Regional development and knowledge-based factors in European Union NUTS 2 regions: a structural equation modelling

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Abstract: This paper examines the relationships among regional development and knowledge-based factors applying a structural equation modelling (SEM). The object of investigation is a large sample of European Union (EU) NUTS 2 regions. The insights confirm the strategic relevance of the knowledge-based factors for the regional development, but they seem to suggest that it is the regional development that drives the attraction and the absorption of critical knowledge resources that, in turn, virtuously support renewed development dynamics.

Keywords: knowledge-based factors; regional development; European Union NUTS 2 regions; structural equation modelling.

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1 Introduction

In the last decade, a debate in academic and policy circles is raised about the relevance and the impacts of the knowledge-based factors for the regional development. Regional scientists, in fact, have increasingly modelled location and spatial competition with particular attention to the knowledge-based dimensions (Agarwal et al., 2010; Asheim et al., 2011; Malecki, 2010; Palma Lima and Ribeiro Carpinetti, 2012; Pike et al., 2006; Storper, 2011b).

On the other hand, on the base of the main concepts expressed by strategic management research streams, such as in particular the *resource-based view* and the *knowledge-based view*, different approaches, framework, tools to identify and leverage knowledge-based factors at territorial level have been introduced (Lerro and Schiuma, 2008, 2009; Sanchez Medina et al., 2007).

Although it is rather clear the position of the factor 'knowledge' for enhancing regional development, the most recent studies point out some problems that need to be further investigated. In particular, it seems important to better understand how the uneven distribution of specific knowledge resources across regions, as well as the causality links existing among regional development and knowledge-based factors may foster or hamper regional advantage (Asheim et al., 2011; Camagni and Capello, 2013; Castellacci and Archibugi, 2008; Dolfsma et al., 2008; Fritsch and Stephan, 2005; Palma Lima and Ribeiro Carpinetti, 2012; Storper and Scott, 2009). Accordingly, a main aim of this paper is to contribute to an improved and more transparent understanding about the relationships between conceptual and applied works in the area of regional development and related knowledge-based factors.

More in detail, this study uses a multivariate analysis – and specifically a structural equation modelling (SEM) – to address a fundamental question: *is the regional development an effect of the development of knowledge-based factors, or, instead, is the regional development driving the development of knowledge-based factors?* The object of investigation is a large sample of EU NUTS 2 regions. NUTS 2 is the framework generally used to define and apply regional policy and it is considered the best suited level for analysing regional issues (Eurostat, 2007; Vieira et al., 2011). From a methodological point of view, the empirical analysis uses a dataset gathered through Eurostat website and specifically through the *Eurostat Regional Yearbook 2009* (Eurostat, 2009).

The empirical work has been performed analysing data through a SEM (Hair et al., 1998). In particular, the application of the SEM has been implemented according to three consecutive stages. First, an *exploratory factor analysis* – based on the main components method – has been carried out on the items for each category of knowledge-based factors and regional development, in order to define the measures of all the constructs (Adelman and Morris, 1965, 1967; Temple and Johnson, 1998). Second, a proper *structural equation modelling* has been identified. The so-called 'structural' and 'measurement' models have been developed. Specifically, the second stage has been grounded on the formulation of the model, the identification of the model and the estimation of the parameters of the model. Finally, the *goodness of the fitting of the proposed model* to the observed data has been tested.

The paper is organised as follows. Section 2 provides the background of the research. Section 3 presents sample, data and indicators used to assess regions' knowledge resources and regional development and briefly introduces the SEM technique. Section 4 presents the results of the SEM, while Section 5 provides a discussion of the main insights of the research. Finally, Section 6 presents the implications of the study, its main limitations and the future development of the research.

2 Background

The first systematic attempts to study the relationships between knowledge and development were made by economic historians who wanted to understand why some territories managed to catch-up with the richer ones while other territories continued to be poor (Gerschenkron, 1962; Abramovitz, 1986, 1994). These works focused mainly on evidence from Europe and the USA.

From the 1970s onwards several studies about the relevance of knowledge for development patterns emerged. Since the beginning of the 1970s, the most advanced economies in the world were undergoing structural changes, turning them from industrialised economies based on labour, tangible capital and material resources into economies-based more and more on the creation, diffusion and exploitation of knowledge as new 'productive' factor. Hence, scholars argued about the emergence of a so-called *knowledge-based economy* (D'Aveni, 1995).

Accordingly, in the last decades, a wide number of research contributions have been produced in economics as well economic geography, arguing that ownership and use of assets, resources and capabilities related – in a direct or indirect way – to the notion of knowledge may represent new and relevant factors to activate and support local and regional development paths (Asheim, 1999; Cooke et al., 1997; Cooke and Morgan, 1998; Maskell et al., 1998; Morgan, 2004; Pinch et al., 2003). The relevance of this kind of factors has been recently recognised also by the stream of the New Economic Geography traditionally focused on tangible causes of the spatial concentration of economic activities such as trade costs, factor mobility, scale economies and product variety (Krugman, 2011).

At the same time, on the base of conceptualisations elaborated by emerging strategic management streams, such as, in particular the *resource-based view* and the *knowledge-based view*, these concerns led to adopt a new systemic conceptualisation for the study of territories' abilities and goods to generate growth from knowledge, focused on the notion of 'knowledge asset' (Teece et al., 1997).

Knowledge assets at territorial and regional level have been recently summarised in the intellectual capital (IC) concept (Bontis, 2004; Bounfour and Edvinsson, 2005; Lerro and Carlucci, 2007; Lerro and Schiuma, 2008, 2009; Malhotra, 2001; Sanchez Medina et al., 2007). It can be interpreted as the region's ability to transform knowledge and intangible resources into wealth. The notion of IC has been identified as relevant driver of the regional development and it has been stressed that the regions that are better equipped with this kind of capital that will make most progress (Sanchez Medina et al., 2007).

The knowledge assets grounding regional development have been traditionally grouped in three main dimensions as follows: human capital, structural capital and social and relational capital (Lerro and Schiuma, 2008, 2009).

The first comprises essentially the know-how characterising the different actors operating within the region (Dakhli and De Clercq, 2004). The concept of human capital pertains to individual's knowledge and abilities that allow for changes in action and economic growth. Human capital may be developed through formal training and education aimed at updating and renewing one's capabilities in order to do well in society. It has been argued that one's overall level of human capital has an impact on economic success, both at the business level and the macro-level (Florida et al., 2008). The traditional argument is that those who are better educated, have more extensive work experience and invest more time, energy and resources in honing their skills so that they are better able to secure higher benefits for themselves, and at the same time are better able to contribute to the overall well-being of the society (Black and Lynch, 1996; Cannon, 2000). As the economic development field adapts to meet the needs of an evolving international economy, regions are increasingly touting strengths in skilled labour to attract and retain innovative companies. In fact, most studies of corporate location decisions have shown skilled labour to be such an important asset that many regions have made it the central theme of regional marketing efforts. Innovative companies choose regions with a reliable and flexible supply of local talent. Further, firms tend to expand in regions in which they can find a core work-force with specialised skills related directly to their industry. According to this point of view, high-skilled people involved in research and development are essential to activate innovation dynamics and long-term economic growth and value creation. Their activities are also critical for developing innovative new products and services that can drive regional wealth-creation and prosperity.

The structural capital includes all those assets tangible in nature relevant for the development, acquisition, management and diffusion of knowledge (Lerro and Carlucci, 2007) as well structural intangible assets. About structural tangible assets, great attention is attributed to the quality and the quantity of *knowledge repositories* – universities, research centres, and knowledge-intensive companies – and *technology infrastructures* as key-value elements of tangible structural knowledge assets grounding regional development (Iyer et al., 2005; Knack and Keefer, 1997). The role of the knowledge repositories for the regional development is linked to the fact that the physical infrastructures often represent a pre-condition for the transfer of tangible and intangible assets from and towards the regional systems. Technological infrastructures, such as ICT, digital communication systems, networks, represent technical assets supporting the information and knowledge transfer processes within region and between region and external environment (Valkokari et al., 2012). In particular, ICT are recognised as a strategic resource for regions, since it supports the integration and coordination of the activities of the companies, of Public Administrations and citizens within the region as well as externally (Lerro and Schiuma, 2009).

The social and relational capital include relationships systems among the stakeholders, regional culture, role of the institutions, history, attitudes, norms, values, behaviours, image, and other cultural dimensions characterising the regional systems (Kitson et al., 2004; Putnam, 1993, 2000; Rodriguez-Pose, 2013; Tura and Haarmaakorpi, 2005).

Although recently the above knowledge-based factors have been largely considered at the basis of regional development, it needs improvements in understanding their capacity to really address dynamics processes of territorial growth.

In fact, despite the role and the relevance of the resource ‘knowledge’ emerge as a crucial source of innovation and competitiveness both at policy and economic level; it refers to phenomena that call for enormous circumspection, not least in view of its deeply positive but also problematical resonances suggestive of inspired and avant-garde accomplishment. Moreover, the issues derived from the mainstream of the research fields describe phenomena often as figures and policy *desiderata* rather than elaborating and applying theoretical frameworks focused on the concrete realities of contemporary capitalism in regional systems.

It should be added that there are aspects of the description that certainly reflect current regional realities, and at least some of the research that proceeds under the rubric of the *knowledge-based factors for regional development* has considerable merit. However, how regional systems create knowledge, access that knowledge and ultimately benefit from that knowledge is less than clear. In endogenous growth theory, it is assumed that the entire geographic context, typically a Country, will automatically benefit from investments in new knowledge (Lucas, 1988; Romer, 1986, 1990). The general underlying assumption of this approach is that newly created knowledge is automatically available to all agents in the economic process. Since knowledge behaves like a public good, all agents will benefit from it, which will increase the rate of economic growth in a knowledge-based economy. However, as the ‘European paradox’ (Audretsch and Kelibach, 2008) has suggested, investments in new knowledge do not automatically translate into competitiveness and growth. It is described a more general paradox associated with knowledge, that high levels of investment in new knowledge do not necessarily and automatically generate the anticipated levels of competitiveness or economic growth. That is, knowledge investments do not automatically translate into higher levels of competitiveness and growth. It has been observed, in fact, that knowledge is inherently different from the more traditional inputs of production, such as labour and physical capital (Arrow, 1962a, 1962b) for at least two main reasons:

1 knowledge has a public good characteristic

2 the economic value of knowledge is intrinsically uncertain and its potential value is asymmetric across economic agents (Audretsch and Kelibach, 2008).

This means that a regional development strategy and the related policy actions may need to take into account several specific elements to help generate growth in regions. In particular, it is it is important to better understand the causality relationships linking knowledge-based factors to regional development and hypothesise that some pre-conditions and filters may exist between endowment of knowledge-based factors, investments in new knowledge, its use, commercialisation and finally regional development, so that, in contrast to the models of endogenous growth, knowledge does not automatically spill over and result in increased competitiveness and regional development patterns.

Accordingly, the research aim of this paper is not to deny that regional systems are often endowed and use effectively with certain kinds of knowledge potentials as it is to propose a theoretical formulation and an empirical testing that resituates these potentials in the context of a more widely ranging portrayal of regional development dynamics in the current and real conjuncture. In pursuit of this goal, an attempt is made to briefly review the extant body of research about *knowledge-based factors for regional development* while simultaneously pointing out an alternative horizon of investigation, and perhaps most importantly of all extending a warming to researchers and policy-makers that the quest for the knowledge-based regions, at least in the terms of many current formulations, is as likely as not to be attended by heavy costs and disappointments as it is by some sort of regional efflorescence.

3 Data and methods

3.1 Sample and data collection

As previously anticipated, a main aim of this paper is to contribute to an improved and more transparent understanding about the relationships between conceptual and applied work in the area of regional development and related knowledge-based factors. For this purpose, we needed a dataset that was as comprehensive as possible, both with respect to measurable aspects and time and regions coverage. The empirical analysis was based on the Eurostat database, the official dataset of European Union (EU) that includes indicators for a large number of EU regions classified according to the different NUTS nomenclatures. Specifically, the Eurostat Regional Yearbook 2009 was used as database to identify and assess the different indicators related to the EU NUTS 2 regions (Eurostat, 2009).

Empirical work started with an initial screening of data for 272 EU NUTS 2 Regions as classified by Eurostat, and more than 60 potentially relevant areas and indicators proposed by the academic literature (Archibugi and Coco, 2004; Huggins and Izushi, 2007), policy-oriented reports (European Commission, 2005) and elaborated by the authors (Table 1). Then, we narrowed down the sample to 184 Regions and 15 indicators. The values of the indicators were considered according to the latest and up-date value available in the database provided by the Eurostat Regional Yearbook 2009. This choice was related to data-coverage and time-setting. Typically, most developed market economies figure prominently with good coverage, while former socialist economies and new entrants lack data on many potential useful indicators. Moreover, a longer and more recent time period would clearly been desiderable, but that would have implied that many of the data sources taken into account would not been available and/or most former socialist regions would have had to be excluded from the analysis. Still there were a few missing data points for many regions/indicators, which we estimated with the help of information on the other indicators and regions. In particular, missing data were substituted with the medium value of the other NUTS 2 belonging to the same State according to the NUTS 1 nomenclature.

Table 1 Measuring regional knowledge-based factors: potential areas and indicators

Number of graduates/100 people 25 years old; number of science and engineering graduates/100 people 20–29 years old; number of graduates employed after three years from the degree/100 people graduates; PC users/100 people; number of professionals employed in public and private R&D activities/100 people employed; number of people with basic educational skills/100 people; number of PhD/number of graduates; number of university students involved in a mobility program/number of the university students; competence of public officials and public administration managers and employees; number of professional managers leading firms of the region/number of firms of the regions; number of participants in life-long learning/100 people aged 25–64; number of firms associated in industry associations/total number of the firms of the region; number of agreements among universities and firms of the regions; number of agreements among universities and industry associations; number of university stages activated within firms; number of agreements among schools and firms of the region; number of agreements among schools and industry associations; number of conflicting labour-employer relationships; number of associations/100 people; civic activities, trust and tolerance; civil and political rights; rate of irregular work; crime rate; gender pay gap; citizens' confidence in EU institutions; Voter turnout in local elections; voter turnout in national and EU parliamentary elections; quality of governance: reputation, corruption, law and order, independence of courts, property rights, business friendly regulation; number of universities in the region; number of research centres in the region; number of technological districts in the region; scientific production of the researchers of the universities of the region; scientific production of the researchers of the research centres of the region; internet access in schools; patenting; e-governments services and tools

3.2 Variables and measures

In order to coherently measure regional knowledge-based factors, we used indicators such as researchers as a percentage of persons employed, human resources in science and technology by virtue of occupation (percentage of active population), employment in high and medium high-tech manufactory (percentage of total employment), students in all level of education (as percentage of total population), students at upper secondary and post-secondary non-tertiary education (as percentage of the population aged 15 to 64), students in tertiary education (as percentage of the population aged 20 to 24), educational attainment level (percentage of the population aged 25–64 having completed tertiary education), lifelong learning (percentage of the adult population aged 25 to 64 participating in education and training during the four weeks preceding the survey), internet access and broadband connections in households (share of households with internet and broadband connections), total R&D expenditure as a percentage of GDO and patent applications to the EPO per million inhabitants[1].

The reason for selecting this set of indicators was two-fold. First, from a conceptual point of view, we followed previous studies (Fagerberg and Srholec, 2008; Castellacci and Archibugi, 2008; Chaminade and Vang, 2008) and argue that these variables represent distinct aspects of the process of regional cognitive and technological accumulation and capacity building. Secondly, from a practical point of view, these indicators were available for a very large number of EU NUTS 2 regions.

For example, human resources involved in science and technology is a measure of the supply of new high-skilled people to the industrial and public system, population with secondary and tertiary education is a general indicator of the supply in basic and advanced skills. Completed upper secondary education is generally considered to be the minimum level required for successful participation in a knowledge-based society. It is increasingly important not just for successful entry into the labour market, but also to allow students access to learning and training opportunities offered by higher education. However, the adoption of innovations in many areas depends on a wide range of skills seeded along the time. Hence, the relevance of other factors measured, for example through the participation in life-long learning programs and the educational attainment level. They are based on the fact that a central characteristic of a knowledge economy is continual technical development and innovation. Individuals need to continually learn new ideas and skills or to participate in life-long learning. The ability to learn can then be applied to new tasks with social and economic benefits. Internet access and broadband connections as well as patent application to the EPO can be considered further good proxies of the knowledge creation and application within the regional systems.

On the other hand, to measure regional development, the following indicators were considered: gross domestic product per inhabitant, in PPS (GDPpi), employment rate for the 15–64 age group (ER), unemployment rate (UR), net migration (NM).

GDPpi is a widely used measure of the economic performance as well as of the standard of living of a society. It is defined as the total value of all goods and services produced in a given region on the population of the same region less the value of any goods or services used in their creation (European Commission, 2005; Krugman, 2011). It is, however, important to emphasise that, if GDPpi is a proxy of citizens' material wealth, it cannot be considered as a holistic measure of their well-being, since some factors can have a positive impact for the increase of GDPpi, but not contribute to the increase of the quality of life. Employment is a key economic and social issue as it contributes to both quality of life and social inclusion, which are among the final objectives of value creation for a region. As exclusion from the labour market is a major factor of social exclusion and an increase of employment is likely to reduce poverty, thus contributing positively to the economic and social aspects of regional development. To assess this dimension we have adopted the ER defined as the ratio between the number of people working and the total work force as total number of people available to work (European Commission, 2005). Unemployment rate (UR) has been defined as the ratio between the number of people not employed and the total active population (European Commission, 2005). Finally, the NM is a proxy of the regions' capacity to attract and retain people on their own contexts. Arguably, this is related in a broader sense to the 'opportunities' that a regional system is able to offer in economic, socio-cultural and environmental perspective as well to the general conditions of well-being that is able to guarantee (Krugman, 2011). Table 2 presents the list of the selected indicators used for the empirical analysis and their synthetic notation.

Table 2 List of the selected indicators and synthetic notations

Net migration (NM), by NUTS 2 regions, coverage 2003–2007 per 1,000 inhabitants – i1
Employment rate for the 15–64 age groups (ER), by NUTS 2 regions, 2006, percentage – i3
Unemployment rate (UR), by NUTS 2 regions, 2007, percentage – i4
Gross domestic product per inhabitant, in PPS (GDPph), by NUTS 2 regions, 2006, in percentage of EU27=100 – i5
Internet access and broadband connections in households, by NUTS 2 regions, 2008, share of households with internet and broadband connections – i6
Total R&D expenditure as a percentage of GDP, all sectors, by NUTS 2 regions, 2006 – i7

Source: Eurostat (2009)

Table 2 List of the selected indicators and synthetic notations (continued)

Researchers as a percentage of persons employed, all sectors, by NUTS 2 regions, 2006 – i8
Human resources in science and technology by virtue of occupation, by NUTS 2 regions, 2007, percentage of active population – i9
Employment in high and medium high-tech manufactory, by NUTS 2 regions, 2007, percentage of total employment – i10
Patent applications to the EPO per million inhabitants, by NUTS 2 regions, 2004 – i11
Students in all level of education, as percentage of total population, by NUTS 2 regions, 2007 – i12
Students at upper secondary and post-secondary non-tertiary education, as percentage of the population aged 15 to 64, by NUTS 2 regions, 2007 – i13
Students in tertiary education, as percentage of the population aged 20 to 24, by NUTS 2 regions, 2007 – i14
Educational attainment level, by NUTS 2 regions, 2007, percentage of the population aged 25–64 having completed tertiary education – i15
Lifelong learning, by NUTS 2 regions, 2007, percentage of the adult population aged 25 to 64 participating in education and training during the four weeks preceding the survey – i16

Source: Eurostat (2009)

3.3 Methods: factor analysis and structural equation modelling

Variables measuring the creation, distribution and use of knowledge tend to be highly correlated. Thus, before proceeding to the core of our empirical analysis, it was important to reduce this large set of indicators to a smaller number of distinct and not overlapping dimensions. A factor analysis has been performed in order to identify the explanatory variables that are better suited to analyse the cross-region distribution of knowledge, i.e., those variables that better discriminate between regions' knowledge levels (Adelman and Morris, 1965, 1967; Basilevsky, 1994; Hair et al., 1998).

An *explorative factor analysis* was performed. It has been carried out in two steps. First, the factors were identified and a solution was found in terms of number of factors to be retained. Principal-component factors estimation, which has been shown to be robust to different assumption on the distribution of the data, was chosen. The so-called Kaiser criterion (eigenvalue above unit) was used to determine the number of factors to be retained. These factors resulted directly orthogonal, and then we assumed that the underlying factors were totally uncorrelated and we did not adjust them through so-called 'rotation' to maximise the differences between them. A characteristic of the factoring procedure is that the variables are standardised by deducting the mean and dividing by the standard deviation. The indicators of regions' knowledge-base have been standardised before entering the factor analysis. The general formula used to standardise the indicators adopts the 'distance from the best and the worst performers' method of standardisation, which is the same used for the indicators composing the Technology Achievement Index (Desai et al., 2002; UNDP, 2001) and the ArCo technology index (Archibugi and Coco, 2004). We used the mean and the standard deviation of the pooled data for the standardisation. We used the method of the principal components factors to arrive at the solution (Hair et al., 1998). In this way, we take into account as much information as possible.

The analysis led to the selection of four principal and latent variables jointly explaining 71% of the total variance. Details of the factor analysis are presented in Appendix A.

The *first latent variable* – grounded on indicators i5, i6, i15, i16 and i9 – loads highly on several indicators associated with different aspects of human capital. We suggest interpreting it as a synthetic measure of the abilities and capabilities characterising people and strongly influencing development, diffusion and application of knowledge within regional systems. Hence, we label this factor 'advanced human capital' (AHC).

The *second latent variable* – grounded on indicators i8, i12, i13 and i14 – is mainly related to levels of education, skills and abilities that can be considered almost pre-requisites for people to have chance to play a role in the economic and social-base of the regional system. Hence, we label this factor 'basic human capital' (BHC).

The *third variable* – grounded on indicators i10, i11, and i7 – loads highly on indicators associated to the effective utilisation of the knowledge-base into the economic and productive system characterising the region. Accordingly, we label this factor 'industrial and structural capital' (ISC).

Finally, the *fourth variable* – grounded on indicators i1, i3 and i4 – loads highly and coherently on several aspects of the economic performance of the regional systems. Then, we label this factor 'performance of regional development' (PRF)[2].

Simple correlations may mask more complex relationships, so in the next step we apply structural equation modelling to analyse the system of relationships among the three groups of knowledge-based factors and the level of regional development[3]. The hypothesised model was estimated using AMOS of SPSS software package. Then, a SEM was elaborated. It required the development of the following steps:

a *Formulation of the model*. The so-called 'structural' and 'measurement' models are elaborated. A path analysis is developed. Then, the hypothesised *path diagram* is designed.

b Identification of the model.

c Estimation of the parameters of the model.

d *Evaluation and improvement of the proposed model.* The goodness-of-fit of the proposed model to the observed data is assessed and tested using the following statistics: the chi-square statistics (χ^2), the expected cross-validation index (*ECVI*); the goodness of fit index (*GFI*); the adjusted goodness of fit index (*AGFI*); the Tucker-Lewis index (*TLI*); the root mean square error of approximation (*RMSEA*). Satisfactory models fit are indicated by non-significant chi-square test values > 0.9 and RMSEA < 0.08.

e *Analysis of the obtained results*. A series of effects identified through the path analysis, are analysed: in particular, the direct and indirect effects of the variables are investigated and summarised in the total effect.

4 Results

Table 3 and Table 4 report the means and standard deviations as well as the correlation matrix for the observed variables.

Table 3 Descriptive statistics

Item	*Mean*	*Std. deviation*
i1	3.53	6.05
I3	64.64	7.54
I4	7.91	4.17
i5	95.20	36.48
i 6	46.54	14.99
i 7	1.34	1.09
i8	0.84	0.55
i 9	27.84	6.91
i 10	6.80	3.78
i 11	101.61	132.08
i 12	21.73	3.59
i 13	38.13	10.79
i. 14	54.35	25.65
i 15	22.23	7.88
i 16	8.50	6.08
Valid N (listwise)	184	184

The structural model was used to assess the validity of causal structures among latent variables. We then proceeded to examine the structure of the relationships through the parameters estimates. The results of the SEM are summarised in the path diagram as in Figure 1. In the path diagram, PFR= ξ_1 is the only exogenous latent variable, while AHC = η_1, BHC = η_2 e ISC = η_3 are the three endogenous latent variables. Consequently, the observed variables assume the labelling as follows:

$$\text{i1} = X_1; \text{i3} = X_2; \text{i4} = X_3;$$
$$\text{i5} = Y_1; \text{i6} = Y_2; \text{i9} = Y_3; \text{i15} = Y_4; \text{i16} = Y_5; \text{i8} = Y_6; \text{i12} = Y_7; \text{i13} = Y_8; \text{i14} = Y_9;$$
$$\text{i7} = Y_{10}; \text{i10} = Y_{11}; \text{i11} = Y_{12}.$$

Details and analytical formulation of the SEM are presented in the Appendix B. Considering the main latent variables, analysis shows that it is the construct PRF – denoted with ξ_1 – that significantly affects AHC – denoted with η_1 (γ_{11} = 1.09; p-value = 0.05) as well as BHC – denoted with η_2 (γ_{21} = 0.47; p-value = 0.05).

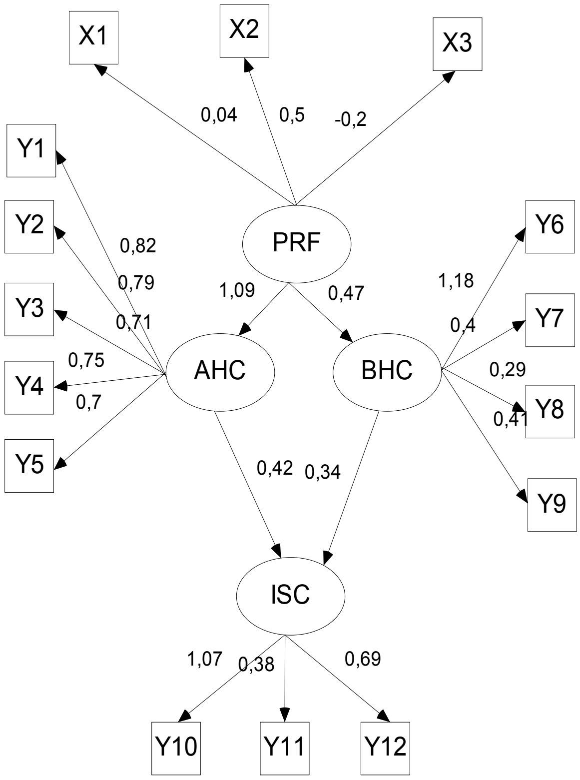
Moreover, both AHC and BHC influence ISC – denoted with η_3 and then play the fundamental role of mediating PRF with ISC. In particular the influence of AHC on ISC is shown by β_{31} = 0.42 (with p-value = 0.001), while the influence of BHC on ISC is shown by β_{32} = 0.34 (with p-value = 0.001).

Moreover, PRF is strongly explained by X_2 (GDPpi), with) $\lambda_{21}^{x} = 0.5$, and then X_3 (ER) with $\lambda_{31}^{x} = -0.2$. AHC, instead, presents standardised regression weights that are relevant for all the variables Y_1, Y_2, Y_3, Y_4 e Y_5. They show values, respectively, equal to $\lambda_{11}^{y} = 0.82$, $\lambda_{21}^{y} = 0.79$, $\lambda_{31}^{y} = 0.71$, $\lambda_{41}^{y} = 0.75$ and $\lambda_{51}^{y} = 0.70$.

Table 4 Correlation matrix

Item	*i1*	*i3*	*i4*	*i5*	*i6*	*i7*	*i8*	*i9*	*i10*	*i11*	*i12*	*i13*	*i14*	*i15*	*i16*
i1	1.000														
i3	.137	1.000													
i4	-.295	-.659	1.000												
i5	.290	.527	-.321	1.000											
i6	-.034	.538	-.126	.576	1.000										
i7	.015	.417	-.111	.481	.487	1.000									
i8	.120	.294	-.033	.529	.422	.673	1.000								
i9	.017	.430	-.248	.659	.566	.637	.570	1.000							
i10	-.135	.237	-.147	.098	-.001	.422	.162	.237	1.000						
i11	-.064	.508	-.269	.555	.482	.724	.410	.556	.495	1.000					
i12	-.220	-.200	.256	.066	.393	.128	.397	.183	-.217	.010	1.000				
i13	-.099	-.066	-.098	.212	.117	.159	.358	.383	.098	.130	.347	1.000			
i14	.135	.144	-.199	.287	.078	.174	.504	.403	-.096	.060	.386	.276	1.000		
i15	.103	.392	-.026	.522	.639	.497	.626	.513	-.115	.371	.326	.074	.345	1.000	
i16	.067	.479	-.168	.431	.630	.413	.457	.433	-.116	.276	.288	.105	.219	.482	1.000

Figure 1 Path diagram



BHC is mainly measured by Y_6, with $\lambda_{62}^{y} = 1.18,$ while it is less influent the relationship that presents with the variables Y_7, Y_8 e Y_9.

Finally, the variable ISC is determined mainly by Y_{10} with $\lambda_{10.3}^{y} = 1.07,$ and then by Y_{12}, with $\lambda_{12.3}^{y} = 0.69$ and Y_{11} with $\lambda_{11.3}^{y} = 0.38.$

We tested the theoretical model, which fit the data adequately. The goodness-of-fit show the following values: the chi-square statistics χ^2 = 117.9, df = 51; the ECVI – *ECVI* = 1.335; the GFI – *GFI = 0.934*; the AGFI – *AGFI* = 0.845; the TLI – *TLI* = 0.922; the RMSEA – *RMSEA* = 0.08. Moreover, the NFI was 0.923, while the CFI was 0.959 on a range 0–1.

The value of χ^2 shows the goodness-of-fit of the model to the empirical data. This is confirmed also by the value of the ECVI, very close to the value of the satured model (1.283), as well as by the values of all the indicators. Each of them is posited in their canonical ranging of acceptance (Hair et al., 1998). Table 5 details the fit statistics.

Table 5 Fit indices

Model	*GFI*	*AGFI*	*TLI*	*RMSEA*	*ECVI*
Default model	0.934	0.845	0.922	0.085	1.335
Saturated model	1.000	1.000	1.000	0.291	1.283

5 Discussion

Recently, the quality and availability of data on different aspects of regional development have improved, but there is still a relevant lack of homogeneous and significant data about the possession and the utilisation of knowledge-based factors as well as new and significant measures of regional development. This shapes the challenge for researchers in this area, on the one hand, to investigate economic performance across regions (Ottaviano, 2011), and, on the other hand, to define and collect not-established data about knowledge sources able to potentially explain the reasons behind the large differences in regional development patterns (Usai, 2011).

Despite the theoretical assumptions that traditionally postulate the role and relevance of the knowledge dimensions as new drivers of the regional development, the empirical analysis on one hand confirms the strategic relevance of knowledge-based factors for local and regional development, but it highlights that it is the regional development that drives the attraction and the absorption of critical knowledge resources that, in turn, virtuously support renewed mechanisms of development.

More in depth, the empirical analysis suggests that a well-developed education system is essential for regions that wish to enhance economic performance. There is a strong and significant statistical relationship between advanced and basic education level and both regional *GDPpi* and ISC. This is aligned with the wide historical and descriptive evidences recommending that regions that have succeeded in catch-up have given a high priority to the education system.

Moreover, the results of this study put forward the idea that workers tend to migrate towards those regional systems that are already characterised by an endowment of relevant knowledge-based factors as well as by high levels of economic development which, in turn, determines opportunities to exploit and share knowledge as well create new value for the local context. This is coherent with recent theories of local growth suggesting that the locational choices of individuals with high level of human capital are principally in response to features of the local environment generally called ‘amenities’ (Storper and Scott, 2009).

Very interestingly, although a well-functioning knowledge-base emerges as a relevant factor for regional development, it is not the driver. Knowledge is critical, but in order to spread its value, it needs to be exploited in a local context which has to be already developed (Hansen and Winther, 2011). This could suggest that it is necessary a kind of critical mass, in terms of tangible and intangible infrastructures, resources, assets and financial capital, in order to allow that specific knowledge may impact regional *GDPpi.* In other words, the development seems to be an essential pre-requisite to attract new knowledge that, in turn, creates new development.

All this seems to support a long tradition of analysing spatial-economic development, mainly based on notions such as path dependency, agglomeration, specialisation, urbanisation, the creation of cores and peripheries, and particularly the tendency for there to be circular and cumulative reinforcement of certain patterns (Storper, 2011a). Moreover, it shares previous findings by Chaminade and Vang (2008) and Castellacci and Archibugi (2008) about the issue that poor regions due to the lack of absorptive capacity are much less likely than other regions to benefit from investments in knowledge – in terms of advanced skills and knowledge structural capital.

Many regions, particularly the regions of the new entrants’ countries in EU, find hard to develop, use and exploit knowledge-based factors. This seems to suggest that regional development is strongly affected by elements of path dependency and endogenous growth and only once the economic development mechanisms are in place, regions can accelerate and support their growth by developing and sustaining basic and advanced skills and well-functioning structural knowledge assets. Of course, the knowledge capital of a region is something that is built incrementally over many years. It emerges, then, the need to build the essential economic pre-requisite for the regional development that in the medium and long term should guarantee the attraction and retention of knowledge-based factors.

Hence, the investments in knowledge-based factors should be thought not as lever to activate first development stage and to gain short term return, but they should be considered as development accelerator. Therefore, regions that succeed in developing and sustaining a competitive private sector and well-functioning public system do attract knowledge and gain economic and social benefits from investments in knowledge, while those that fail tend to fall behind. However, many NUTS 2 regions, also in the richer nations of the EU find it hard to develop economic endogenous growth necessary for joining virtuous knowledge-based dynamics.

6 Implications and conclusions

This study is an empirical application of some theoretical foundations of the knowledge-based development research stream applied to regional level. In particular, we have tried to bridge existing gaps between theory and reality by overcoming at least three limitations of previous studies: use of quantitative methods to evaluate relationships between knowledge-based factors and regional development, the hypothesis and the examination of the causal links and, finally, the use of a consistent sample from EU dataset. Hence, this study may make a significant contribution both to the theoretical side of the knowledge-based development research streams as well as to the empirical one. Our research methodology has the potential to provide a solid platform for future research to support the theoretical foundations of the knowledge-based development research streams, and to enhance understanding of the role knowledge-based factors play in the regional development dynamics. The results are especially interesting because they are one of the first attempts to reveal the causality links of a set of knowledge-based factors on a set of regional development measures.

Two important theoretical implications arise from our research. About the first implication, we argued that, although over the last years the emphasis on the knowledge-based factors has strongly contributed to create a wide acknowledgement of its strategic role for the regional development dynamics, we did not have still developed a clear, coherent and shared framework of analysis of knowledge-based factors of the regions. In particular, we underlined that the literature rarely has focalised the attention both on empirical researches finalised to explore and test the causal relationships among knowledge-based factors, sustained competitive advantage and regional development. This study offers one of the first known tests of the knowledge-based development view's main prescriptions in which a more precise operationalisation of multiple factors constructs is used rather than general proxy measures or even isolated, individual factors. In fact, our study has been interested in better understanding whether the regional development is an effect of the development of knowledge-based factors, or, instead, is the regional development driving the development of knowledge-based factors. Although the research question was basic and fundamental, it had rarely been appropriately or adequately tested both within the knowledge-based development literature and the regional economics streams. Although difficulty in operationalising the constructs, this study does help to answer Carmeli and Tishler's (2004) call for more fine-grained analysis of intangible elements of all the organisations. Moreover, on a theoretical point of view, the research represents one of the first contributions to synthesise, develop and enriches the existing literature about knowledge-based factors and its role and relevance for regional development.

About the second theoretical implication, recognising that regions are complex entities, researchers often describe and analyse them as a systems of interdependent core elements – resources, processes, policies – that by complementing each another contribute to enhancing and sustaining performance. The problem is that measuring core resources and their relationships with the region's performance is often difficult, particularly when it is intended to estimate the effect of a possibly large set of knowledge-based factors with all manner of possible complementarities and interactions among them, on a possibly large set of performance measures. Though anecdotal and case study evidence does exist (i.e., Bounfour and Edvinsson, 2005), we had not yet sample study that demonstrate how several core elements with cognitive nature enhance regional development.

Substantial efforts have been devoted in the last years to enhancing the theoretical insights of the resource-based view and knowledge-based development view to regional level. Generally, the design of most quantitative view studies has employed a single major factor to explain variations in performance, which often consists of a single measure.

This study has attempted to bridge different gaps of the existing literature by using a quantitative approach to empirically test the causal relationships between knowledge-based factors and regional development. The findings are especially important considering that we estimated the simultaneous impact of a set of knowledge-based factors on a set of several regional development performance measures. Specifically, the application of the SEM let to analyse and relate contemporaneously the set of the knowledge-based constructs to the set of the regional development constructs. This technique facilitated the identification of the relationships of key variables in one dataset on all the variables in other set.

The insights deriving from this research suggest further few key points. In particular, the results of this study suggest that while some knowledge-based factors s are important sources of regional development, other business, geographical and institutional factors may be also important. Thus, one of the potential theoretical implications to be drawn from this study is that knowledge-based factors should never be studied in isolation, but rather should be studied with respect to regional economic, geographical, institutional, cultural and historical characteristics. As it is argued, knowledge-based factors are mainly valuable in the context of the regions in which they are applied. That is, knowledge value might be contingent upon the region, and even country, context.

In terms of policy implications, it emerges that a critical issue for decision-makers is how they can drive their regions to a consistent level of development exploiting effectively knowledge-based factors. Of course, there are no definitive answers and this research does not provide any. However, the results of this research provide insights that might be helpful to decision-makers. The first and perhaps less obvious managerial and policy implication is that regional development that drives the attraction and the absorption of critical knowledge resources that, in turn, virtuously support renewed development dynamics. At the same time, it is highlighted the need to enlarge the temporal perspective by which investments in knowledge should return and to consider the adoption of strategies in the medium-long term: the investments in knowledge-based factors cannot be based on the short term return, but they have to be considered as an accelerator for the development of 'assets' and 'technologies' that potentially will have effect in the next decades. While the above implications offer potentially helpful normative insight and offer confirmation of other previous studies, the results of this study also suggest some more difficult to interpret policy actions. Despite of the theoretical relevance of the knowledge-based factors it is to underline that managers and policy-makers need first of all to be supported in identifying the levers through which potentially exploit and gain benefits from regions' knowledge-base, and they need to seriously evaluate if real economic and social benefits will be achieved from such efforts, particularly with respect to investments in specific resources and assets that 'should' create value.

No research study is without limitations and this is no exception. The first limitation may rest with the methodology. Within a recent debate around the methods used to study the theory, Rouse and Daellenbach (1999), for example, argue that large sample studies based on secondary sources of data fail to untangle the resources that might provide organisational sustainable advantage. Secondary sources of data, according to Rouse and Daellenbach (1999), simply do not provide the level of detail on resources; this must largely come from research inside the object of analysis, in our case region. Indeed, Rouse and Daellenbach (1999, p.490) call for researchers to consider 'intrusive' methods. However, field-based case studies limit the generalisability of results and do not fit at producing empirically robust conclusions (Dess et al., 1990; Michalisin et al., 1997).

With respect to the methodology employed in this study, it is recognised that the conceptual model designed to test our research question can be considered simplified and imposed on the availability and proxies of the knowledge-based factors data. However, using secondary sources to obtain proxies and objective data to study resources effects on performance is a common problem regarding intangible resources (Das and Teng, 2000). Unlike tangible resources and assets, intangible, knowledge-related data are still very difficult to collect and often researchers are left with any or only a few proxy measures.

A second limitation is that although the application and the results obtained by the SEM can determine easy enthusiasms, they must certainly be treated with caution: many other factors, resources and assets underlying regions' performance in terms of development might be considered. In contrast to the broad discussion of resources and assets in the literature, this study examines only a small portion of the resources and assets, specifically knowledge-based ones, which might potentially affect region's performance and does not perfectly measure resources and assets as per theory. It may be that the knowledge-based factors constructs – and even structural factors – under study are but a small sample of the many relevant variables important to region's development and growth.

The third limitation concerns the limited relevance provide to the concepts of capabilities and capacity. Starting from the first elaborations of the resource-based theory, all the research streams developed along its pillars have largely suggested that capabilities and capacity are some of the most important determinants of systems' success. This research, however, did not explicitly considered capabilities and capacity as constructs, since the intent of the study is not to isolate on any given set of knowledge-based factors, but rather to afford all knowledge-based factors items ‘equal’ treatment in their assessment through the data sources. However, capabilities and capacity’s relevance is implicitly considered as a pre-condition to activate policies and managerial actions by policy-makers of the region as well as by each stakeholder.

The final limitation is the narrow population of the study. The EU NUTS 2 regions may not be representative of the broader regions and/or regional contexts in the world. However, as highlighted by Bontis (2004), research on knowledge-based within regional and national contexts are still in their infancy and till now they failed to uncover any substantial empirical efforts exploring and testing the knowledge-based view with regional data. Although in a limited domain, this study can be considered one of the first efforts to get over anecdotic and basic case-studies to explore and test the main assumptions of the knowledge-based development research stream through the definition of a theoretical model as well as the application of a multivariate analysis technique.

About the future development of the research, although there are many possible future directions, the discussion below focuses on three relevant options. Specifically, the discussion centres on constructs refinement, the extension of the assets and the resources under study, and the study of assets and resources interactions.

The first area for future research simply focuses on refining the constructs used in this study while replicating the research effort across additional regions and according to a wider time. One potential way to achieve construct refinement is by testing the hypothesis posited in this study across multiple regions in different countries. As Levitas and Chi (2002) argue, one of the main efforts of researchers in the resource-based field should be to empirically verify patterns in various populations in order to corroborate theoretical predictions about resources effects on performance. Based on the results of this study, empirical replication is warranted and necessary not only for statistical verification, but also to improve the characteristics of the constructs. Based on previous discussions, widely accepted and consistent operazionalisation of the relevant constructs of the knowledge-based view – at firm as well as at regional level of analysis – is far from mature and further work is clearly needed (Caloghirou et al., 2004).

The second direction for future research focuses on the resources and assets themselves. The present study examined a general set of specific assets, i.e., the knowledge-based factors. However, a variety of other factors, assets and resources may be brought to bear in the quest for regions’ development, including additional endogenous as well as exogenous factors, assets and resources. Thus, future research might expand the factors, assets and resources pool. Future empirical research should pay close attention also to how – and perhaps why – various factors, resources and assets combinations and interactions determine the development of regions, as well as which combination and interactions are more likely to lead to regional development dynamics. Of particular interest may be understanding the role that some regional tangible assets play, if any, in generating benefits when taken in the context of resources and assets combinations, interactions and recombination.

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Notes

1 It is important to acknowledge that these indicators do not consider any measure of international integration (Castellacci and Archibugi, 2008). It could be argued that two regions with identical performance in the selected dimensions highlighted above will have different patterns if their level of international integration is substantially different, since that none of the key characteristics of knowledge is precisely its global dimension.

2 It is important to underline that, in addition to the factors previously mentioned, a battery of exogenous variables – related to nature, geography, culture and history – that are the results of processes in the distant past and that may well influence the formation of localised knowledge and economic development could be considered in the analysis. However, since they are extremely hard or impossible to change within a reasonable time frame and require long-term political actions, they were not considered in this analysis.

3 SEM is a significant statistical techniques grouped in the multivariate analysis. Multivariate analysis refers to all statistical techniques that simultaneously analyse multiple measurements on objects under investigation. To be considered truly multivariate, however, all the variables must be random and interrelated in such ways that their different effects cannot meaningfully be interpreted separately. This method facilitates the identification of the effects of key variables in one dataset on all or several of the variables in other sets (Hair et al., 1998).

Appendix A

Factor analysis

Factor analysis, including both principal component analysis and common factor analysis, is a statistical approach that can be used to analyse interrelationships among a large number of variables and to explain these variables in terms of their common underlying dimensions, or factors. The objective is to find a way of summarising the information contained in a number of original variables into a smaller set of factors with a minimal loss of information. By providing an empirical estimate of the structure of the variables considered, factor analysis becomes an objective basis for creating summated scales (Hair et al., 1998). Factor analysis is carried out in two steps. First, the factors are identified and a solution is found in terms of number of factors to be retained. Principal-component factors estimation, which has been shown to be robust to different assumption on the distribution of the data, was chosen. The so-called Kaiser criterion (eigenvalue above unit) was used to determine the number of factors to be retained. These factors resulted directly orthogonal; then we assumed that the underlying factors were totally uncorrelated and we did not adjust them through so-called 'rotation' to maximise the differences between them. A characteristic of the factoring procedure is that the variables are standardised by deducting the mean and dividing by the standard deviation. Details of the factor analysis are provided below, while, for sake of brevity, the factors scores of each NUTS 2 Regions are not reported and can be required directly to authors.

Table 1 Communalities

Item	*Extraction*
i1	.560
i3	.789
i4	.704
i5	.672
i6	.806
i7	.749
i8	.725
i9	.718
i10	.789
i11	.782
i12	.743
i13	.608
i14	.691
i15	.700
i16	.629

Note: Extraction method: principal component analysis.

Table 2 Total variance explained

Component	*Initial eigenvalues*			*Extraction sums of squared loadings*			*Rotation sums of squared loadings*		
	Total	*% of variance*	*Cumulative %*	*Total*	*% of variance*	*Cumulative %*	*Total*	*% of variance*	*Cumulative %*
1	5,505	36,703	36,703	5,505	36,703	36,703	4,032	26,879	26,879
2	2,178	14,518	51,221	2,178	14,518	51,221	2,426	16,173	43,052
3	1,638	10,923	62,144	1,638	10,923	62,144	2,200	14,667	57,720
4	1,342	8,948	71,093	1,342	8,948	71,093	2,006	13,373	71,093

Note: Extraction method: principal component analysis.

Table 3 Rotated component matrix

	Component			
	1	*2*	*3*	*4*
i1	.043	–.267	.084	.692
i3	.550	.352	–.149	.583
i4	–.064	–.207	–.051	–.809
i5	.609	.261	.263	.405
i6	.885	.148	.005	–.039
i7	.549	.634	.214	–.001
i8	.551	.238	.604	.013
i9	.542	.437	.454	.162
i10	–.169	.872	.009	.020
i11	.452	.752	.046	.101
i12	.379	–.243	.533	–.506

Notes: Extraction method: principal component analysis.
Rotation method: varimax with Kaiser normalisation.

Table 3 Rotated component matrix (continued)

	Component			
	1	*2*	*3*	*4*
i13	–.047	.199	.747	–.084
i14	.179	–.147	.762	.238
i15	.805	–.010	.225	.019
i16	.782	–.047	.080	.096

Notes: Extraction method: principal component analysis.
Rotation method: varimax with Kaiser normalisation.

Appendix B

Structural equation modelling (SEM)

The origins of the mathematical framework of the 'structural equation models with latent variables' are attributed to Jöreskog (1973). The theoretical scheme grounding these kinds of models is characterised by the fusion of two statistical analysis: the factor analysis about the latent variables, and the structural equation models about the causal modelling. For sake of brevity, this analysis is commonly called 'structural equation model' (SEM).

The basic unit of a SEM is the regression equation that in this context is called *structural equation.* It is about the relationship between a dependent variable (effect), and a certain number of independent variables (causes) that, in turn, might present among them a system of relationships of causality and/or association. The SEM becomes, then, a set of causal links among variables formalised through a system of algebraic equations as adequately as possible to represent the phenomena under investigation.

In the same model, a variable can play both as independent and dependent variable. This justifies the distinction of the variables in *exogenous* and *endogenous* ones.

The constituent elements of a SEM are the *structural model* and the *measurement model*.

The first model is constituted by a series of equations in which are specified only the causal relationships existing among latent variables. The second model is composed by a series of equations explaining the relationships among latent variables and the corresponding observed variables.

Mathematically, the structural model is represented as follows:

$$\begin{pmatrix} \eta_1 \\ \eta_2 \\ \eta_3 \\ \vdots \\ \eta_m \end{pmatrix} = \begin{pmatrix} 0 & \beta_{12} & \beta_{13} & \dots & \beta_{1m} \\ \beta_{21} & 0 & \beta_{23} & \dots & \beta_{2m} \\ \beta_{31} & \beta_{32} & 0 & \dots & \beta_{3m} \\ \vdots & \vdots & \vdots & 0 & \vdots \\ \beta_{m1} & \beta_{m2} & \beta_{m3} & \dots & 0 \end{pmatrix} \begin{pmatrix} \eta_1 \\ \eta_2 \\ \eta_3 \\ \vdots \\ \eta_m \end{pmatrix}$$

$$+ \begin{pmatrix} \gamma_{11} & \gamma_{12} & \gamma_{13} & \cdots & \gamma_{1n} \\ \gamma_{21} & \gamma_{22} & \gamma_{23} & \cdots & \gamma_{2n} \\ \gamma_{31} & \gamma_{32} & \gamma_{33} & \cdots & \gamma_{3n} \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ \gamma_{m1} & \gamma_{m2} & \gamma_{m3} & \cdots & \gamma_{mn} \end{pmatrix} \begin{pmatrix} \xi_1 \\ \xi_2 \\ \xi_3 \\ \vdots \\ \xi_n \end{pmatrix} + \begin{pmatrix} \zeta_1 \\ \zeta_2 \\ \zeta_3 \\ \vdots \\ \zeta_m \end{pmatrix}$$

That, in compact form, is:

$$\eta = B\eta + \Gamma\xi + \zeta \qquad (1)$$

The equation (1) expresses the vector η (of dimensions $m \times 1$) of the endogenous latent variables as linear combination of the same endogenous and the vector ξ (of dimensions $n \times 1$) of the exogenous latent variables. The vector ζ (of dimensions $m \times 1$) of the erratic components is considered additive of the structural model, while the matrices B (of order m) e Γ (of dimensions m x n) are referred, respectively, to the matrix of the structural coefficients among the endogenous variables, and to the matrix among the exogenous and endogenous variables.

The elements of the matrices B and Γ are also called 'regression weights'. The generic parameter β_{ij} of the matrix B represents the causal direct of the j-esima endogenous latent variable of the vector η on that i-esima, while the generic parameter γ_{ij} of the matrix Γ represent the direct causal effect of the j-esima exogenous latent variable of the vector ξ on the i-esima endogenous latent variable of the vector η.

The second part of the SEM, as previously said, is referred to the measurement model, both for the endogenous and exogenous variables. The first measurement model is obtained from the following equations:

$$\begin{pmatrix} Y_1 \\ Y_2 \\ Y_3 \\ \vdots \\ Y_p \end{pmatrix} = \begin{pmatrix} \lambda_{11}^y & \lambda_{12}^y & \lambda_{13}^y & \cdots & \lambda_{1m}^y \\ \lambda_{21}^y & \lambda_{22}^y & \lambda_{23}^y & \cdots & \lambda_{2m}^y \\ \lambda_{31}^y & \lambda_{32}^y & \lambda_{33}^y & \cdots & \lambda_{3m}^y \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ \lambda_{p1}^y & \lambda_{p2}^y & \lambda_{p3}^y & \cdots & \lambda_{pm}^y \end{pmatrix} \begin{pmatrix} \eta_1 \\ \eta_2 \\ \eta_3 \\ \vdots \\ \eta_m \end{pmatrix} + \begin{pmatrix} \varepsilon_1 \\ \varepsilon_2 \\ \varepsilon_3 \\ \vdots \\ \varepsilon_p \end{pmatrix}$$

That, in a compact form, is:

$$Y = \Lambda_y \eta + \varepsilon \tag{2}$$

where the vector Y (of dimensions $p \times 1$) of the observed endogenous variables is expressed as linear combination of the vector η of the endogenous latent variables, with ‘regression weights’ provided by the matrix Λ_y (of dimensions $p \times m$) of the structural coefficients among the observed variables and the latent variables. The vector ε (of dimensions $p \times 1$) of the erratic components is considered additive in the model.

The measurement model of the exogenous variables is obtained from the following equations:

$$\begin{pmatrix} X_1 \\ X_2 \\ X_3 \\ \vdots \\ X_q \end{pmatrix} = \begin{pmatrix} \lambda_{11}^x & \lambda_{12}^x & \lambda_{13}^x & \cdots & \lambda_{1n}^x \\ \lambda_{21}^x & \lambda_{22}^x & \lambda_{23}^x & \cdots & \lambda_{2n}^x \\ \lambda_{31}^x & \lambda_{32}^x & \lambda_{33}^x & \cdots & \lambda_{3n}^x \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ \lambda_{q1}^x & \lambda_{q2}^x & \lambda_{q3}^x & \cdots & \lambda_{qn}^x \end{pmatrix} \begin{pmatrix} \xi_1 \\ \xi_2 \\ \xi_3 \\ \vdots \\ \xi_n \end{pmatrix} + \begin{pmatrix} \delta_1 \\ \delta_2 \\ \delta_3 \\ \vdots \\ \delta_q \end{pmatrix}$$

That, in a compact form, is:

$$X = \Lambda_x \xi + \delta \tag{3}$$

Where the mathematical meaning is the same explained for the (2), except the change of the symbols.

Definitively, the SEM appears in the following general form:

$$\begin{cases} \eta = B\eta + \Gamma\xi + \zeta \\ Y = \Lambda_y \eta + \varepsilon \\ X = \Lambda_x \xi + \delta \end{cases} \tag{4}$$

and it is described by four matrices of structural coefficients (B, Γ, Λ_y, Λ_x) and by four matrices of co-variance (Φ, Ψ, Θ_ε, Θ_δ).

The theoretical model comprises a certain matrix of co-variance $\sum$ among the observed variables. It can be expressed as function of the 8 matrices of the parameters of the model. Consequently, the estimation of the numeric values of the structural parameters of the model happens giving the condition that the distance between the matrix of the theoretical co-variance $\sum$ and the matrix resulting from the data really observed is minimum. To estimate the parameters, it generally used the method of the maximum likelihood (ML) or the generalised least squares one (GLS).

The first step to do to evaluate the model is to verify is goodness to reproduce the observed data. The fitting measures of the single equations of the model are provided by coefficients R^2. While, a common measure of the goodness of the fitting of the whole model to the sample data is provided by the ratio between $\chi^2$and its freedom degrees. If this ratio is less than 2, then, the model can be considered a 'good' model.

Unfortunately, this latter test is influences by the sample dimension (expressed by the freedom degrees) as well as by the non-normal distribution grounding the variables in input. Therefore, it is very useful to apply different fitting tests, each of them accounts of a particular aspect of the adaption of the model to the real data. The most commonly tests are the following:

- the χ^2, with its freedom degrees and its significance
- the *ECVI*
- the *GFI*
- the AGFI)
- the *TLI*
- the *RMSEA*.

Details of these tests can be found in: Hair et al. (1998).