, 17(6), 105–115.

26 Schumpeter, J.A. (1939) *Business Cycles*, New York: McGraw-Hill.

27 Hall, P. and Preston, P. (1988) The Carrier Wave: New Information Technology and the Geography of Innovation 1846–2003, London: Unwin Hyman.

28 Wymbs, C. (2004) Telecommunications, and instrument of radical change for both the 20th and 21st centuries, *Technological Forecasting & Social Change*, 71(7), pp. 685–703.

29 Devezas, T.C., Linstone, H.A., Santos, H.J.S. (2005) The growth dynamics of the Internet and the long wave theory, *Technological Forecasting & Social Change*, 72(8), pp. 913–935.

30 Linstone, H.A. and Devezas, T. (2012) Technological innovation and the long wave theory revisited, *Technological Forecasting & Social Change*, 79(2), pp. 414–416.

31 Korotayev, A., Zinkina, J., and Bogevolnov, J. (2011) Kondratieff waves in global invention activity (1900–2008), *Technological Forecasting & Social Change*, 78(7), pp. 1280–1284.

32 Huggins, R. and Izushi, H. (2013) Knowledge-based development in leading regions across the globe: An exploratory analysis of the co-evolution of resources, capabilities and outputs, *Urban Studies*, 50(5), pp. 1030-1048.