PRACE GEOGRAFICZNE, zeszyt 130

Instytut Geografii i Gospodarki Przestrzennej UJ
Kraków 2012, 73–89
doi: 10.4467/20833113PG.12.021.0662

LABOUR FLOWS IN THE BIOTECH SECTOR IN POLAND

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Abstract: Based on an analysis of personnel flows (managerial and employee), the authors show that knowledge flows in the biotech sector in Poland are strongly concentrated in space. With respect to managerial intra-metropolitan flows, Warszawa has a similar position to Cracow and the Tri-City (Gdańsk–Gdynia–Sopot conurbation). Cracow is characterised by strong isolation with respect to personnel flows from the outside. On the other hand, within the scope of inter-metropolitan flows, Poland's capital is dominant, in particular in terms of flows to the Tri-city, Poznań and Łódź. In the case of employee flows, the most important features of the examined issue are: dominance of intra-metropolitan flows and strong relationship between flows and the headquarters of the largest biotechnological companies. The conducted studies have shown that in the context of the Polish biotech sector, the concept of "local buzz, global pipelines" is corroborated, in line with which local and global knowledge flows are complementary with respect to each other.

Keywords: labour (personnel) flows, knowledge flows, biotechnology industry, local buzz, global pipelines, Poland

Introduction

Apart from classic production factors, knowledge resources are currently believed to be an important factor explaining differentiation in local, regional and international development. From the point of view of development processes analysis, it is worth analyzing mechanisms which lead to knowledge flows. Those flows constitute an important link in collective learning processes (Keeble, Nachum 2002) or so-called knowledge spillovers (Pinch, Henry 1999).

Knowledge resources are transferred together with people (e.g. by changes in work places – personnel flows) or with the transfer of information (orally or electronically). It is usually assumed that the types of knowledge, which have the strongest impact on the development of certain enterprises (e.g. specialist tacit knowledge) are characterised by little mobility (Breschi, Lissoni 2006). From a geographic point of view, the analysis of knowledge concentration, its exchange among various entities and the impact those processes have on local development are all interesting. The main purpose of this article is to discuss the scale and spatial range of personnel flows in the biotech industry in Poland. In order to do this, the authors constructed a database of biotech companies operating in Poland.

This article places emphasis on personnel flows related to workplace changes as main vehicles of knowledge transfer. Various authors (Dosi 1988; Boschma *et al.* 2009; Al-Laham *et al.* 2011) indicate that the remaining mechanisms of flows (e.g. patent citations) play only a slight role in knowledge transfers.

After a brief terminological introduction, the authors present the current status of research on knowledge flows. Subsequently, methods of study are presented. The next chapter discusses the scale and direction of labour flows in Poland exemplified by changes in the work places of the managerial personnel and employees of biotech firms.

Taking into account the actors sharing the information, knowledge flows can be divided in a most simple manner into external and internal flows. The latter occur within a single company or organization, e.g. knowledge is transferred from the parent firm to a branch at internal training sessions. In this article, the authors are interested solely in inter-firm knowledge (especially personnel) flows. They are important in comparison with internal flows because they enrich the entire firm with knowledge that is new from its point of view and contribute to an increase in its innovativeness and competitiveness (Al-Laham *et al.* 2011; Boschma *et al.* 2009). The authors of this article divide inter-firm knowledge flows, taking into account their local range, into local (intra-metropolitan) and non-local (inter-metropolitan).

There is no single definition of the biotech industry. This article adopts the definition presented by *OECD Biotechnology Statistics* (van Beuzekom, Arundel 2009), describing a biotech company as a firm whose main activity relies on the use of "biotechnological techniques" for the production of goods, provision of services or conducting R&D (Table 1).

Table 1. Biotechnological techniques, as listed by OECD

Group	Techniques
DNA/RNA	genomics, pharmacogenomics, gene probes, genetic engineering, DNA/RNA sequencing/synthesis/amplification, gene expression profiling, and use of antisense technology
Proteins and molecules	sequencing/synthesis/engineering of proteins and peptides (including large molecule hormones); improved delivery methods for large molecule drugs; proteomics, protein isolation and purification, signaling, identification of cell receptors
Cell and tissue culture and engineering	cell/tissue culture, tissue engineering (including tissue scaffolds and biomedical engineering), cellular fusion, vaccine/immune stimulants; embryo manipulation

Group	Techniques
Process biotechnology techniques	fermentation using bioreactors, bioprocessing, bioleaching, biopulping, biobleaching, biodesulphurisation, bioremediation, biofiltration and phytoremediation
Gene and RNA vectors	gene therapy, viral vectors
Bioinformatics	construction of databases on genomes, protein sequences; modelling complex biological processes, including systems biology
Nanobiotechnology	Applies the tools and processes of nano/microfabrication to build devices for studying biosystems and applications in drug delivery, diagnostics etc.

Source: *A Framework for...* 2005.

The biotech sector is traditionally divided into three sub-sectors: medical (red), industrial (white), and agricultural (green). Firm characteristics among these sub-sectors differ slightly, although the following features: high innovativeness, dominance of small and medium enterprises, high spatial concentration and important role of external funding (venture capital), remain common across the whole industry (Lawton-Smith 2004).

The term *academic spin-off* is understood here as an economic entity, which became separated from a parent unit (another firm or scientific institution) for the purpose of undertaking economic activity in a similar field. The creation of such an entity is often accompanied by personnel and knowledge flows from the parent unit. Most academic spin-offs are characterised by low capitalization, scientific (or technical) background of the founding team and innovative product or service ideas that need a long gestation (R&D) period before reaching the market stage (Tamowicz 2006; Clarysse *et al.* 2003).

Previous studies on knowledge flows

Researchers' interest in knowledge flows in high-tech industries is closely related to new views on the location of economic activity and competitiveness of spatial clusters. Clusters described by M. Porter and the "re-discovered" theory of industrial districts of A. Marshall, along with issues of simultaneous competition and cooperation, creation of a milieu of trust and dynamic business environment, constitute a solid basis for future studies focused on such issues.

The section below presents a selection of studies dealing with the issue of knowledge flows in various branches of the economy, both technologically advanced and traditional. The following issues are discussed with respect to knowledge flows: various types of knowledge networks, their range and role in the concentration of economic activity, significance of knowledge flows for the functioning and development of an enterprise, place and role of individual actors in knowledge networks, and finally, the effect of physical and relative distance on the shaping of a knowledge network.

Knowledge flows between firms, business environment institutions and other actors, and in consequence, the networks that are created can be divided according to various criteria; however, the most intuitive seems to be a typology relying on the physical distance between knowledge senders and recipients. Considering the characteristic features of the biotech industry, being a strong tendency for spatial clustering around leading research and development units, and the dominance of small and medium enterprises (Coenen *et al.* 2004; Lawton-Smith 2004), it is possible to divide knowledge flows into two types: local, inside a given cluster and non-local (external) – those beyond a cluster.

The strong connection between the biotech sector and scientific centres results from features characteristic of this type of activity: high innovativeness and significant role of tacit knowledge (Coenen *et al.* 2004; Gertler 2003). The effect of this is the creation of strong clusters integrating universities and R&D centres, technology transfer units and specialist biotech and pharmaceutical firms (Cooke 2004). It might seem that in such conditions, strong local knowledge networks should be created, whereas the role of non-local networks will be marginal.

Studies on knowledge flows in the Medicon Valley biotech cluster on the border of Denmark and Sweden conducted by L. Coenen *et al.* (2004) contradict this thesis. Bathelt *et al.* (2004) describe knowledge flows in high technology sectors, comparing the significance of local buzz and global pipelines. In line with this approach, local and global knowledge flows are complementary. Buzz encompasses local, most often informal, contacts among various enterprises, institutions, their employees, *etc.* consisting of an exchange of diversified knowledge. Pipeline represents non-local (or even global) connections, frequently more formal, consisting e.g. of license agreements or the establishment of *joint ventures*. The authors emphasize the necessity of maintaining both types of contacts because of different types of knowledge that can be obtained through them. Focusing solely on local buzz leads, inevitably, to a loss of innovativeness due to the fact that most innovations are created in different regions of the world, whereas neglecting local buzz leads to a decrease in competitiveness by the loss of the possibility of cooperation with other companies in a given cluster (Coenen *et al.* 2004).

These concepts have also been confirmed by studies on Canadian biotech sector, conducted by S. Bagchi-Sen and J.L. Scully (2004). The examined firms indicated, among their major partners, two types of entities: firms located within a distance of up to 50 miles and foreign firms, mainly American. Similar conclusions can be found in R. Boschma and A. Ter Wal's (2007) study of the shoemaking cluster in southern Italy (Barletta, 50 km west of Bari). These authors consider having a well developed local knowledge network supplemented by non-local contacts as an optimal state for a company's competitiveness. Furthermore, they criticize the notion of all firms in a given cluster having access and making use of knowledge externalities. Studies on knowledge networks in Barletta indicate the incorrectness of such reasoning – the authors indicated not only various positions of individual firms in the network (along with varying types of knowledge which they use), but also existence of two independent knowledge networks – one focused on technical knowledge and the other on business and market knowledge. A firm's position in one network resulting from its contacts with other firms has no reflection on the position in other networks (Boschma, Ter Wal 2007).

On the basis of previous studies (Jaffe *et al.* 1993; Boschma, Ter Wal 2007), it is possible to differentiate six major mechanisms facilitating the creation of knowledge flows: knowledge spillovers created through mobility of managerial personnel and employees among firms; informal meetings and contacts between entrepreneurs and key engineers within a cluster; formalised contacts among firms and other participants of a knowledge network pursuant to cooperation agreements, consortiums, etc.; establishment of spin-offs; and co-patenting. In this article, we focus on the first type of knowledge flows related to workplace changes.

Personnel (labour) mobility is considered by many researchers (Dosi 1988; Boschma *et al.* 2009; Al-Laham *et al.* 2011) to be a key channel of knowledge flows. Employees who change workplaces carry with them their experience and tacit knowledge, often impossible to obtain in another manner. Access to knowledge carried by new employees may have a positive impact on the innovation and competitiveness of a firm, provided that two conditions are met:

– complementarity of new employees' knowledge in relation to knowledge stocks already existing within a company – research by R. Boschma *et al.* (2009) proves that the inflow of knowledge thematically related to its existing resources, yet offering new possibilities (e.g. alternative manners of problem solving) stimulates learning processes and has a positive impact on innovativeness;
– absorptive potential of a company – knowledge accepted along with new employees cannot be utilised without the means for understanding and processing it, therefore, a proper level of technical and organizational knowledge is required (Boschma *et al.* 2009).

In the case of the biotech sector, where competitiveness is closely related to innovation and access to knowledge, personnel flows seem to be one of the most important (next to alliances among enterprises and joint R&D) factors influencing the potential of firms. As indicated by A. Al-Laham *et al.* (2011), a regular refreshing of the company's knowledge stocks through the acquisition of new employees allows a company to use market opportunities, which would be otherwise beyond its reach.

Numerous researchers (Coenen *et al.* 2004; Boschma, Ter Wal 2007; Ter Wal, Boschma 2007; Ter Wal 2009) pay attention to the overestimated significance of physical distance and its impact on shaping knowledge flows and networks. Physical proximity is still deemed an important factor facilitating the creation of knowledge flows, as it makes interaction among actors cheaper and better. Nevertheless, thanks to modern communication technologies, physical proximity has been – to some extent – replaced by relational proximity, which denotes possibilities for interaction between actors (Coenen *et al.* 2004).

According to A. Ter Wal (2009: 130) "…geographical proximity is neither a sufficient nor a necessary condition for firms to get connected. Social and cognitive proximity might be required as complementary conditions for the formation of local linkages or might even act as substitutes for geographical proximity at the formation of non-local linkages."

Physical proximity also cannot be treated as a simple function of the distance between two actors. There are other factors to consider – for example, transport infrastructure development, i.e. motorways, railways, airports and the destinations they serve (Coenen *et al.* 2003).

L. Coenen *et al.* (2003) divide proximity into two types: functional proximity related to physical distance and relational proximity, referring to cultural and social factors. Functional proximity is more than distance – it is rather related to the accessibility of a given location with the use of existing transportation infrastructure. On the other hand, relational proximity refers to factors influencing mutual trust and understanding between the senders and the recipients of information. In communities dealing with specific types of knowledge and making use of specialist terminology, such as the biotech community, the possibility of finding a common language (cultural proximity) is a key condition for establishing contact (Gertler 1995).

In summary, previous studies on knowledge flows (Table 2) show the changing role of geography in the establishment and functioning of knowledge networks. The results of studies presented above show that physical distance is not the only and not the most important condition for the establishment of knowledge flows – in many cases, relational proximity tends to be much more important. The positions of firms within networks vary, similarly to knowledge which flows trough different channels. Openness towards local and non-local flows is the key for maintaining innovativeness and competitiveness in a globalising economy.

Table 2. Main research problems in the field of knowledge flows

Main theoretical problems	Selected bibliography
Role of knowledge flows in spatial clustering	Coenen et al. 2004, Cooke 2004, Gertler 2003
Firm variety	Boschma, Ter Wal 2007
Local knowledge flows	Boschma, Ter Wal 2007, Jaffe *et al*. 2003,
Non-local knowledge flows	Boschma, Ter Wal 2007, Coenen *et al.* 2004 , Ter Wal, Boschma 2007, Ter Wal 2009
Interaction between global and local knowledge flows	Bagchi-Sen , Scully 2004, Bathelt *et al.* 2004, Coenen 2004
Role of personnel mobility	Al-Laham *et al*. 2011, Boschma *et al.* 2007, Dosi 1988

Source: authors' elaboration.

Research methods and data sources

The analysed personnel flows were divided into two basic groups: manager and employee flows. Employee flows were further divided into scientific, technical and administrative, considering the person's education and function within a company. Because of the lack of any complete database of Polish biotech sector companies, the authors created a full list of active Polish biotech enterprises, combining data from the National Court Register, lists of cluster initiatives members, the Hoppendstedt

Bonnier database, reports on the Polish biotech sector (*The current state…* 2007; *Life Sciences…* 2006), as well as a query of Internet sites. Thanks to the combination of information originating from various sources, it was possible to obtain data about all firms in the biotech sector currently operating in Poland. Additionally, in order to determine the scale of joint R&D activities of Polish biotech companies, a database of joint inventions based on data from the Patent Office of the Republic of Poland, was also created by the authors. Moreover, a series of seven in-depth interviews with the managers of Cracow's biotech and life science firms was conducted by the authors in order to gain a better understanding of the sector's functioning in Poland.

Analyzing changes in managers' workplaces required the authors to use data from the Polish National Court Register. Based on NCR information, a database of 162 current owners, members of management boards and supervisory boards of all 49 biotech firms was created by the authors of the study. With the aim of following labour flows, the database was subsequently enriched with information regarding the previous collaboration of such persons with other companies (via searches in the National Court Register) and R&D units. In order to identify connections with R&D units, a database known as Nauka Polska was searched (http://nauka-polska.pl/) for the presence of scientists among owners and members of management boards and supervisory boards of firms in the database.[1] Following the creation of the database, the identification of companies' place of registration was made, whose owners, members of management boards or supervisory boards had held similar functions earlier. Subsequently, a matrix of labour flows between various locations was completed with values of the flow index. For each direction of flow, a specific index of flow volume W_{pij} was calculated with the use of the following formula:

$$W_{pij} = 5 \times N_S + 3 \times N_{FB} + 1 \times N_{FR} + 0.5 \times N_{OF}$$

where:

N_S – number of personnel with previous involvement with R&D units newly employed by biotech companies;

N_{FB} – number of personnel with previous involvement with other biotech companies newly employed by biotech companies;

N_{FR} – number of personnel with previous involvement with related industries (pharmaceutical, medical, life sciences) newly employed by biotech companies;

N_{OF} – number of personnel with previous involvement with other sectors newly employed by biotech companies;

i – first location;

j – second location.

[1] On account of the adopted source, the analysis of managerial flows did not encompass all flows of knowledge from abroad. According to estimates made in the course of interviews, at least 8 biotechnological firms were created on the basis of their owners' knowledge procured to a significant degree during their studies (mostly Ph.D.) or internships abroad.

The following assumptions were used:

– the importance of a labour flow depends on the institution or company where a given person had worked previously and it is expressed by a system of weights[2] (with greatest emphasis for knowledge flows from R&D institutions and smallest for work on supervisory boards of companies not related to the biotech sector);
– a given person had to work in a firm or institution from which knowledge flows for at least one year;
– in the case of supervisory board members, the weights in the formula were decreased by half due to less significant knowledge obtained in the course of board membership;
– the weight of flow was decreased from 5 to 3 in the case of individuals who were not related to the biotech sector and had some involvement with universities or scientific institutions (e.g. lawyers or economists).

The analysis of employee flows was performed on the basis of CVs published on the GoldenLine social network website. The use of CVs in research related to personnel and knowledge flows in high-tech sectors has its clear benefits. The most important of the benefits, indicated by Dietz *et al.* (2000) include:

– access to the complete career path of a given person – most frequently from the moment of graduation, through subsequent workplaces along with dates of their changes, promotions and changes in work positions, which allows for an evaluation of the knowledge carried by such a person and the recognition of trends in the analysed changes. From a geographic point of view, the indication of changes in the place of residence is also important, allowing for an evaluation of scale and migration trends;
– standardization: the majority of published CVs are created according to a certain template;
– ease of procurement – e.g. with the use of the Internet.

Apart from the benefits listed above, the use of curriculum vitae as a research tool also carries certain risks. The possibility of inadequate representation of the examined sample (especially in the case of an Internet query) is considered as the most important of them. Hence the need for proper prudence in the interpretation of research results. The subjective nature of a CV, written by a given person wishing to improve the image of their career is another risk. The third risk is the opposite of the previous situation, i.e. high-ranking personnel omitting some less important (from their point of view) stages of their career, but nevertheless important for an analysis of their career path. Despite the indicated drawbacks, with proper precautions, the analysis of CVs is deemed an interesting research tool with immense possibilities (Dietz *et al.* 2000).

For the purpose of this study, a database of 183 CVs of biotech sector employees in Poland was created – all individuals were identified on the GoldenLine social network.

[2] Due to the fact that the adopted weight values for individual types of flows may raise certain doubts, a simulation was also conducted with the use of other values, decreasing the significance of flows from the science sector to 3 and from biotech firms to 2. The spatial distribution of flows obtained in this manner was similar to that obtained in the studies listed below.

The analysed labour flows took place between 1994 and 2011. For the purpose of evaluating the ratio of the number of procured CVs with the total number of employees in the sector, employment in identified biotech firms was analysed. It was possible to obtain employment data from 38 out of 49 firms (77%). These firms had over 2,800 employees in total. Taking into account the possibility of an underestimation related to incomplete data, the final number of employees in the sector in Poland has been determined to be approximately 3,000. Therefore, the prepared database of 183 CVs constitutes approximately 6% of the total employment in the biotech industry. Excluding members of supervisory boards, both analyses of flows (managerial and employee), encompassed over 9% of total employment in the sector.

Properly prepared CVs were assigned – according to positions held – to one of three types of networks:

– scientific network, consisting of laboratory personnel and other personnel related to R&D work. Specialised education in the life sciences (biology, biochemistry, biophysics) is the key feature of this group;
– technical network, which consists of skilled workers, production line technicians, IT specialists, etc;
– administrative network, composed of people employed in office administration, marketing and accounting departments.

In the database, CVs belonging to the scientific network constitute 37%, technical network – 25%, whereas administrative – 38% of the total number.

Trade representatives working «in the field» were excluded from the study; it was acknowledged that on account of the specific nature of their work (sales), great mobility between industries and short periods of employment, this group of employees does not contribute significantly to knowledge diffusion in the biotech sector.

Subsequently, the flow index was calculated upon principles identical as in the case of managerial personnel, yet with the use of slightly different weights (resulting from the division into three networks – table 3) and a shorter minimum work period in a biotech firm from 1 year to 6 months.

Table 3. Flow index weights for different types of networks

Industry/ sector from which a flow occurred	Networks		
	Scientific	Technical	Administrative
Education: after M.Sc. studies	1.0	1.0	1.0
Education: after Ph.D. studies	5.0	2.5	2.5
R&D activity	5.0	2.5	2.5
Biotech industry (another firm)	2.0	1.5	1.5
Pharmaceutical industry	2.0	1.5	1.5
Other industries, sectors and networks	1.5	1.0	1.0

Source: authors' elaboration.

Spatial concentration of the biotech sector in Poland

The Polish biotech sector is concentrated in large metropolitan areas. Warszawa, the Tri-city, Łódź, Poznań, Kraków and Wrocław account for 67% of firms in the sector (33 out of 49). Based on the authors' research, it may be stated that the Warszawa agglomeration is the largest area of concentration of the biotech industry, accounting for 9 firms, which have approximately 1,200 employees. In the Tri-city, there are 7 companies (approx. 200 employees), in Łódź – 5 firms with fewer than 100 employees. Kraków has 5 firms and over 400 employees, similarly to Poznań, yet employment in the Poznań cluster does not exceed 100 employees. In Wrocław, there are 4 companies with approximately 50 employees.

The spatial concentration of biotech firms in large metropolitan areas may be explained by the previously mentioned close links between biotech companies, leading universities and R&D units. The location of some companies dealing with "green" (agricultural) biotechnology (mainly sewage treatment technologies) is an exception to this rule, as those firms are usually located outside major cities. The majority of biotech firms (over 70%) are spin-off companies characterised by a tendency to be located in direct geographical proximity to their parent institutions (most frequently universities and R&D centres).

Managerial flows in the biotech sector in Poland

An analysis of managerial flows confirms the tendency for local migrations of key personnel. Flows within metropolitan areas constitute approx. ⅔ of the total number of flow volumes for all directions. Hence, local environments are able, to a certain extent, stimulate their own development. However, local environments are not entirely self-sufficient. Figure 1 depicts the dominance of Warszawa as a centre exporting knowledge to the majority of key cities in the country (in particular to Tri-city, Poznań and Łódź). This direction of mobility does not stem from the organisational hierarchy and dominance of Warszawa as a headquarters of biotech companies. Flows in the opposite direction (from regional capitals to Warszawa) have only little significance. The Warszawa–Poznań–Łódź triangle is connected by the strongest relationship, with the capital city as the leading centre (Fig. 1). This is probably the result of the high past and present position related with biotech, pharmaceutical industry in these metropolitan areas. Within the scope of local flows, the position of the country's capital is not as strong as in the previous case. Equally high are internal flows of key personnel in Kraków and in the Tri-city and slightly smaller in Poznań. The isolation of the capital of Małopolska with respect to the inflow and outflow of non-local knowledge seems to be an interesting case. In the case of Kraków, even flows to and from Warszawa do not exist. Based on the interviews conducted by the authors, the foreign work experience of Kraków's managers and owners of firms shows that the capital of Małopolska uses knowledge obtained from abroad.

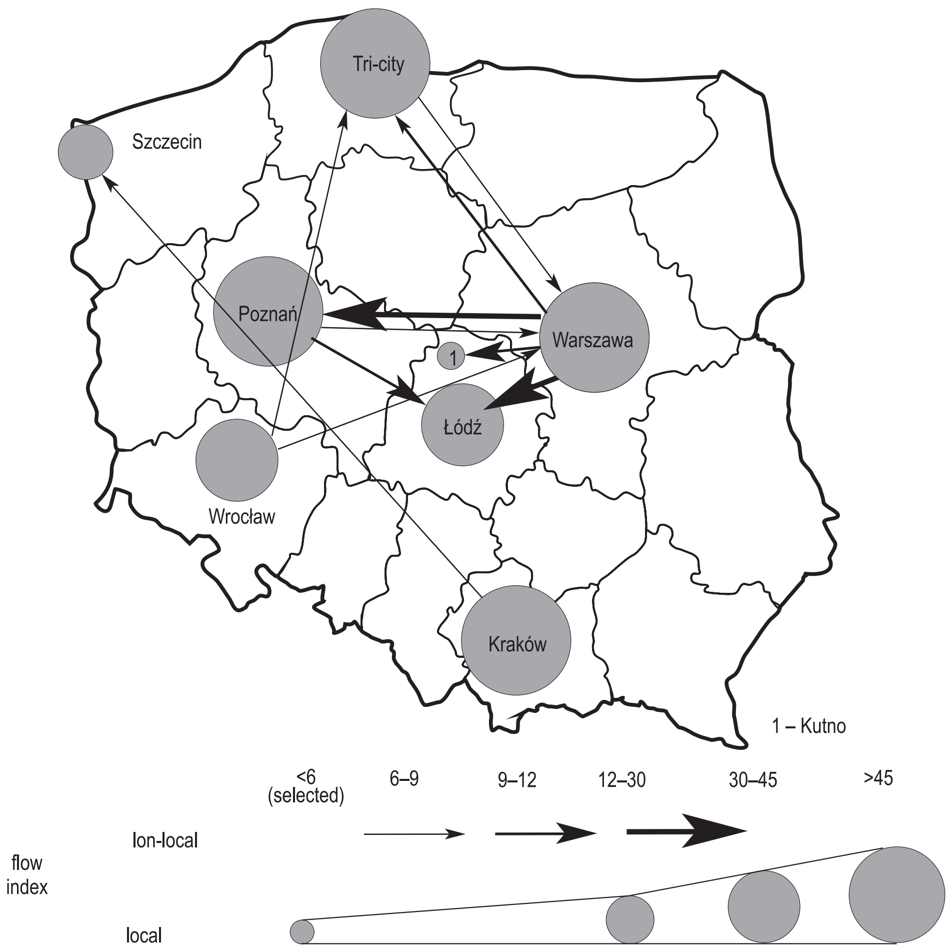

Fig. 1. Flows of managerial personnel in the biotech sector in Poland

Note: Only selected directions of flows with W_{pij} > 5 are presented.

Source: authors' elaboration.

Employee flows in the biotech sector in Poland

In the case of biotech firms' employees, the tendency for local closure of labour flows is slightly less apparent, yet it still encompasses the majority (53%) of flows. Warszawa is dominant in the area of intra-metropolitan flows (W_{pij} = 100), in spite of a relatively slight dominance over other metropolitan areas with respect to the number of firms (Fig. 2). However, thanks to the presence of the largest Polish biotech firm – Bioton, employing approximately 400 people – and the nearby location of the pharmaceutical-

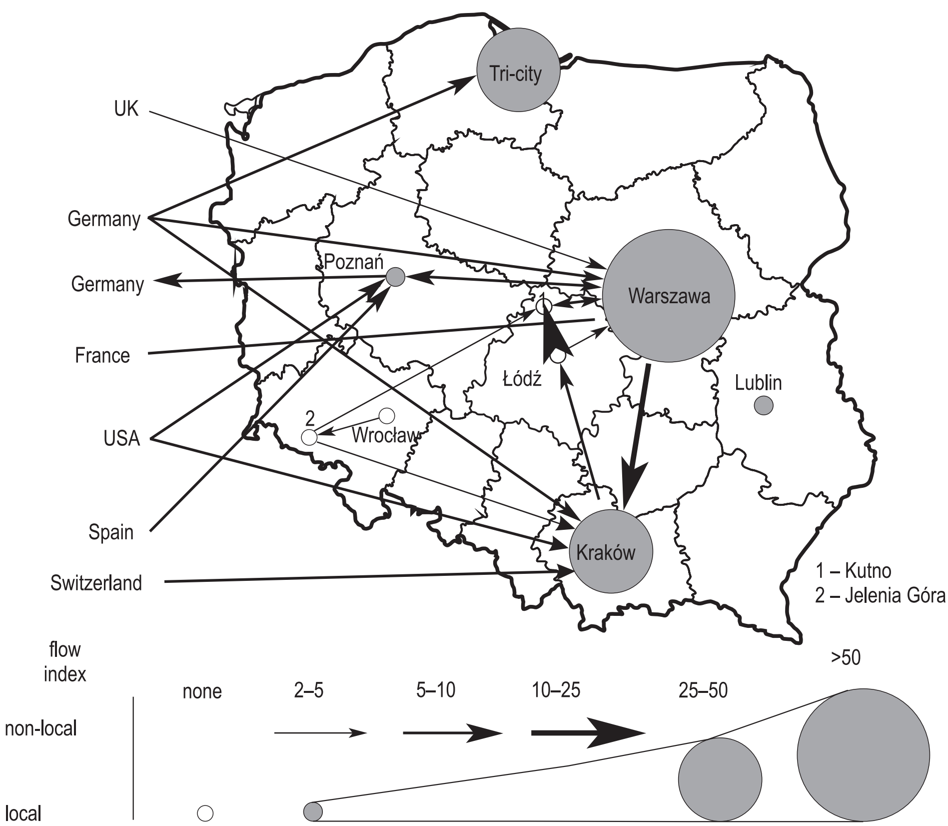

Fig. 2. Employee flows (all knowledge networks) in the biotech sector in Poland

Note: only selected directions of flows with$W_{pij} > 2$ are presented.

Source: authors' elaboration.

-biotechnological firm Celon Pharma (Łomianki), Warszawa has a significant advantage over other clusters of the sector. The above listed firms generate approximately 80% of local personnel flows in the area of Warszawa, whereas the next 7 firms are responsible for approx. 20%.

The Kraków and Tri-city metropolitan areas are also characterised by strong local flows of personnel. The presence of leading universities and the existence of developing clusters in the sector, grouping more than five entities stimulate personnel flows as well as the establishment of academic spin-offs, whereas the absence of large entities such as Bioton prevents an increase in the value of flow to values comparable with Warsaw.

Small local flows were also recorded in Lublin and Poznań. In the case of Lublin, the BioMaxima Company is considered to be the main generator of flows, whereas

Poznań is the location of one of the sector's clusters. The low value of internal flows in this case may be explained by strong ties with Warszawa, which is also indicated by an analysis of connections of managerial personnel.

The most important characteristic of the examined external (non-local) flows is much smaller values than in the case of local flows. The highest obtained value of the W_{pij} index in the case of non-local flows was 15.5 (for comparison – the index of internal flows for the metropolitan area of Warszawa was 100). This shows strong ties with the local environment. Domestic non-local personnel flows are mainly related to the location of key enterprises in the sector, also outside of the existing clusters. Thanks to the location of large pharmaceutical companies, Kutno and Jelenia Góra are also important points on the personnel flows map. Most existing clusters do not show direct flows of personnel from other clusters – only the existence of flows Warszawa–Kraków, Kraków–Łódź and Warszawa–Poznań was recorded.

The research network plays a key role in the shaping of non-local personnel flows. In the case of international flows, there are only two cases of persons changing their job within the sector, who are not biotechnology specialists. Most domestic clusters show an inflow of personnel from abroad, however, in all recorded cases, these were Polish citizens, returning home after working at foreign companies and scientific centres.

Non-local technical and administrative personnel flows are limited – this confirms entrepreneurs' tendency to use local human resources (Fig. 3). At the same time, the dominance of scientific personnel flows within the scope of non-local mobility indicates entrepreneurs' willingness to procure the best possible stocks of specialist knowledge, carried by new research employees.

When analyzing Polish biotech clusters with respect to personnel flows, it is possible to divide them into inflow centres and outflow centres (Table 4). The former are characterised by the dominance of incoming connections, while outgoing connections dominate the latter. The most important inflow centres are Kraków and Warszawa, whereas a comparison of the value of flows for these cities indicates very strong accumulation of human capital in Kraków (outflow amounts to 10% of inflow). The Bioton and Celon companies are responsible for a clear majority of labour inflows to the Warszawa metropolitan area, whereas most personnel inflows to Kraków are driven by recruitment activities by IBSS Biomed and Selvita, both with over 100 employees.

Table 4. Outflow and inflow knowledge indices for selected metropolitan areas

Metropolitan area	Outflow (W_{pji})	Inflow (W_{pij})
Cracow	5.0	51.0
Łódź	13.0	4.5
Poznań	8.0	17.5
Tri-city	2.5	6.0
Warsaw	28.5	44.0
Wrocław	8.0	1.0

Source: authors' elaboration.

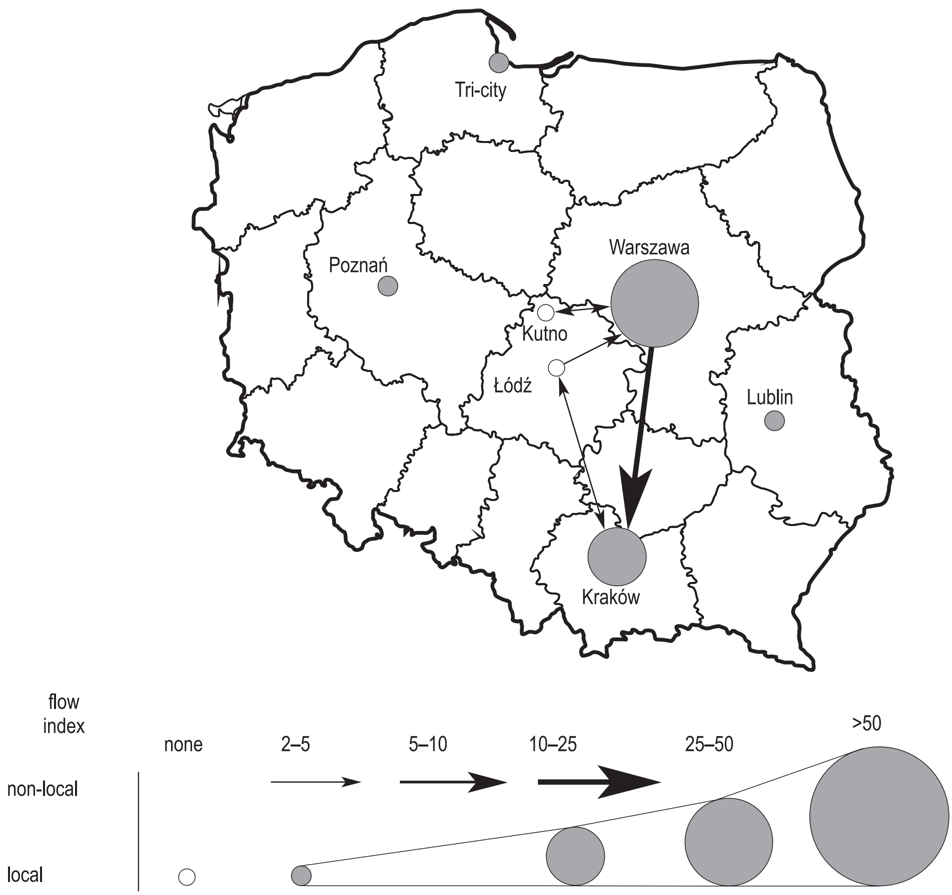

Fig. 3. Technical and administrative personnel flows in the biotech sector in Poland

Note: only selected directions of flows with $W_{pij} > 2$ are presented.

Source: authors' elaboration.

A dominance of inflow also takes place in Poznań and the Tri-city, whereas most important outflow centres are Wrocław and Łódź. In case of these cities, the most important directions of outflow are nearby localities, which serve as the headquarters of large biotechnological and pharmaceutical companies – Jelenia Góra (Jelfa) for Wrocław, Ożarów Mazowiecki (Bioton) and Kutno (Mabion) for Łódź. The absence of large biotechnological employers and the initial stage of cluster development in these cities additionally stimulates high outflows.

Considering the entire sector, the most important sources of personnel for businesses are other biotechnological companies (27% of flows) and universities (graduates – 20%). The source of 13% of flows is the pharmaceutical industry. Taking into account strong technical and market relations between these two industries, that is understandable. Only 12% of flows referred to the scientific staff at universities; however; considering the significance of knowledge carried by this part of personnel, they may be deemed of key importance for the migration of knowledge in the sector.

Discussion and conclusions

This article is one the first attempts to combine various data sources in order to assess the scale and scope of labour flows in the Polish biotech industry. The use of CVs to detect labour flows may be debatable due to a limited sample. Hence, future studies should be more comprehensive and include questionnaires for employees. A new index of personnel flows was tested as part of this research. The use of the index provided interesting results, although it needs more testing, especially when it comes to applying various weights.

The research has shown that knowledge resources in the Polish biotech sector are strongly concentrated spatially – flows of managerial and university personnel are limited to local environments. Even though Warszawa is the dominant personnel exporter, yet as far as intra-metropolitan flows are concerned, the position of the country's capital is not so strong. The internal flows of managerial personnel within Kraków and the Tri-city are equally high. In this case, isolation from flows from the outside and the use of local managerial personnel is relevant.

The most important features of employee flows are: the dominance of internal flows and the key role of large companies in shaping flows. Large companies often "drain" the labour market of desirable specialists also on a non-local scale. Kraków's firms, isolated from flows of managerial personnel, procure employees from the entire country and also from abroad. Another city with respect to the size of inflow that attracts employees is Warszawa, which is much more open to local flows (mainly to large companies).

The greater mobility of R&D personnel (in comparison to auxiliary employees) indicates significant possibilities of attracting the most desirable personnel by Polish biotech firms. It also shows that employers are aware of the significant role of personal experience and accumulated tacit knowledge of research team members in the success of R&D.

In the biotech sector, knowledge contributed by experienced personnel constitutes an important element of the development and competitiveness of a firm. Non-local migrations of personnel allow for a refreshing of a firm's knowledge pool, as well as stimulate the learning process, as has been indicated in research by A. Al-Laham *et al.* (2011) and R. Boschma *et al.* (2009). At the same time, the small scale of personnel flows in the technical and administrative network indicates a much smaller role of so called tacit knowledge in these networks and a high level of codification and standardization of knowledge by employees. Therefore it may argued that the personnel representing these networks is available locally by the entrepreneurs. The H. Bathelt *et al.* (2004) concept appears to be valid in Poland, where local and global knowledge flows are complementary

In spite of the significant role of clusters, the most important factor shaping non--local personnel flows, along with the knowledge carried with them, seems to be the location of large (with respect to employment) business entities. Companies such as Bioton, Celon, Selvita, IBSS Biomed, which have over 100 employees, and smaller (approx. 50 employees), but dynamically developing companies (e.g. Mabion) possess the ability to attract valuable employees from distant regions of the country and also from abroad. Taking into account the initial stage of development of the biotech industry in Poland, characterised by a large number of small spin-off companies, often employing a only few employees, the long period of the R&D phase and high risk of R&D business failure, dominance of large entities in the shaping of knowledge networks, as well as attempts at draining the labour market of the best specialists seem to be the factors, which will shape non-local flows of personnel in the Polish biotech sector in the nearest future.

In the case of local flows, the establishment of spin-off companies by scientists, assisted by the initiatives of local authorities such as centres of technology transfer, science parks and technological incubators may mitigate the dominance of large companies. Taking into account the fact that success and failure in the biotech industry is determined by innovation, a very important role will be played by local research centres – universities and R&D units – which are the source of personnel for spin-offs.

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