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Regional innovation systems in Hungary:

The failing synergy at the national level

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Abstract

We use entropy statistics in this paper to measure the synergies of knowledge exploration, knowledge exploitation, and organizational control in the Hungarian innovation system. Our data consists of high- and medium-tech firms and knowledge-intensive services categorized by sub-regions (proxy for geography), industrial sectors (proxy for technology) and firm size (proxy for organization). Configurational information along these three dimensions is used as an indicator of reduction of uncertainty or, in other words, the synergy across the knowledge functions. Our results indicate that three regimes have been created during the Hungarian transition with very different dynamics: (1) Budapest and its agglomeration emerge as a knowledge-based innovation system on every indicator; (2) the north-western part of the country, where foreign-owned companies have induced a shift in knowledge-organization; while (3) the system in the eastern and southern part of the country seems to be organized as a response to government expenditure. The national level no longer adds to the synergy across these regional innovation systems.

Keywords: *innovation system, knowledge function synergy, configurational information, entropy statistics, transition economy, regions.*

JEL codes: B52, O18, P25, R12

1. Introduction

When the Soviet-Union fell apart in the years 1989-1991, the countries of Eastern and Middle Europe regained their autonomy. A major task confronting national governments was to guide both the transition of their economies to modern knowledge-based economies in rapidly globalizing markets and to achieve accession to Western institutions such as NATO, the OECD, and thereafter also the European Union. The accession to the EU—achieved in 2004—required a transformation of the economic and legal systems of these countries. The institutionally-shaped bureaucracies of the socialist economies were unable to absorb the emerging knowledge-based dynamics sufficiently (e.g., Richta *et al*., 1968). The newly elected governments were confronted with two transformations: economic opening up to the world market and the innovation dynamics of external forces such as transnational corporations. Foreign direct investment (FDI) became decisive in shaping the national and regional innovation systems in these countries (INZELT, 2003, RADOSEVIC, 2002).

In this paper, we focus on Hungary as a country that went through the process of transition and thereafter accession to the EU. The study follows the format of previous studies of the measurement of regional and national systems of innovation in The Netherlands and Germany (LEYDESDORFF *et al*., 2006; LEYDESDORFF and FRITSCH, 2006) and combines their statistical apparatus with in-depth insights into the Hungarian system. The added value of this paper is the extension of the empirical model to transition economies. We have access to unique data that allow us to measure the effects of the transformation in terms of synergies in relevant innovation systems (CARLSSON, 2006). We use micro-level data on 660,290 firms in Hungary. These firms are classified as high- or medium-tech manufacturing or knowledge-intensive services by the Hungarian Central Statistical Office (HCSO). In addition to this classification, the data contains the postal address and size (in number of employees) of each firm.

The second main contribution is a more refined theoretical background of the empirical model. We distinguish three knowledge functions of innovation systems, namely: knowledge exploration, knowledge exploitation, and organizational control. Following the above-mentioned studies, we use firm size as an indicator of organization (PUGH et al, 1969, BLAU and SCHOENHERR, 1971), whereas the addresses allow us to decompose regional dynamics at various levels of aggregation. Our research question is whether a national system of innovation has been established in Hungary and, if not, how should the system be characterized regarding differences across regions? We operationalize an innovation system as a configuration along technological, geographic, and organizational dimensions (STORPER, 1997) in which knowledge functions generate synergy. As a methodology, we use configurational information as a measure of synergy among distributions in the three dimensions.

We shall argue that Hungary should now be understood as composed of three innovation systems with very different dynamics: (1) the capital Budapest can be characterized as a metropolitan innovation system, and operates increasingly on a par with Vienna, Prague, and Munich as centers for knowledge-intensive services and knowledge-based manufacturing; (2) the north-western parts of the country have been absorbed into the Western-European innovation systems surrounding it; and (3) the eastern and southern parts of the country are still predominantly integrated within old systems dynamics, largely determined by and dependent upon government spending. The national system of Hungary no longer adds to the knowledge-based dynamics of these three regional systems as it does in the case of the Netherlands. In Germany, we found synergy at the state level (also defined as NUTS-1). These conclusions will be quantitatively underpinned by the measurement of synergies across technological, organizational, and territorial distributions of firms at the various NUTS-levels.[i]

2. The evolutionary model

The literature on innovation systems starts by asking why and how nations and regions differ in terms of the evolution in technology, industrial structure and institutional setting of certain territories (COOKE et al., 2004, EDQUIST, 1997, LUNDVALL, 1992, NELSON, 1993). The inter-relatedness of the above mentioned settings is discussed in institutional and evolutionary research agendas as the notion of co-evolution (BOSCHMA and FRENKEN, 2006, CORIAT and DOSI, 1998). However, the investigation of these co-evolutionary mechanisms has focused primarily on innovation systems at the national level (NELSON, 1995). The model elaborated in this section enables us to investigate whether this inter-relatedness occurs at national or regional levels of innovation systems.

Our model is based on Storper's (1997, at pp. 26 ff.) conjecture that the interrelationships between technology, organization and territory in an economic system can be considered a "holy trinity." Storper emphasizes that this holy trinity should not be studied as an aggregate of its composing elements, but in terms of the relations between and among these elements. These relationships shape regional economies. However, his proposal for a "relational paradigm" was not operationalized in a way which permitted measurement.

Based on Triple Helix model of university-industry-government relations, Leydesdorff (2003) proposed the concept of configurational information as an indicator of synergy in

Triple-Helix relations. This information measure—discussed in more detail below—can be negative or positive, indicating the presence of synergy across three independent sources of variance. For example, one can ask whether the interaction among sources in a region is further enhanced by additionally considering the national level. By applying this concept to Storper's three dimensions, one can consider the following model. Here we used the organizational dimension of the "holy trinity" as an operationalization of economic exchange relations, as the latter can be expected to determine the size and scope of firms through transaction costs in the market (COASE, 1937).

Figure 1 around here

This model enables us to distinguish knowledge functions in innovation systems in addition to the two main dimensions of a political economy. Agents are geographically positioned and endowed but are able to exchange irrespectively of these boundaries in economic relations. A knowledge-based economy can be considered as based on interactions between these two (traditional) drivers of a political economy with the new dimension of knowledge creation, dissemination, and control (NELSON and WINTER, 1982; WHITLEY, 1984, 2001). The three dimensions operating upon each other can also be considered as a triple helix which endogenously might be able to reduce uncertainty in a process of self-organization. Our intent is to measure this reduction of uncertainty as a synergy. The method is explained in detail below.

In our three-dimensional model, knowledge functions of innovation systems are defined as follows: knowledge exploration, knowledge exploitation and organizational control. These can be considered the interaction terms at the interfaces between the three independent dimensions. This specification of the knowledge functions in terms of relevant dimensions enables us to connect the model to Storper's "holy trinity" beyond the operationalizations in previous studies of innovation systems in the Netherlands and Germany.

Knowledge exploitation can be considered as the selection of existing routines, while *knowledge exploration* refers to concerted variation and planned experimentation (MARCH, 1991, BAUM et al., 2000). In other words, exploitation is associated with the reuse of existing competences and means, while exploration is associated with creating new alternatives. At the systems level, mechanisms of knowledge exploitation represent the interface between economic welfare and technological knowledge creation (GIBBONS et al., 1994). In our understanding this interface does not necessarily depend on geographical locations because economic welfare is created at the level of global markets, even if certain technologies originate in single regions. We also argue that knowledge exploitation is connected to locations only when there exists some synergy within an innovation system: the local pool of suppliers, qualified labour, etc. Knowledge exploration, however, can be considered as a place-dependent rather than a market-dependent mechanism because tacit knowledge is essential in creating new knowledge and relates significantly to places. Strong evidence was found on the effect of university R&D on the local economy (JAFFE et al., 1993) and on the regional production of knowledge (ACS et al., 2002, VARGA, 2007).

Organizational control mechanisms of innovation systems (e.g., economic policies) focus mainly on territorial units having direct influence on economic exchange relations (taxes and incentives etc.), but affect knowledge exploration and exploitation only indirectly (infrastructure, cluster-programmes etc.). Institutions of innovation systems increase the probability of the emergence of new knowledge. However, organizations are needed to foster these institutions through organizational arrangements, new connections, and formal responsibilities (LOASBY, 2001). Thus, the *organizational control* function in our model represents the institutional and organizational elements of innovation systems. In our opinion, it follows from the above outlined knowledge functions that the synergies across them mark the quality of innovation systems.

As noted, this study leans methodologically on two previous studies of Germany and the Netherlands. The main conclusions of these studies form the basis of our expectations in the current study. These conclusions were as follows:

- medium- and high-tech manufacturing couple knowledge synergies of innovation systems to geographical location;
- medium-tech does this to a higher extent than high-tech;
- knowledge-intensive services tend to decouple knowledge synergies from their geographical location;
- high-tech services counter-act this latter effect.

The authors explained these findings in terms of the relative "footloose-ness" of knowledge-intensive services and high-tech manufacturing (VERNON, 1979). Knowledge-intensive services can be offered outside a region assuming the availability of transportation. Thus the vicinity of an airport or major railway station is often more important than local and regional factors. High-tech manufacturing is less embedded in a local economy than medium-tech. The latter can be expected to enhance absorptive capacity in the region to an extent larger than the former (COHEN and LEVINTHAL, 1989). High-tech services counter-act the decoupling effect by tending to make R&D facilities (e.g., laboratories) a necessary condition.

Furthermore, these authors found an additional synergy at the level of the nation in the case of Holland, but not in the case of Germany. In Germany, innovation systems are integrated more at the level of federal states than the level of the nation according to this indicator. In the case of Hungary, we initially expected it to function as a national system like the Netherlands due to its' relative size. As noted, our data suggest that Hungary's national innovation system decomposed into smaller subsystems, i.e. parts of the country operate under different dynamics. Coordination problems at the national level will also be discussed.

3. Selected issues of the Hungarian transition: regional distribution of FDI and R&D expenditure

Since the political changes in 1989 and 1990, the relatively small Hungarian economy has opened up. After a transition period, the country joined the EU in 2004. Articles in economic geography note that the transition from a planned to a market economy first caused significant economic decline (LENGYEL, 2004; VARGA, 2007): many medium-tech state-owned companies went bankrupt and R&D expenditure wained. In the late '90s, three regions (Central Hungary, Central Transdanubia and Western Transdanubia) began reducing the gap between them and their Western-European counterparts with growth rates of 4-5% a year. The three regions with dynamically expanding economies are situated in the northwest of Hungary between Budapest and the Austrian border. Out of these three regions, the Central Hungarian region (Budapest) had attained 96.5 % of the EU-25 average GDP per capita by the year 2005. The economic growth of the other four regions remained at 1.6-3% per year (HSCO, 2007). These four regions (Southern Transdanubia, Northern Hungary, the Northern Great Plain and the Southern Great Plain) are situated south and east of Budapest.

In the Hungarian economy more than 50% of the registered capital of companies and partnerships is in the hands of foreign owners. The international stake is significant in all SME types, reaching at least 27-28 % (KÁLLAY and LENGYEL, 2008). As in large companies, half of the capital of medium-sized enterprises is in foreign hands.[ii] The R&D index in Hungary lags behind the European average. The total share of R&D expenditure in GDP was 0.95% in 2005. 44,8 % of R&D expenditure took place in the business sector, 29,1 % in public research organizations and 26,1 % in universities (HCSO, 2006). Previous studies have concluded that university-industry relations are weak in Hungary (INZELT, 2004; PAPANEK, 2000). However, some regional centres have important universities that have taken an active role in the transition. The Central-Hungarian Region (CHR)—including Budapest—absorbs a significant share of Hungarian R&D resources Figure 2).

Figure 2 around here

The motives of foreign-owned companies for selecting specific locations (mainly in the energy, banking and manufacturing sectors) were primarily labour costs, accessibility and opportunities for privatisation at the beginning of the transition (BARTA, 2002). However, the Budapest knowledge-base and the regional centres were more and more attractive for multinational R&D (LENGYEL and CADIL, 2009; INZELT, 2003). In the period 1995-2003, the growth of R&D spending by foreign affiliates was among the highest in Hungary (UNCTAD, 2005, p. 127). The share of large foreign-owned companies in manufacturing R&D is around 40 % (EUROSTAT, 2005); and the share of foreign affiliates in business R&D around 80% (EC, 2005). The territorial distribution of foreign investment in the Hungarian economy is uneven. The majority of foreign shares in foreign-owned companies are located in Budapest, Central Hungary, Central Transdanubia and Western Transdanubia.

As noted, this paper focuses on how regional differences have developed during the transition as a result of the entrance of foreign investors and the maintenance of public expenditure. We consider foreign direct investment as an *external force* on innovation systems (LORENZEN and MAHNKE, 2002; LUNDVALL et al, 2002). Companies locate their R&D facilities in a region either to exploit their existing knowledge or to have access to the local knowledge base (VON ZEDTWITZ and GASSMAN, 2002). Public expenditure on R&D is transferred to the regions from the central budget. Private R&D is mostly controlled by foreign-owned firms in Hungary. However, we follow here only the general outlook on R&D, as it is an *internal mechanism* of regional innovation systems (TÖDTLING and TRIPPL, 2005). In summary, we expect that:

– foreign-owned firms have a restructuring effect on the synergy of knowledge functions;
– the contribution of research and development to the knowledge synergies is strongly differentiated by regional innovation systems.

4. Data and methods

In the analysis we use a unique dataset to measure the existence of synergy at different levels of innovation systems. Our indicator, configurational information, measures the reduction in uncertainty of three independent sources of variance in the system. The stronger the synergy across knowledge functions the more uncertainty is reduced in the system. A three-dimensional matrix of data was needed to create this indicator based on the model illustrated in Figure 1.

The dataset consists of 659,701 firms and was collected by the Hungarian Central Statistical Office (HCSO). Since firms are required to supply data to the HCSO, our dataset encompasses the entire population of firms. All data is from December 31, 2005. The use of the statistical register of enterprises provides us with information at the company level. Each company was classified into geographical, technological and organisational categories.

The geographical dimension was investigated at the LAN 1 (previously called NUTS 4) level of sub-regions. Hungary as a whole is considered a NUTS 1 unit according to the Eurostat classification. There are seven regions (NUTS 2), 19 counties (NUTS 3) and 168 subregions (LAN 1) in Hungary. Since the data were collected at the level of subregions, we were able to aggregate the information and define the uncertainty in geographical distributions at the NUTS 3 county-level. Since Budapest is the only metropolitan district in Hungary, it must be considered a special category in regional surveys: thus data from Budapest were collected at the NUTS 3 level.

In order to measure the technological dimension we use the NACE code of industrial sectors developed by the OECD and Eurostat. Since various sectors of the economy can be expected to use different technologies, sector classifications can be used as a proxy for the technology (PAVITT, 1984). The OECD (2001, pp.137 ff.) has provided indications of the relative R&D intensity of the various sectors. Each enterprise is classified by its first activity at the two-digit level. Our data consists of all firms classified within one of the 22 categories listed in Table 1.

Table 1 around here

The dimension of economic exchange relations in our model is operationalized by organisational terms, i.e. the size of enterprises measured by the number of employees (PUGH et al., 1969; BLAU and SCHOENHERR, 1971). The Hungarian enterprise register has a category with zero or unknown number of employees that includes SMEs without employees or that represent self-employment. This category contains, among others, spin-off companies that are already on the market but whose owners are employed by mother companies or universities (Table 2). Surprisingly, a high percentage of firms (53.7%) are classified in the categories high- and medium-tech industries and knowledge-intensive services.

Table 2 around here

We composed our dataset into a three-dimensional matrix of 168 lines (LAN 1 regions), 22 columns (NACE codes) and 6 levels (size categories).

Methods

Configurational information is closely connected to entropy measures. Entropy is widely used in geography as a measure of inequalities across or diversity within territorial units (BOSCHMA and IAMMARINO, 2009). We use it here as a measure of uncertainty represented in a probabilistic distribution or system of distributions (Johnston *et al*., 2000). According to SHANNON's (1948) formula,[iii] uncertainty in the distribution of variable x ($\sum_x p_x$) is defined as $H_x = -\sum_x p_x \log_2 p_x$. Analogously, for two dimensional distributions $H_{xy} = -\sum_x \sum_y p_{xy} \log_2 p_{xy}$. This uncertainty is the sum of the uncertainty in the two dimensions diminished by their co-variation.

When the basis of the logarithm is two, the values are expressed in bits of information. Therefore our entropy measures are formal (probability) measures and thus independent of size or any other reference to the empirical systems under study. The sigma in the formula allows all the information terms to be fully decomposed. Our analysis is built on these characteristics of the entropy. We measure how the system affects the decline in uncertainty

In the case of two dimensions, the uncertainty in the two potentially interacting dimensions (x and y) can be reduced with the common entropy. Our aim is to mark systems, thus we use the concept of configurational information or transmission, which captures the reduction of uncertainty and is formalized in two dimensions as follows: $T_{xy} = (H_x + H_y) - H_{xy}$ (Equation 1).

In the limiting case that the distributions x and y are completely independent, $T_{xy} = 0$ and $H_{xy} = H_x + H_y$. In all other cases $T_{xy} > 0$, and therefore $H_{xy} < H_x + H_y$ (THEIL, 1972, at pp. 59f.). In general, two interacting systems (or variables) determine each other in their mutual entropy (H_{xy}). However, in the case of three interacting variables, one has two options: the three interacting systems may have a common segment shared by all of them or not (Figure 3a and 3b, respectively). In the latter case, the overlap can also be considered as negative.

Figure 3 around here

In the case of overlaps, the mutual information is redundant. But in the other case the cycling of the information between two dimensions can generate a synergy. This redundancy of synergy can be expressed by an information measure (T_{xyz}) which ABRAMSON (1963, at p. 129) derived from the Shannon formula[iv]: $T_{xyz} = H_x + H_y + H_z - H_{xy} - H_{xz} - H_{yz} + H_{xyz}$ (Equation 2).

While two-dimensional systems reduce uncertainty, the trilateral term in turn feeds back on this reduction and therefore adds another term to the uncertainty. Thus, the configuration of the system determines the net result in terms of the value of T_{xyz} (MCGILL, 1954).

As noted, the three dimensions under study in this case will be (G)eography, (T)echnology and (O)rganization and configurational information among them will accordingly be indicated as the T_{GTO}. Similarly to Equation 2 one can formulate as follows:

$T_{GTO} = H_G + H_T + H_O - H_{GT} - H_{GO} - H_{TO} + H_{GTO}$ (Equation 3).

The value of T_{GTO} measures the interrelatedness of the three sources of variance and the fit of the relations between and among them. The synergy across knowledge exploitation, knowledge exploration and organizational control reduces uncertainty in the system. We use T_{GTO} as a measure of the reduction of the uncertainty at a system level: high negative values indicate a better fit. Note that the indicator does not measure the innovative activity or the economic output of a system. It measures only the structural conditions in the system for innovative activities and thus specifies an expectation.

5. Results

As noted, the data can be disaggregated in terms of geographical regions (NUTS 2 and NUTS 3) and we are able to distinguish between high- and medium-tech sectors and knowledge-intensive services. The various dimensions can also be combined in order to compute the configurational information among them in a next step.

The counties differ in the number of firms and their geographical distribution inside the counties (Table 3). While according to NACE categories only 8,722 enterprises proved to be high-, medium-tech or knowledge-intensive in Nógrád county, Budapest contains 229,165 firms and Pest county 67,342 enterprises. The mean of analysed firms at the county level (excluding Budapest) is 22,690.

5.1. Entropy values

As the data were collected at the LAN 1 level, the first column of Table 3 informs us about the uncertainty of the sub-regional distribution at the county level or, in other words, about the concentration of economic activity. Budapest is a special case, as it is at the same time a NUTS 3 and a LAN 1 region. Thus, there can be no uncertainty for the concentration within the Budapest area. However, the Pest county has a large value on this indicator: it contains 15 subregions. In this case, 3.54 bits of information is equal to 90.7% of the maximum entropy of $\log_2(15) = 3.91$. One can understand this as a representation of the spread of economic activity in sub-regions of the Budapest agglomeration. The remaining counties with a high number of sub-regions are more centralised. For example, the distribution of firms in Borsod-Abaúj-Zemplén (with Miskolc as the second largest settlement in Hungary) corresponds to 62.7% of the maximum entropy. The counties with strong university centres are also more centralised. In these cases the value of probabilistic entropy shows a lower percentage of the maximum entropy: Csongrád 62,5%, Baranya 54,2%, Hajdú-Bihar 59%, Győr-Moson-Sopron 66,2%.

Table 3 around here

The maximum entropy in the technological distribution is $\log_2(22) = 4.459$, and $\log_2(6) = 2.584$ in the organisational distribution. The entropy values in both dimensions indicate a very skewed distribution at the country level. In the technological and organisational dimensions the percentages of this maximum entropy are 61.1% and 44.9% at the national level. In the analyses, the probabilistic entropy indicates the uncertainty only across high- and medium-tech industries and knowledge-intensive services.

The probabilistic entropies (H_t and H_o) in the county decomposition show relatively small variance. Counties do not differ in terms of their organizational or technological variety. The value of H for the country as a whole corresponds to the mean of the values for counties in technological and organisational dimensions: $H_t = 2.744 \pm 0.071$ and $H_o = 1.145 \pm 0.035$ bits of information. The low percentages of expected entropy indicate asymmetric distributions in the organisational dimension. A possible reason for these skewed distributions could be the large share of micro companies and firms without employees in our data.

Surprisingly, 75% of the total number of registered firms without employees in Hungary is represented in the 22 NACE categories of high- and medium-tech industries and knowledge-intensive services (see Table 2). The category of firms without employees in the real-estate sector (NACE 70) is a good example for illustrating this highly uneven distribution. There are 140,078 and this category contains 21,2% of all the establishments included in the analysis. The category of micro firms with other business activities (NACE 74) has a similar weight: 156,807 units (23.7%). The firms without employees are included in the analysis as the were in previous studies (LEYDESDORFF *et al*, 2006, LEYDESDORFF and FRITSCH, 2006).

The entropy values in two dimensions reduce the uncertainty of the system and can be used as proxies to measure the knowledge functions outlined in section 2. Consequently, H_{gt} is a proxy for knowledge exploration, H_{to} is a proxy for knowledge exploitation and H_{go} is a proxy for organizational control. However, one can observe that redundancies in the geographical and technological dimensions (H_{gt}), are relatively low in the counties with big universities (Baranya, Csongrád, Győr-Moson-Sopron, Hajdú-Bihar). Consequently, interdependence in the geographical and technological distribution of the studied industries is low in these areas. On the other hand, interdependence seems to be high in Pest county, though it has more centres, more universities and therefore a more diversified economy. This means that knowledge exploration occurs on a higher level in the broader Budapest agglomeration than in university towns, where one might also expect knowledge exploration to stand out. It is an interesting issue for further research to prove this statement. We focus our attention on configurational information in three dimensions and analyze the main anomalies at the systems level in what follows.

5.2. The geographical decomposition of the configurational information

While high values for mutual information between two dimensions indicate the strength of interaction across them, configurational information of three interacting dimensions can be negative or positive. The value of configurational information depends on the relation between the entropy values of two- and three-dimensional distributions (see Equation 3 above). The question in our case is whether the knowledge functions of the innovation system reduce the uncertainty among the geographical, technological and organizational distributions. The synergy across knowledge exploration, knowledge exploitation and organizational control may reduce the three-dimensional term (YEUNG, 2008). Thus, a more negative value of configurational information in three dimensions indicates a decrease in the uncertainty prevailing at the systems level.

The values for configurational information in three dimensions are negative for all counties (Table 4). This indicates that counties are relevant innovation systems in Hungary.

Table 4 around here

The values for T_{GTO} already take account of the geographical distributions as one of the relevant dimensions. Since the number of sub-regions varies across counties, these values cannot be compared directly with one another. However, it can be noted that the value of T_{GTO} is less pronounced for Hungary as a country than for any of its parts. In order to make this comparison among regions possible, we weighted the values of T_{GTO} with the number of firms in the counties. ΔT in millibits represents a value that we can interpret as a measure of synergy within innovation systems. There is an inverse relation between the absolute value of the indicator and the reduction of uncertainty in the system.

Our line of argument calls for marking the national innovation system first. In order to do this, one advantage of entropy statistics is that the values can be fully decomposed (THEIL, 1972): $T = T_0 + \sum_i n_i/N \times T_i$ (Equation 4); where T_0 is the in-between county entropy, T_i is the entropy measured in county i, n_i is the number of firms in county i, N is the number of firms in the whole country.

The in-between group uncertainty (T_0) is defined as the difference between the sum of the uncertainties of the contributions and the uncertainty prevailing at the level of the composed set (LEYDESDORFF et al., 2006). In this case T_0 is an indicator of the in-between group contribution to configurational information in three dimensions. A negative value would indicate that the national agglomeration adds to the synergy in the system, while a positive value indicates that the synergy occurs on regional rather than national levels.

The high *positive* value of T_0 indicates that Hungary is far from integrated as a national innovation system. The in-between region term adds to the uncertainty at the national systems level. Previous studies found a negative value for the Netherlands (LEYDESDORFF et al., 2006) and separate German states, but a positive value for Germany as a nation (LEYDESDORFF and FRITSCH, 2006). Unlike the Netherlands, Germany is both a federal state and a country with several eastern states "in transition." Thus one would not expect this synergy at the national level. The results for Hungary, however, are more dramatic. Hungary is a nation-state and the contribution of the in-between county uncertainty (T_0 = +10.94 mbits) is far larger than any of the reductions of uncertainty at the regional level. We will elaborate our further tests on this finding and investigate the forces that shaped innovation systems in the Hungarian transition.

Figure 4 around here

The synergies across knowledge functions in Hungary stand out in Budapest (ΔT =–9.63 mbits), Pest county (–3.39 mbits), and Borsod-Abaúj-Zemplén (–2.39 mbits). Our results suggest that the strong differentiation in regional prosperity can be verified using this methodology: the knowledge base of Budapest and its agglomeration becomes visible as central to the country's economy (Figure 4).

In addition to Central Hungary's strong position, a few annoying problems emerge. While one can observe parallel rankings across counties in the West in terms of configurational information and on indicators of economic performance or internalization, one does not find such correspondence in Eastern Hungary. In particular, the high level of integration in Borsod-Abaúj-Zemplén is unexpected: the employment rate in this area is among the lowest and economic performance is the lowest in Hungary. It is also surprising that the values for configurational information in Csongrád and Hajdú-Bihar do not stand out from the surroundings, despite the presence of relatively large universities.

Previous studies analyzing the transition period suggest that Budapest and the north-western part of Hungary, where most multinational firms put down stakes (these trends were introduced in section 3), have developed a strong endogenous knowledge base (ANTALÓCZY and SASS, 2005; INZELT, 2003; SZALAVETZ, 2004; TÖRÖK and PETZ, 1999). As our analysis is based on complexity perspectives and on stochastic measures, our results indicate otherwise. Is it possible that the foreign-owned corporations have disturbed the self-organization of local innovation systems, the texture of university-industry-government relations in which medium-tech companies frequently play a leading role in integrating the system?

We suggest that, with the exception of the metropolitan area of Budapest, the foreign-owned capital have decoupled the knowledge synergies from their geographical rooting. These companies have their headquarters in Western capitals and most important decisions are not made in the local systems. In terms of knowledge functions, we argue that exploitation came to the fore after the marketopening, contributing also to the transformation of local synergies. The dynamics are thus very different from those of the Netherlands and (Western-) Germany because these latter systems did not go through a transition period. Could this geographical decoupling mean that the areas in Western Hungary are more integrated in the EU or neighbouring countries than in the national system? Previous empirical studies have found that FDI from Austria is concentrated in the North-Western regions of Hungary, close to the Austrian border (INZELT, 2003, at p. 256). Moreover, these regions have been incorporated in the Regional Innovation Strategy of Vienna, the capital of Austria (BORSI et al., 2007). The eastern and southern part of Hungary have thus far been least affected by the transition and therefore older innovation synergies appear to have remained in place.

6. Investigating our expectations

While the geographic comparison is compounded with traditional industrial structure such as firm density, all effects of the decomposition in terms of the sectoral classification of high- and medium-tech sectors and knowledge-intensive services can be expressed as relative effects, that is, as percentage increases or decreases of the negative value of configurational information in three dimensions when a specific selection is compared with the population. In the remainder of this study, we use the categories provided by the OECD and Eurostat (see Table 1 above) as selection criteria for subsets and compare the results with those of the full set—provided in the previous section—as a baseline. The structure of this section elaborates our expectations: the first subsection reflects on the findings of previous studies in the Netherlands and Germany while the second and third subsections investigate our expectations in Hungary as a transition economy.

6.1. The role of geographical location in the synergy across knowledge functions

To pursue this investigatin we first need a comparison of the sectoral effects on configurational information in three dimensions. The sectoral effects were calculated as shares in configurational information of the total system:

$$(\text{Sector } T_{gto} - \text{Total } \Delta T) / \text{Total } \Delta T \times 100 \qquad (5)$$

In this case, a negative value means that uncertainty reduction is lower in the sector than the reduction in the total set and a positive value indicates a stronger sectoral effect on knowledge function synergy in the region than on average.

The number of companies in high- and medium-tech sectors is declining compared to knowledge intensive services but these sectors have strong effects on the knowledge function synergy in the innovation system (Table 5). This small subgroup has an enormous effect on configurational information in three dimensions and thus on the reduction of uncertainty; in some cases by even more than 1000%. The selection of high- and medium-tech manufacturing results in large differences. Budapest and Pest stand out with respect to the strength of synergy in these sectors followed by counties like Fejér, Komárom-Esztergom, Borsod-Abaúj-Zemplén, Jász-Nagykun-Szolnok, and Bács-Kiskun (column 7 in table 5). The knowledge function synergies are the weakest in South Transdanubia and the Southern Great Plain.

Table 5 around here

One can observe that high- and medium-tech companies had positive effects on the reduction of uncertainty in all counties and at the national level as well. Knowledge exploration, knowledge exploitation and organizational control have synergistic effects on each other in these sectors.

Comparing the sectoral effects of knowledge-intensive services on configurational information our findings are similar to the results of studies following similar methods in the Netherlands and Germany (LEYDESDORFF et al., 2006; LEYDESDORFF and FRITSCH, 2006). Column 4 of Table 5 indicates that knowledge-intensive services reduce uncertainty less than the total set in all regions (the rates are all negative). We may therefore conclude that knowledge-intensive services (KIS) have negative effects on knowledge function synergy in Hungarian regional innovation systems. These services can be provided over a bigger distance. Consequently they may link the local self-organization of regional innovation systems to global contexts. The negative effect seems less pronounced than in the Netherlands or Germany. However, this finding is an artefact of the comparatively large size of this subset in the total population of firms: 97.1% of the units of analysis are classified in this category. We may assume that this share also includes less active firms.

In summary, we find that medium- and high-tech manufacturing couple knowledge synergies of innovation systems into geographical location in Hungary. Knowledge-intensive services tend to decouple knowledge synergies from their geographical location. These findings are similar to results in previous studies of the Netherlands and Germany.

6.2. The effect of foreign-owned companies

Figure 5 shows the reduction of uncertainty due to configurational information in high- and medium-tech sectors across the various regions. The selection of high- and medium-tech manufacturing has a significant impact. The effects of the Budapest agglomeration stand out. One can find an emergent North-South pole in the eastern part of the country.

Figure 5 around here

Not Budapest, but Fejér, Komárom-Esztergom, Pest, Jász-Nagykun-Szolnok, and Vas show the largest effects (column 5, Table 5). The knowledge function synergy in these counties appears to be driven mostly by foreign-owned high- and medium-tech companies. Unfortunately we were unable to address company ownership as a fourth dimension in our model and we had insufficient longitudinal data to analyze the relation between FDI and configurational information. However we are able to highlight some interesting correspondences with the results of a spatial analysis (Figure 6).

Figure 6 around here

In Figure 6, we plotted the effect of high- and medium-tech industries' on entropy against the county measures of foreign share in foreign-owned companies. The correlation between the two indicators (0.53) becomes significant (at the 5% level) only when we remove Budapest from the sample. Consequently, different tendencies prevail in the capital and in the counties. One can observe a moderate positive relation among the foreign investment and knowledge function synergies of high- and medium-tech industries, which is due to the decisive role of foreign-owned firms in both knowledge exploration (e.g. their major part in business R&D) and the opening-up in knowledge exploitation.

Foreign stake in foreign-owned companies reached 24 500 million EUR in Budapest and exceeds two billion EUR only in four other counties: Pest, Komárom-Esztergom, Győr-Moson-Sopron, and Fejér. In these counties the high- and medium-tech sectors contribute importantly to the synergy across knowledge functions in the system. The results suggest that the rise of value added and the development of supply chains caused these positive effects during the transition. However, these sectors contain only a small number of companies that can easily move to new locations. In other counties, the low level of foreign investment is frequently linked to various levels of knowledge function synergy.

This result accords with the expectation concerning the effect of the entrance of foreign-owned companies on the restructuring of innovation systems. Foreign-owned firms played a significant role in the transformation of innovation systems in Hungary, through the privatization of R&D facilities, and green-field investments in knowledge exploration and exploitation. However, a conditional statement has to be made here: foreign investments induce different spatial synergies across knowledge exploitation, knowledge exploration, and organizational control. In this sense, Hungary's Western regions stand out from the rest of the country.

6.3. Effects of high-tech knowledge-intensive services and R&D

High-tech knowledge-intensive services (HT-KIS) that played a core role in the investigation of our last expectation are only a minor part of KIS: research and development, IT services and post- and telecommunication services belong to this category. In our opinion, the effects of HT-KIS and the remaining part of KIS have to be compared. HT-KIS can mean knowledge- and technology creation whereas KIS can be considered representative of the adaptation of knowledge and technology. More than knowledge-intensive services in general, high-tech services can be expected to produce and transfer technology-related knowledge (BILDERBEEK et al., 1998) and R&D is also expected to have stronger local knowledge spillover effects (VARGA, 2007) than KIS. However, we find a relative decline of configurational information in three dimensions in most regions when the subset of sectors indicated as 'high-tech services' is compared with KIS (Table 6).

Table 6 around here

One can ask to what extent the trends of local knowledge transfer are similar in the three sectors of HT-KIS. According to Miozzo and Soete (2001) telecommunication and IT services belong to information network services while research and development belongs to science-based services. Their taxonomy implies that the former group of services has an increased transportability and make "networks work up to full capacity", assimilating them with scale-intensive services. From this perspective, post- and telecommunications, and IT services have different effects on knowledge function synergies than R&D. The former rather decouple them from local circumstances while the later couple them to spatial systems, as in the case of some East-German regions (LEYDESDORFF and FRITSCH, 2006). According to our dataset, post- and telecommunications and IT services are more spatially distributed than R&D. By nature, R&D is more concentrated. For example, from the seven R&D organizations with more than 250 employees, five are located in Budapest and two in Szeged, the seat of Csongrád county.

Figure 7 around here

HT-KIS effects on system synergy appear only in Budapest and Csongrád (Figure 7). They also have the highest values on public research expenditure. However, one can argue that the reasons for these effects differ: Budapest has a strengthening knowledge base in the business sphere and employment in high-tech knowledge-intensive services surpasses 4.5% of total employment (EUROSTAT, 2007, at p. 5). Our data show that Csongrád is relatively strong in basic research (see Figure 1) despite the otherwise low level of economic performance in the region (LENGYEL, 2009). Thus, knowledge function synergy in HT-KIS exihibits different mechanisms in these areas. The coupling effect of R&D is stronger than the decoupling effect of post- and telecommunications and IT services in Csongrád; large centres of these services integrate innovation system synergies in the capital.

In sum, the contribution of research and development to the knowledge synergies are strongly differentiated across regional innovation systems. Research and development seems to couple the knowledge function synergy of HT-KIS to the geographical location in two emerging centres. On the other hand, the decoupling effect of post- and telecommunications and IT services on the synergy from spatial circumstances in other regions may outweigh the coupling effect of R&D. Public R&D still plays a major role in raising knowledge synergies in the south-eastern part of the country. This means that transition in the Eastern part of the country, where foreign investments are moderate, remains dependent on the institutions of the state. This represented by organizational control in our model in section 2.

7. Conclusion and discussion

The analysis has illustrated that high- and medium-tech manufacturing strengthens the geographical characteristics of the knowledge-based economy in Hungary. In all cases they have the effect of reducing uncertainty in regional innovation systems. Knowledge-intensive services have weaker effects on decoupling from the geographical dimension in Hungary than was found in the Netherlands and Germany (LEYDESDORFF et al., 2006, LEYDESDORFF and FRITSCH, 2006). As found in the former East-German cases, high-tech knowledge-intensive services couple the knowledge function synergies to geographical locations in R&D centres. Values for configurational information based on high- and medium-tech industries are more pronounced in the regions with a higher share of foreign-owned firms.

FDI in Hungary was initially driven by low labor costs. After a 10 to 15 year acclimation period, these trends have been replaced by investments focused on improving research potentials. This happened for example in the case of Audi in North-West Hungary (LENGYEL et al., 2006). In terms of its share of GDP production, its leading role in the local automotive cluster, its extended supply chain and its ownership of an institute at the local university, Audi is one of the leading companies in Hungary. Such companies transform the knowledge exploration and knowledge exploitation of innovation systems. Building on this example, one could argue that the synergy of three knowledge functions in high- and medium-tech industries measured by configurational information has been strongly reconstructed by FDI in Hungary.

According to these results we were able to identify three archetypes or paths of regional innovation systems in terms of knowledge function synergy: Budapest as an agglomeration economy; the north-western part of the country, which integrated to the European Union; and the southern and eastern parts of the country, where central planning and public R&D still have major effects on innovation system synergy.

When Hungary entered the transition period it was probably too late to shape the National Innovation System with innovation policy initiatives to fulfil the requirements of global competition (ENYEDI, 1995). In the period of transition from a centrally planned economy to a market economy and under the pressure of globalization and Europeanization, the Hungarian system was restructured not only in terms of linkages within the production system, but also in relation to its relevant external environment. During this process internal linkages were weakened and external linkages asynchronously reinforced (BARTA, 2002). Budapest and the north-western part of the country were able to find a path to the European marketplace more easily than the eastern part. Universities could further develop and build upon existing international relations, never fully disrupted to begin with, and FDI became a major factor in the transformation process. Thus to an even greater extent than traditional economies like the Netherlands, able to transform and adapt their national structures more gradually, the Hungarian system may have lost control of its political economy.

Our analysis was based on a three-dimensional model of innovation system synergy built on Storper's 'holy trinity'. The indicator, the measurement of reduction in uncertainty, has implication for further theoretical and empirical research. In particular, the complexity aspects of evolutionary economic geography raise questions concerning the role of external forces in local systems (MARTIN and SUNLEY, 2007). We believe that such forces, public R&D spending and foreign investment, may induce shifts in uncertainty through bifurcation effects. On the other hand, uncertainty is reduced in the system when agents develop their expectations of others, which is the phenomenon of knowledge-based development. Complexity aspects also highlight that agglomeration trends lead to far-from-equilibrium states, in which the measurement of uncertainty in innovation systems might open up new avenues for future research. Our model explained in section 2 also needs further elaboration. Further attempts are also needed to empirically test Storper's 'holy trinity' model, possibly through the use knowledge functions. However, these arguments remain for further papers.

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Table 1: Classification of high-tech and knowledge-intensive sectors

High-tech and medium-high-tech Manufacturing	Knowledge-intensive Services (KIS)
High-tech Manufacturing **30** Manufacturing of office machinery and computers **32** Manufacturing of radio, television and communication equipment and apparatus **33** Manufacturing of medical precision and optical instruments, watches and clocks *Medium-high-tech Manufacturing* **24** Manufacture of chemicals and chemical products **29** Manufacture of machinery and equipment n.e.c. **31** Manufacture of electrical machinery and apparatus n.e.c. **34** Manufacture of motor vehicles, trailers and semi-trailers **35** Manufacturing of other transport equipment	*Knowledge-intensive Services (KIS)* **61** Water transport **62** Air transport **64** Post and telecommunications **65** Financial intermediation, except insurance and pension funding **66** Insurance and pension funding, except compulsory social security **67** Activities auxiliary to financial intermediation **70** Real estate activities **71** Renting of machinery and equipment without operator and of personal and household goods **72** Computer and related activities **73** Research and development **74** Other business activities **80** Education **85** Health and social work **92** Recreational, cultural and sporting activities Of these sectors, **64, 72** and **73** are considered *high-tech services*.

Source: Laafia, 2002: 7.

Table 2: Distribution of company data by size

Number of employees	**Number of firms included in this study**	**Number of registered firms – 31st Dec. 2005**	**% included**
0 or unknown	275,202	365,861	75
1-9	369,280	805,209	46
10-19	5,976	20,870	29
20-49	4,921	11,046	45
50-249	3,733	4,860	77
250 or more	589	944	62
Total	659,701	1,228,999	54

Source: Hungarian Central Statistical Office (HCSO)

Table 3: Values of probabilistic entropy of the distributions in three dimensions and their combinations, bits

Regions	Counties	$H_{geography}$	$H_{technology}$	$H_{organisation}$	H_{gt}	H_{go}	H_{to}	H_{gto}	Number of firms	Number of subregions
Central Hungarian Region	Budapest	0.000	2.598	1.169	2.598	1.169	3.644	3.616	229,165	1
	Pest	3.544	2.786	1.120	6.311	4.662	3.755	7.245	67,342	15
Western Transdanubia	Győr-Moson-Sopron.	1.858	2.658	1.130	4.500	2.985	3.577	5.380	28,177	7
	Vas	2.061	2.711	1.172	4.750	3.225	3.674	5.655	14,490	9
	Zala	1.978	2.717	1.155	4.679	3.132	3.663	5.595	16,538	6
Central Transdanubia	Fejér	2.345	2.715	1.152	5.043	3.493	3.701	5.984	24,075	10
	Komárom-Esztergom.	2.496	2.747	1.185	5.229	3.679	3.700	6.131	17,760	7
	Veszprém	2.739	2.756	1.144	5.474	3.880	3.671	6.342	20,533	9
Southern Transdanubia	Baranya	1.717	2.790	1.139	4.483	2.853	3.742	5.402	25,308	9
	Somogy	2.445	2.804	1.160	5.218	3.601	3.767	6.135	15,680	10
	Tolna	2.084	2.699	1.122	4.761	3.203	3.652	5.677	12,344	5
Northern Hungary	Borsod-Abaúj-Zemplén	2.449	2.809	1.138	5.238	3.584	3.769	6.142	30,174	15
	Heves	2.174	2.832	1.195	4.991	3.366	3.788	5.901	15,095	7
	Nógrád	2.225	2.771	1.186	4.982	3.405	3.687	5.841	8,722	6
Northern Great Plain	Hajdú-Bihar	1.871	2.743	1.130	4.596	2.998	3.687	5.505	26,624	9
	Jász-Nagykun-Szolnok	2.215	2.801	1.181	4.996	3.392	3.772	5.920	16,513	7
	Szabolcs-Szatmár-Bereg	2.435	2.842	1.116	5.251	3.548	3.792	6.158	20,422	11
Southern Great Plain	Bács-Kiskun	2.574	2.769	1.174	5.329	3.745	3.742	6.258	25,158	10
	Békés	2.678	2.574	1.067	5.189	3.733	3.537	6.096	19,003	8
	Csongrád	1.755	2.767	1.067	4.506	2.819	3.686	5.397	26,122	7
Hungary		5.189	2.722	1.159	7.875	6.334	3.712	8.823	659,701	168

Table 4: The mutual information in three dimensions statistically decomposed at NUTS 3 level (counties) in millibits of information

Regions	Counties	T_{tgo} in millibits	ΔT in millibits	Number of firms
Central Hungary	Budapest	-27.75	-9.63	229,165
	Pest	-33.22	-3.39	67,342
Western Transdanubia	Győr-Moson-Sopron	-34.13	-1.46	28,177
	Vas	-48.89	-1.07	14,490
	Zala	-27.78	-0.70	16,538
Central Transdanubia	Fejér	-39.93	-1.46	24,075
	Komárom-Esztergom	-49.70	-1.34	17,760
	Veszprém	-43.45	-1.35	20,533
Southern Transdanubia	Baranya	-29.59	-1.13	25,308
	Somogy	-41.87	-0.99	15,680
	Tolna	-33.95	-0.63	12,344
Northern Hungary	Borsod-Abaúj-Zemplén	-52.32	-2.39	30,174
	Heves	-42.19	-0.96	15,095
	Nógrád	-50.37	-0.67	8,722
Northern Great Plain	Hajdú-Bihar	-31.93	-1.29	26,624
	Jász-Nagykun-Szolnok	-42.04	-1.05	16,513
	Szabolcs-Szatmár-Bereg	-38.53	-1.19	20,422
Southern Great Plain	Bács-Kiskun	-41.28	-1.57	25,158
	Békés	-41.85	-1.20	19,003
	Csongrád	-25.26	-1.00	26,122
Hungary		-23.55		660,290
Sum			-34.48	
T_0			10.94	

Note: In order to avoid reading difficulties we multiplied T_{GTO} values by 1000 and use the terms of millibit.

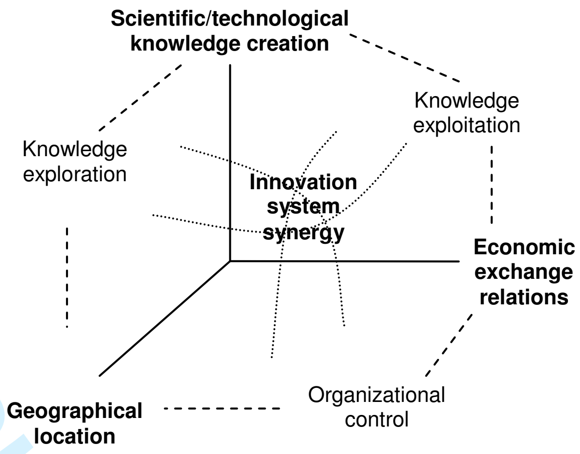
Table 5: High- and medium-high tech manufacturing vs. knowledge-intensive services and the effects on the mutual information in three dimensions

Regions	Counties	Knowledge-intensive services ΔT, millibits	Effect on the entropy %	Number of firms among knowledge-intensive service	High- and medium tech ΔT, millibits	Effect on the entropy %	Number of high-tech and medium-tech firms
Central Hungary	Budapest	-2.64	-18.9	64,791	-1.30	366.6	5,840
	Pest	-0.16	-51.7	8,495	-1.26	1179.0	2,551
Western Transdanubia	Gyor-M.-S.	-0.03	-47.9	24,684	-0.46	980.4	850
	Vas	-0.01	-57.0	18,563	-0.36	1064.9	321
	Zala	-0.01	-35.2	641,143	-0.15	636.0	464
Central Transdanubia	Komárom-E.	-0.01	-58.4	29,327	-0.53	1257.2	741
	Fejér	-0.02	-55.8	19,888	-0.54	1172.0	776
	Veszprém	-0.02	-46.3	25,299	-0.41	957.4	645
Southern Transdanubia	Baranya	-0.04	-16.9	27,327	-0.14	329.3	624
	Somogy	-0.02	-21.1	25,928	-0.11	298.5	394
	Tolna	-0.01	-29.6	24,313	-0.13	632.8	349
Northern Hungary	Borsod-A.-Z.	-0.07	-31.2	17,019	-0.51	633.8	847
	Heves	-0.01	-45.3	11,995	-0.29	948.5	498
	Nógrád	0.00	-49.6	14,597	-0.21	969.3	227
Northern Great Plain	Hajdú-Bihar	-0.03	-37.8	15,286	-0.30	712.4	696
	Jász-N.-Sz.	-0.01	-52.1	19,793	-0.37	1102.3	557
	Szabolcs-Sz.-B.	-0.03	-27.8	15,956	-0.23	551.7	629
Southern Great Plain	Bács-Kiskun	-0.03	-42.0	14,169	-0.45	886.5	845
	Békés	-0.03	-19.7	16,074	-0.16	351.0	440
	Csongrád	-0.03	-11.6	23,299	-0.09	206.4	823
Hungary		-19.28	-15.7	223,325	-3.08	351.7	19,147

Table 6: The contribution of high-tech services to knowledge function synergy

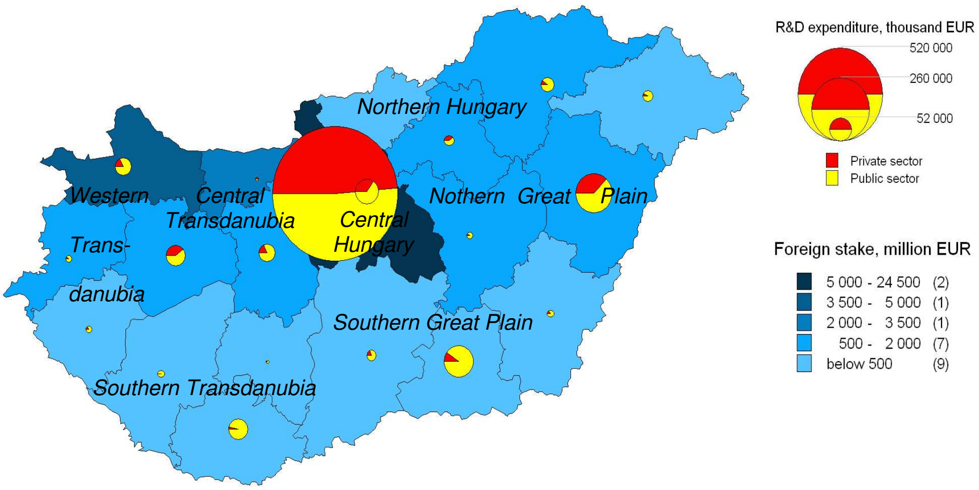
Regions	Counties	KIS mutual information ΔT, mbit	Effect on the entropy %	Number of records	HT-KIS mutual information ΔT, mbit	Effect on the entropy %	Number of records
Central Hungary	Budapest	-2.64	-18.9	64,791	-13.05	35.5	18,491
	Pest	-0.16	-51.7	8,495	-2.75	-18.7	5,019
Western Transdanubia	Gyor-Moson-Sopron	-0.03	-47.9	24,684	-0.25	-83.1	1,195
	Vas	-0.01	-57.0	18,563	-0.39	-63.3	640
	Zala	-0.01	-35.2	641,143	-0.24	-65.2	586
Central Transdanubia	Komárom-Esztergom	-0.01	-58.4	29,327	-0.31	-76.5	794
	Fejér	-0.02	-55.8	19,888	-0.67	-54.1	1,211
	Veszprém	-0.02	-46.3	25,299	-0.35	-74.4	836
Southern Transdanubia	Baranya	-0.04	-16.9	27,327	-0.14	-88.1	1,325
	Somogy	-0.02	-21.1	25,928	-0.58	-41.9	638
	Tolna	-0.01	-29.6	24,313	-0.32	-49.7	517
Northern Hungary	Borsod-Abaúj-Zemplén	-0.07	-31.2	17,019	-0.81	-66.0	1,387
	Heves	-0.01	-45.3	11,995	-0.21	-78.1	668
	Nógrád	0.00	-49.6	14,597	-0.19	-71.3	332
Northern Great Plain	Hajdú-Bihar	-0.03	-37.8	15,286	-0.38	-70.4	1,225
	Jász-Nagykun-Szolnok	-0.01	-52.1	19,793	-0.38	-64.1	709
	Szabolcs-Szatmár-Bereg	-0.03	-27.8	15,956	-0.49	-58.9	811
Southern Great Plain	Bács-Kiskun	-0.03	-42.0	14,169	-0.91	-42.0	1,075
	Békés	-0.03	-19.7	16,074	-0.39	-67.8	571
	Csongrád	-0.03	-11.6	23,299	-1.82	82.0	1,383
Hungary		-19.28	-15.7	223,325	-12.02	-49.0	39,415

Figure 1. Synergy of knowledge functions in an innovation system



Source: adapted from LEYDESDORFF, 2006.

Figure 2. Distribution of foreign stake and R&D expenditure in Hungarian counties, 2005



Source: Based on unique data request from the HSCO and on data downloaded from the HSCO website:

http://portal.ksh.hu/pls/ksh/docs/eng/xstadat/xstadat_annual/tabl6_03_02_05ie.html

Figure 3: Relations between probabilistic entropies (*H*), transmissions (*T*), and configurational information for three interacting variables.

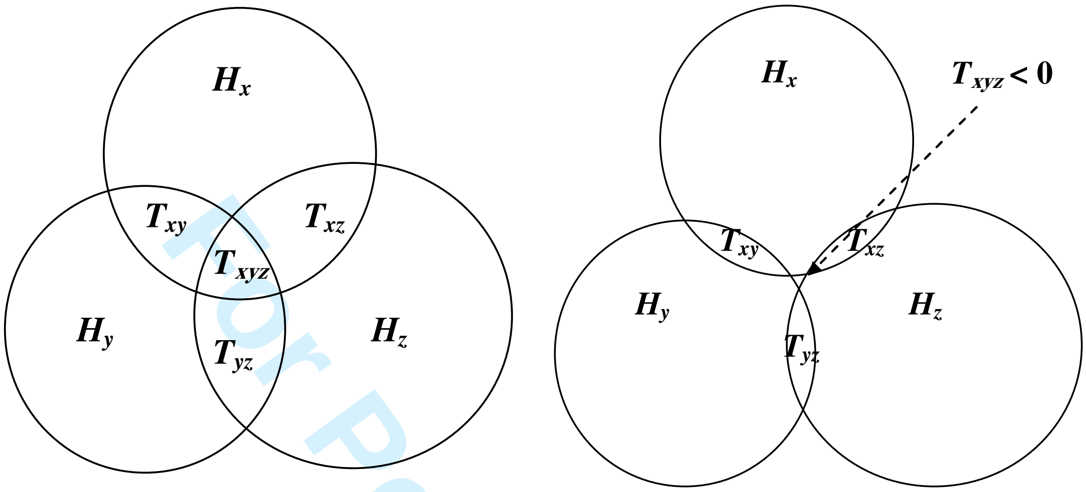


Figure 4: Configurational information among three dimensions at NUTS 3 level in Hungary

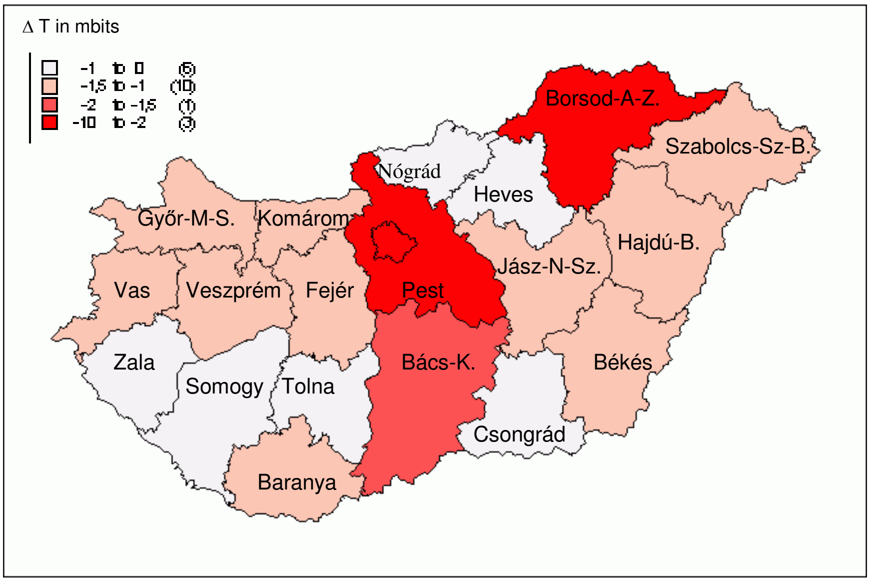


Figure 5: Configurational information in high- and medium-tech sectors at the NUTS 3 level in Hungary

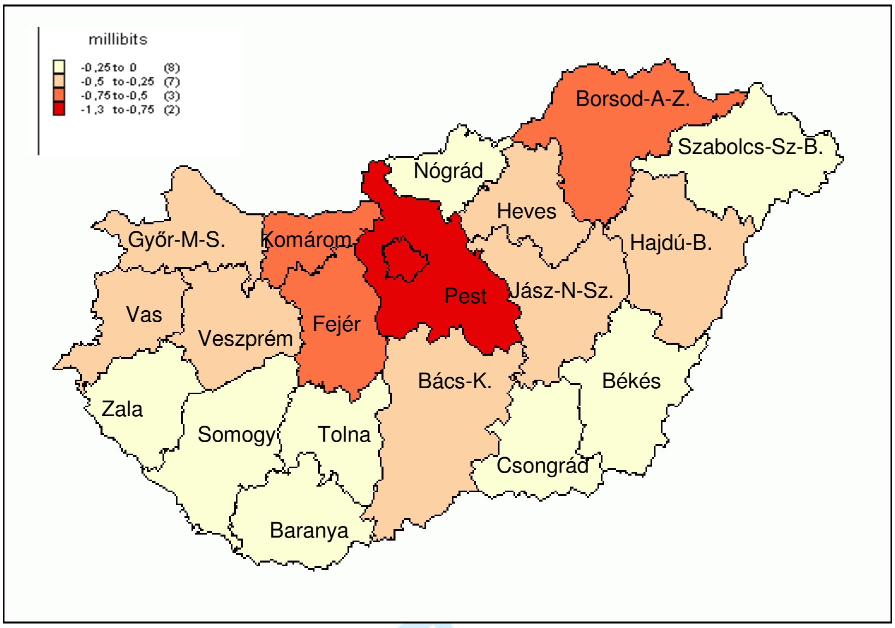


Figure 6. Size of foreign stake in foreign-owned companies and the knowledge function synergy in high- and medium-tech industries, 2005

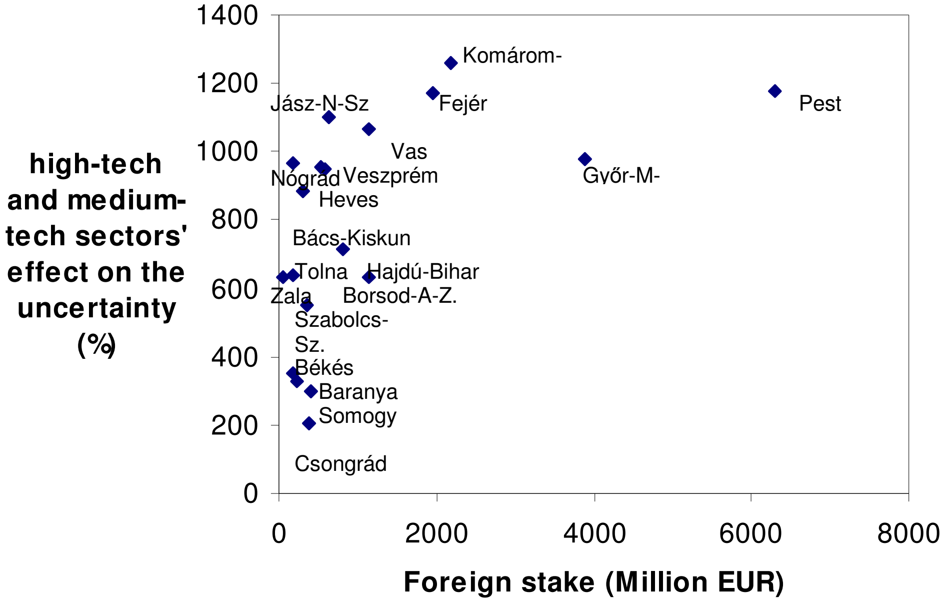
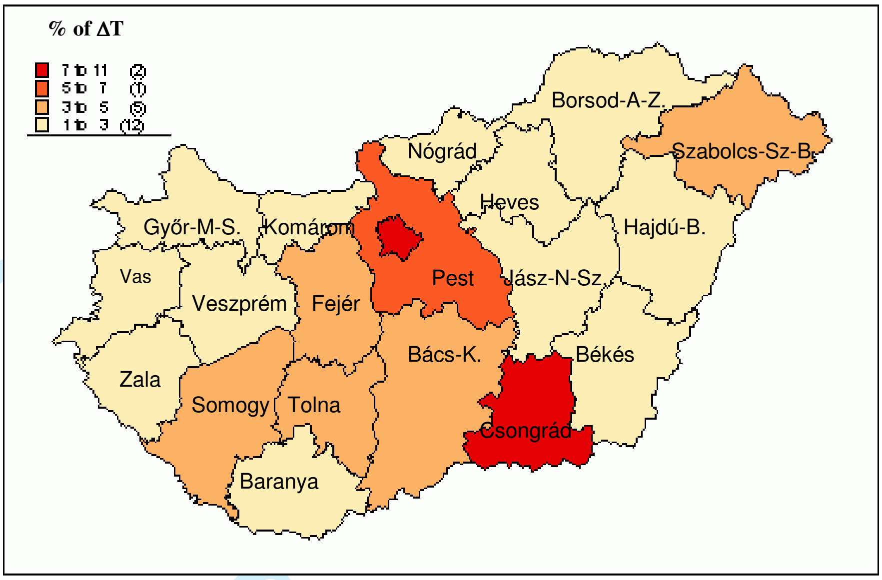


Figure 7: Contribution of high-tech services to configurational information in three dimensions (% of normalized ΔT in mbits by HTKIS)



Notes:

[i] NUTS is an abbreviation of "Nomenclature des Unités Territoriales Statistiques". This classification was established by Eurostat more than 25 years ago in order to provide a single uniform breakdown of territorial units for the production of regional statistics for the European Union; at http://europa.eu.int/comm/eurostat/ramon/nuts/introduction_regions_en.html.

[ii] It is important to note that in Hungary an enterprise with at least 10 % foreign business share falls in the definition of enterprises with a foreign stake.

[iii] The higher the indicator of H_x the more diverse the system and the higher the prevailing level of uncertainty.

[iv] Both YEUNG (2008, p. 59f.) and KRIPPENDORFF (2009, p. 200) noted that this information measure can no longer be considered a Shannon-type measure because of the possible circularity in the information transfers. Shannon-type entropy measures are by definition linear and positive. Since the measure sums Shannon-type measures in terms of bits of information, its dimensionality is also bits of information, and therefore it can be used as a measure of uncertainty and uncertainty reduction, respectively. YEUNG (2008, at pp. 51 ff.) further formalized configurational information in three or more dimensions into the I-measure μ^*.