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THE ROLE OF INNOVATION POLICY IN THE NATIONAL INNOVATION SYSTEM: THE CASE OF ESTONIA

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Abstract. The article highlights the unifying role of innovation policy in shaping and ensuring the functioning of a national innovation system. The first part of the article deals with the need for public sector intervention in innovation processes. A new national innovation system model that reflects the unifying role of innovation policy is developed. The second part presents the result of the empirical analyses of the structure and influence of innovation policy and its relations with the innovation-related activities of the enterprise sector. Macro-quantitative approach is used as the actors of innovation policy are governments. The problem of assuring the robustness of statistical models will be solved by using the principal component analysis (PCA) method. The functioning of Estonian national innovation system is assessed on the basis of robust statistical models of innovation policy structure and influence.

Keywords: innovation policy, national innovation system, dimensions of innovation policy, innovation performance

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1. Introduction

With the support from national regulations (laws, standards and norms) and public sector institutions, the task of innovation policy is to integrate in a national innovation system the formal and informal institutions (social, political, economic, educational, scientific, etc.) of the society in order to create and develop a united environment which guides economic agents to the search and implementation of innovations and promotes their innovation performance. The government sector directly guides the innovation processes through various political support activities (public procurement, tax breaks, subsidies, etc.).

In the modern world the activities and effectiveness of economic units in their innovation processes is largely dependent on the smooth functioning of the

innovation system, including the effectiveness and coordination of innovation policy measures.

The goal of this article is to highlight the unifying role of innovation policy in shaping and ensuring the functioning of a national innovation system. The following research tasks have been set:

- explain the nature of national innovation system and develop a new national innovation system model that reflects the unifying role of innovation policy;
- analyse empirically the dimensions of innovation policy and the relations of its components with the innovation performance of enterprise sector.

2. The unifying role of innovation policy in national innovation system

It is generally recognised that the public sector has an important role in promoting innovation – its task is to support the development, diffusion and implementation of innovations (Edquist 2006:182). Public sector intervention in the economy is usually justified by the need to overcome market and system failures. The need for government intervention in innovation processes derives mostly from market failures: the results of research work often have the nature of public good and positive externalities occur; educational processes create positive externalities, etc. The spontaneous institutions and deliberately created formal institutions that help to overcome market failures are becoming more complicated. Furthermore, system failures occur on the contact points of institutions and overcoming (integrating, coordinating, harmonising) these failures requires even more attention by the government sector.

The role of the public sector is to promote the innovation processes by reducing risks with subsidies (compensation for the nature of public good) or by protecting intellectual property (excluding the nature of public good) (Edquist et al. 2004:438). Theoretically, the value of public sector support measures should equal the social benefits created by economic agents in their innovation activities.

The theory of system failures explains that failures in collaboration between different parties of the innovation system are the main reasons for low innovation performance (Soete et al. 2009:15). System failures are innovation hindering incompatibilities (including contradictions) between organisations and institutions in the innovation system, as well as between various policies. Therefore, the role of the public sector lies not so much in supporting the individual innovation actions of economic agents, but in ensuring the emergence and development of a well-functioning innovation system: the creation of missing components in the innovation system, the development of co-operative relationship and the correction of errors made in the development (OECD 1997:41, Metcalfe 2005:68).

According to Arnold's (2004:7) approach, system failures can be divided into four types: capability failures, failures in institutions, network failures, framework failures. Tsipouri et al. (2008:15) add policy failure to the previous four. Edquist et

al. (2004:430) state that two conditions have to be fulfilled for public sector intervention: firstly there has to be a problem (a market or a system failure) and secondly public sector institutions have to be able to solve or relieve problems in market processes. Each country has to develop and implement a suitable system of innovation policy instruments for itself. The Estonian innovation system development requires giving special attention to these innovation policy instruments that are suitable for a small country (see Friedrich et al. 2011).

Christopher Freeman (1987:1) introduced the term national innovation system (NIS): a network of institutions in the public and private sectors whose activities and interactions initiate, import, modify and diffuse new technologies. Nelson (1992: 365) defines a national innovation system as an associated network of institutions and organisations whose interactions determine the innovation performance of companies. Metcalfe (1994:940) defines a national innovation system as a system of institutions and organisations that promotes the development and diffusion of technologies. The OECD report (1997:9) states that the national innovation system approach is based on the assumption that innovation and technological progress is the result of complex relations between subjects creating, diffusing and implementing new knowledge. Edquist (2006:182) defines an innovation system as a set of all important economic, social, political, organisational, institutional and other factors that influence the development, diffusion and implementation of innovations.

The innovation system approach emphasises that companies do not carry out innovations in isolation but in collaboration with other organisations and in a framework of specific institutional rules (Edquist 2002:226). Organisations and institutions are referred to as the components of the innovation system. According to the OECD (1999:32), organisations in the national innovation system can be divided into five types: governmental organisations; bridging organisations, such as research councils and research associations; universities and other related agencies; other public and private organisations that have a special role in the national innovation system (public laboratories, technology transfer agencies, joint scientific and research institutes, patent offices, educational institutions, etc.).

In summary, organisations take the role of players in the innovation system and institutions act as the rules of the game. Despite similarities in formal definitions, the innovation system components may have different content in different countries. The development of a successful innovation system is not only the result of spontaneous activities of enterprises and organisations. There has been a growing understanding over the last 15–20 years that the role of the public sector, through coordinated purposeful policy measures, is to contribute to the establishment and functioning of a national innovation system.

In order to improve the innovation performance of a country as a whole, the public sector contribution to R&D alone is not enough. The education system that prepares the innovation minded and innovation capable workforce provides a basis for successful R&D development and implementation of the results in companies. In order to diffuse experience gained from innovations implementation, public information systems and networks accessible for those interested have to be

developed. Systematic policy measures must be developed to encourage innovative activities and to reduce the associated risks. However, it is important to emphasise that innovation policy can affect the spontaneous activities of economic agents towards innovation only to a limited extent (Edquist 2006:191).

Up to now, the place and role of innovation policy in the national innovation system has remained unclear. Reid (2009:1) defines innovation policy as a set of activities designed to increase the intensity and efficiency of innovation activities. Innovation policy can be treated not as a policy besides others, but as a comprehensive and coherent unifying system of innovation promoting components in all policies.

Policy measures aimed at promoting innovation have been structured very differently in different studies. The Oslo Manual identifies four areas of innovation policy (OECD 1997a:19–23). The European Commission (Cunningham et al. 2008:44–45) also distinguishes four areas of innovation policy, which are significantly different from the structure used by the OECD. Arundel and Hollanders (2005:10–15) provide a more detailed division – eight areas of innovation policy. Manjón (2010:16–17) distinguishes seven areas of innovation policy. This kind of diversity in the discussions of the structure of the innovation policy clearly indicates that innovation policy is not seen as a whole but rather as a group of components from different innovation areas. Because of the lack of one common theoretical base different authors present a narrower or a wider list of innovation policy areas depending on their research objectives.

Various authors have used visual models to characterise the national innovation system. Models developed by the OECD (1999:23), Fischer (2001:208), Kuhlmann and Arnold (2001:2) and Feinson (2003:29) reveal that there is no common understanding of the structure of the national innovation system. In this study, a new comprehensive innovation system model (see Figure 1) was synthesised on the basis of different previous model versions. The new model emphasises more clearly the role of innovation policy in designing the innovation-related relationships between institutions and organisations.

Organisations that create, diffuse and use new and economically useful knowledge are at the centre of the national innovation system. These organisations include enterprises, educational and research institutions, government agencies and others. Organisations are affected by formal and spontaneously developing informal institutions. Informal customs, norms of co-operation and value judgments express in particular the path dependency of the development of the society. Formal institutions (consciously and intentionally created rules and relationships) try to organise and develop relationships needed for the development of different areas. The main task of the innovation policy is to coordinate and integrate all the policies into a national system that promotes innovation performance. The national innovation system cannot be imagined without the coordinating and integrating role of innovation policy. The role of innovation policy is to evoke and strengthen the positive impact created by informal and formal institutions on the innovation performance of the country (enterprises and organisations).

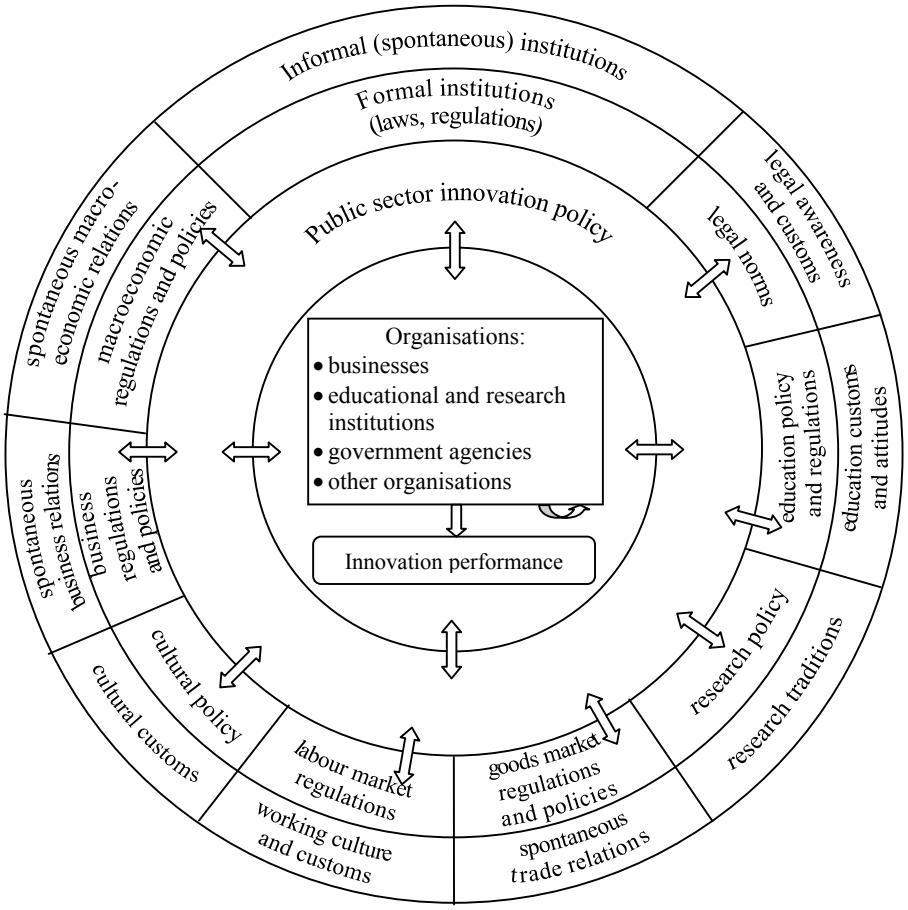

Figure 1. A comprehensive national innovation system model describing the role of the innovation policy (compiled by authors).

National innovation system approaches are mainly criticised because of their vagueness – the national innovation system seems to cover almost everything. It was attempted to reduce this deficiency by distinguishing between the broad and narrow approach to national innovation systems (Lundvall 2007:102). However, this cannot be assessed as a systematic approach. Studies of innovation, including innovation system approaches, are vague because of the fact that there is little understanding of the causes of innovation and innovation promoting factors. In particular, little research on theoretical innovation systems approaches has been done on the role of the public sector, although public sector agencies are important both in the creation and diffusion of new knowledge (Edquist 2001:3). The new comprehensive national innovation system model presented in this study allows to define public sector organisations that have been created to promote innovation

but also the role of the public sector in shaping the institutional environment and comprehensive system of innovation.

3. Relations of innovation policy dimensions with the innovation performance of business enterprise sector

3.1. Data for analyses

Next, we present the results of the empirical analyses of the structure of innovation policy and the relations of its components with the innovation performance of enterprise sector.

A total of 32 countries are used in the analysis (27 European Union member states, Croatia, Turkey, Iceland, Norway and Switzerland). The statistical data used is from Eurostat on-line database, the World Competitiveness Yearbook by the International Institute for Management Development (IMD) and The Global Competitiveness Report published by the World Economic Forum.

In the current study, data from four years – 2004, 2006, 2008 and 2010 – is applied in order to follow the dynamics of different policy aspects. The given years have been chosen because for those years all the variables have values available. Several variables come from the Community Innovation Survey (CIS) study, which is conducted every two years and data from year 2010 is the newest available.

Many theoretical approaches and empirical research studies (European Commission 2003; Falk 2004; OECD 2005; Koch et al. 2007; Manjón 2010) have brought out several variables that describe innovation policy and which can be used to assess the level and structure of innovation policy in different countries. In the current study, the following variables will be used to comparatively assess innovation policy activities in investigated sample of countries (see Table 1). Analysing different variables separately would give fragmented results. In the current analysis, data describing innovation policy activities are considered as a whole complex taking into account the interconnections of these variables.

One of the goals of the innovation policy is to develop R&D activities carried out by the public sector. The first section of variables describes this aspect. The second important area of innovation policy is supporting business sector R&D activities; this is described by the second section of variables in Table 1. The third section of variables describes the innovation co-operation between public and enterprise sector.

Human resource plays an important role in the national innovation system – skilled labour force is an essential input to innovation processes. Therefore, the public sector has to prepare competent employees; this aspect is described by the fourth section of variables. The fifth section of variables describes the role of the public sector in implementing laws, regulations and standards that promote and direct innovation activities. Altogether, 25 variables are used in the analysis (see Table 1).

Table 1. Variables describing public sector innovation policy

1. Public sector R&D activities	
GOVgdp	Government sector R&D expenditure (% of GDP)
GOVshr	Share of government sector R&D expenditure (% of total R&D expenditure)
HESgdp	Higher education sector R&D expenditure (% of GDP)
HESshr	Share of higher education sector R&D expenditure (% of total R&D expenditure)
empGOV	Share of government sector R&D personnel in total employment (% according to data converted to full time equivalents)
empHES	Share of higher education sector R&D personnel in total employment (% according to data converted to full time equivalents)
2. Public sector support to business sector innovation and R&D activities	
GOVto BESgdp	Business sector R&D financing from the government sector budget (% of GDP)
GOVto BESshr	Share of government sector financing in business sector total R&D expenditure (%)
funPUB	Share of innovative enterprises that received any public funding (% of total innovative enterprises)
funLOC	Share of innovative enterprises that received funding from local or regional authorities (% of total innovative enterprises)
funGMT	Share of innovative enterprises that received funding from central government (% of total innovative enterprises)
3. Support for innovation co-operation between public and enterprise sector	
COuni	Share of enterprises that co-operated with universities or other higher education institutions
COgov	Share of enterprises that co-operated with government or public research institutes
BEStoHES	Enterprise sector funding for higher education sector R&D expenditure (% of GDP)
BEStoGOV	Business enterprise sector funding for government sector R&D expenditure (% of GDP)
4. Development of human resources needed for innovation	
educgdp	Total public expenditure on education (% of GDP)
educshr	Total public expenditure on education (% of total public expenditure)
educ14	Total public expenditure on education at primary and secondary level of education (ISCED 1–4) (% of GDP)
educ56	Total public expenditure on education at tertiary level of education (ISCED 5-6) (% of GDP)
terteduc	Persons aged 25–64 years with tertiary education attainment (% of 25–64 year-olds)
lifelong	Participation of people aged 25–64 in lifelong learning (% of 25–64 year-olds)
5. Shaping the institutional environment that promotes innovation	
IntelProp	Intellectual property rights are adequately enforced (on scale 0-10)
LegalEnv	Development and application of technology are supported by the legal environment (on scale 0–10)
TechReg	Technological regulation supports enterprises development and innovation (on scale 0–10)
Procure	Government procurement decisions foster technological innovation (on scale 1–7)

Source: compiled by the authors.

3.2. Synthesizing complex independent innovation policy components

For systematic analyses of innovation policy content and impact, it is necessary to put into order and compress the information describing innovation policy. To bring out the independent dimensions of innovation policy activities, principal component analysis (PCA) is conducted with the variables presented in table 1. For the PCA, the data has been standardized across years (mean value is 0 and standard deviation is 1 for all indicators). The results of component analysis (Table 2) show the structure of public sector activities promoting and supporting innovation. Component analysis is based on the internal connections in the set of variables describing the areas of public sector innovation activities and support measures to enterprise sector innovation-related activities.

The PCA brought out seven independent synthetic complex indicators (components) describing the internal structure of the variables (see Table 2). As the result of component analysis the number of variables describing countries' innovation policy decreased over 70% (i.e. from 25 to 7), but less than 20% of the information (variation) included in initial variables was lost (81.75% of the variance of initial variables is explained). Explaining the nature of synthetic components and giving adequate names for the new indicators is a complicated task. In the current study, the interpretation approach applied by authors (see Reiljan 1981, Reiljan 2014) was used to name (to bring out the content of) the components.

The content of synthetic components is revealed on the basis of component loadings (correlation coefficients of the components with initial variables) presented in table 2 and expressed by their names:

C1 – "The level of public sector support to the education sector";
C2 – "The development level of institutional environment for innovation";
C3 – "The level of the government sector R&D financing";
C4 – "The share of central government in the financing of the innovation activities of firms";
C5 – "The level of co-operation between public and enterprise sector";
C6 – "The level of the higher education sector R&D financing";
C7 – "The level of the enterprise sector R&D financing by public sector".

These synthetic components are relatively robust against adding new variables characterising innovation policy – until these new variables do not reflect a new innovation policy dimension. The variation of the innovation policy will be described through the existing synthetic components, but if added new variables describe a new independent innovation policy dimension, a new component will be added to the existing set of components.

Some initial variables are statistically sufficiently related to various synthetic independent components. The share of higher education sector R&D expenditure in GDP (*HESgdp*) has positive correlation with the component C1 (as a significant part of the financing of the whole education sector), with the component C2 (as support to the forming of the institutional environment of innovation activities),

Table 2. Component analysis in the set of variables describing public sector innovation policy

	C1 Level of public support to the education sector	C2 Development level of institutional environment for innovation	C3 Level of the government sector R&D financing	C4 Share of central government in the financing of the innovation activities of firms	C5 Level of co-operation between public and enterprise sector	C6 Level of the higher education sector R&D financing	C7 Level of the enterprise sector R&D financing by public sector
educgdp	**0.93**	0.01	0.04	0.09	0.09	0.10	0.03
educ14	**0.92**	–0.01	–0.02	0.10	0.00	0.02	–0.09
educshr	**0.85**	–0.11	0.05	–0.13	0.01	–0.09	0.04
terteduc	**0.71**	0.29	0.09	0.10	0.14	0.12	–0.14
educ56	**0.71**	0.23	–0.03	0.35	0.23	0.07	0.05
lifelong	**0.71**	**0.44**	0.04	–0.05	0.22	0.15	0.00
empHES	**0.47**	0.39	–0.06	–0.14	**0.44**	**0.42**	-0.02
LegalEnv	0.06	**0.93**	0.15	–0.01	0.11	0.09	0.05
IntelProp	0.14	**0.92**	0.11	0.04	0.11	0.10	0.14
TechReg	0.03	**0.92**	0.15	0.02	0.11	0.09	0.05
Procure	**0.57**	**0.59**	0.01	0.09	0.03	–0.24	-0.06
HESgdp	**0.55**	**0.59**	–0.13	0.05	0.14	**0.47**	0.08
GOVgdp	0.09	0.20	**0.92**	–0.04	0.06	0.01	0.07
empGOV	–0.03	0.14	**0.88**	0.00	0.11	–0.12	–0.21
BEStoGOV	0.11	0.07	**0.78**	0.06	0.24	0.20	0.17
GOVshr	–0.36	**-0.47**	**0.54**	–0.17	–0.11	–0.21	–0.04
funGMT	0.14	0.04	0.03	**0.94**	0.13	–0.03	–0.05
funPUB	0.05	0.00	–0.07	**0.92**	0.15	0.11	0.20
COuni	0.11	0.20	0.11	0.17	**0.90**	0.01	0.07
COgov	0.23	0.09	0.32	0.20	**0.85**	0.02	–0.07
BEStoHES	0.13	0.38	0.23	0.03	0.08	**0.73**	–0.05
HESshr	–0.04	–0.37	**–0.40**	0.17	–0.13	**0.59**	–0.21
GOVtoBESgdp	0.15	**0.45**	0.11	0.04	0.15	–0.19	**0.73**
funLOC	–0.06	0.21	–0.18	0.23	–0.02	0.28	**0.68**
GOVtoBESshr	–0.20	–0.26	0.12	–0.06	–0.09	–0.31	**0.66**
Component eigenvalue	8.11	3.51	2.69	2.24	1.73	1.08	1.07
Cumulative variance explained	32.44	46.50	57.25	66.20	73.11	77.45	81.75
Significance of Bartlett test	0.00						
KMO	0.72						

Rotation method: Varimax
Source: calculated by the authors using SPSS.

and with the component C6 (as part of the higher education sector R&D financing). The share of higher education sector research staff in total employment (*empHES*) is also statistically significantly related to three synthetic components: C1 (considerable part of the higher education sector financing is directed to the employment of the research staff), C5 (as support for the co-operation of enterprise and public sectors), and C6 (forms a basis for the higher education sector R&D financing).

Subsequently, these seven synthetic independent components of innovation policy are used to analyse the influence of innovation policy on the innovation-related activities in the business sector.

3.3. Multiple regression analyses of innovation policy influence on enterprises' innovation-related activities

The contribution of the business sector to the R&D activities is described through the indicators presented in Table 3. The enterprise sector develops the R&D activities on the base of own finances, but very often the public sector supports these activities financially. The business sector enterprises develop the internal R&D activities, but they are also outsourcing the R&D projects.

Table 4 presents the multiple regression models of indicators describing the contribution of the enterprise sector to the R&D and innovation activities. Models are constructed on the basis of independent (non-correlated) synthetic components of innovation policy as factor variables. On this factor base we have got robust multiple regression models – that means regression coefficients do not change if some (insufficient) innovation policy components will be excluded from the model. The influence intensity of factor components in models is directly comparable because all synthetic components have the same scale of measurement – the mean value is 0 and standard deviation is 1.

Table 3. Indicators describing the contribution of enterprise sector to the R&D activities

No	Abbrev.	Variable
1	BESgdp	The whole expenditure of enterprise sector on the R&D activities (% of GDP)
2	BESshr	The financial contribution of enterprise sector to the whole expenditure on R&D activities of the country (%)
3	BEStoBES	The contribution of enterprise sector to the own R&D activities (% of GDP)
4	empBES	The share of enterprise sector R&D staff in the whole amount of employees (% calculated on the base of full time employment data)
5	RDin	The share of enterprises developing internal R&D activities (% of whole innovative enterprises)
6	RDex	The share of enterprises outsourcing the R&D activities (% of whole innovative enterprises)

Source: compiled by the authors.

Table 4. Multiple regression models of indicators describing the shaping of enterprise sector to R&D activities under influence of synthetic components of innovation policy

	BESgdp	BESshr	BEStoBES	empBES	RDin	RDex
Constant	0.920***	53.161***	0.761***	0.542***	45.504***	23.312***
	(0.030)	(0.928)	(0.029)	(0.021)	(1.043)	(0.538)
C1: Level of public support to the education	0.340***	4.013***	0.293***	0.175***	1.718*	2.044***
	(0.030)	(0.931)	(0.029)	(0.021)	(1.047)	(0.540)
C2: Development level of institutional environment for innovation	0.490***	10.214***	0.414***	0.285***	5.378***	2.503***
	(0.030)	(0.931)	(0.029)	(0.021)	(1.047)	(0.540)
C3: Level of the government sector R&D financing	0.011	–1.483	0.021	0.036*	–0.043	0.750
	(0.030)	(0.931)	(0.029)	(0.021)	(1.047)	(0.540)
C4: Share of central government in the financing of the innovation activities of firms	–0.005	–0.241	–0.011	0.042**	4.594***	3.351***
	(0.030)	(0.931)	(0.029)	(0.021)	(1.047)	(0.540)
C5: Level of co-operation between public and enterprise sector	0.225***	3.276***	0.212***	0.098***	7.689***	5.663***
	(0.030)	(0.931)	(0.029)	(0.021)	(1.047)	(0.540)
C6: Level of the higher education sector R&D financing	0.027	–4.105***	0.033	–0.079***	–0.136	–0.263
	(0.030)	(0.931)	(0.029)	(0.021)	(1.047)	(0.540)
C7: Level of the enterprise sector R&D financing by public sector	0.123***	3.087***	0.065**	0.015	2.593**	0.293
	(0.030)	(0.931)	(0.029)	(0.021)	(1.047)	(0.540)
R^2	0.795	0.606	0.756	0.706	0.475	0.609
Adjusted R^2	0.783	0.583	0.741	0.689	0.444	0.586
No. of observations	128	128	128	128	128	128

In brackets is presented the statistical error of coefficient assessment.
*, **, *** – statistically significant on the level accordingly 0.1, 0.05, 0.01.
Source: calculated by the authors using SPSS.

The innovation policy has sufficient influence on the R&D activities of the enterprise sector – 44.4-78.3% of indicators values variation between countries is described through regression models (adjusted R^2). The innovation policy has the most intensive influence on the indicator "The whole expenditure of enterprise sector on the R&D activities (% of GDP)" – *BESgdp* (adjusted R^2=0.783). Four innovation policy components have statistically significant influence on this indicator on the significance level 0.01. The most intensive influence have indirect factors: C2 (institutional environment for innovation – 0.49) and C1 (public support to education – 0.34). But important influence also belongs to direct factors: C5 (co-operation between public and private sector – 0.225) and C7 (enterprise sector R&D financing by public sector – 0.123). Most important for the effective function of NIS in the countries observed is a strong educational base and advantageous institutional conditions for innovation, the direct public support to innovation activities of enterprise sector plays only a secondary role. About the

same intensity (R^2=0.741) and pattern of relationships with innovation policy components has indicator "The contribution of enterprise sector to the own R&D activities (% of GDP)" – *BEStoBES*, because enterprise sector contribution is mostly directed to own R&D activities.

More innovation policy components (i.e. five), although not so intensively (adjusted R^2=0.583), shape the countries' variation on the base of indicator "The financial contribution of enterprise sector to the whole expenditure on R&D activities of the country" – *BESshr*. Differently from the two models already observed it adds a statistically significant negative relationship with policy component C6 (financing higher education R&D activities). That means the rise of higher education R&D financing is in general not accompanied with (proportional) rise in enterprise sector contribution to R&D activities in the countries observed. A little stronger (adjusted R^2=0.689) but nearly the same pattern of relationships with policy components has indicator "The share of enterprise sector R&D staff in the whole amount of employees" – *empBES*. But interestingly, the policy component C7 (public sector financing to enterprise sector R&D activities) has no statistically significant relationship with the R&D employment in enterprises. It can mean that the public support is directed to enterprises already endowed with necessary R&D staff.

In the countries observed the variation of indicator "The share of enterprises outsourcing the R&D activities" – *RDex* is shaped by four statistically significant policy components – C1, C2, C4 and C5 (adjusted R^2=0.586). The indicator "The share of enterprises developing internal R&D activities" – *RDin* forms statistically significant relationships (on the significance level 0.01) with three policy components – C2, C4 and C5 (adjusted R^2=0.444). In comparison with the previously presented models, in these two models the policy component C4 (share of central government in the financing of the innovation activities of firms) has replaced the policy component C7 (level of the enterprise sector R&D financing by public sector).

In all models presented in Table 4 the statistically significant and positive role have policy components C2 (institutional environment for innovation) and C5 (co-operation between public and enterprise sector). The development of these innovation policy components is most important to form effective NIS of the countries observed. Next it is important to pay attention to developing the general education system. However, the role of R&D in the higher education system has to be cleared through specific analyses. The component analysis has brought out that R&D in the higher education is important for developing the institutional environment for innovation and education system. Thus, the direct relationship between C6 and the enterprise sector innovation indicators describes the covariance, not the influence. Only one policy component – C3 (financing of government sector R&D activities) has no relationships to enterprise sector innovation activities – probably the R&D in the government sector serves only the solution of specific public sector development problems in the countries observed.

Table 5 presents the indicators describing innovation-related co-operation between enterprises: co-operation in their own enterprise group, with other enterprises of the industry (competitors), with suppliers, customers, consultants and R&D institutes.

The influence of innovation policy on the indicators characterising innovation-related co-operation between enterprises is described by multiple regression models presented in Table 6. These regression models have about the same variation description rate (44.5–70.8%) of dependent indicators as the variation description rate of indicators characterising the contribution of enterprise sector to the R&D activities. This means that innovation policy significantly shapes the innovation-related co-operation between enterprises. All innovation policy components have a statistically significant relationship (on the significance level 0.1) with at least two or more indicators describing innovation-related co-operation between enterprises. Innovation policy components have a controversial relationship with innovation-related co-operation indicators. E.g. components C2 (development level of environment for innovation), C3 (level of the government sector R&D financing) and C6 (financing of R&D activities in higher education sector) have a negative (partly insignificant) relationship with the co-operation between enterprises. Statistically significant positive connection with all indicators characterising innovation-related co-operation between enterprises have policy components C1 (level of public support to education) and C5 (level of co-operation between public and enterprise sector). The most intensive positive connection with all indicators describing innovation-related co-operation in enterprise sector has component C5, which means that the co-operation is often initiated through the public sector.

It is evident from Table 6 that the innovation policy has the most intensive influence on innovation-related co-operation between enterprises and consultant firms (adjusted $R^2 = 0.708$), followed by co-operation with customers (adjusted $R^2 = 0.664$), surprisingly with competitors (adjusted $R^2 = 0.632$) and suppliers ($R^2 = 0.554$). The innovation-related co-operation between enterprises of the own group ($R^2 = 0.445$) is shaped less than a half under influence of innovation policy components.

Table 5. Indicators describing innovation co-operation in the enterprise sector

No.	Abbrev.	Description
1	COgroup	Share of enterprises that co-operate with other enterprises within the enterprise group (% of total innovative enterprises)
2	COsupplier	Share of enterprises that co-operate with suppliers of equipment, materials, components or software (% of total innovative enterprises)
3	COcustomer	Share of enterprises that co-operate with clients or customers (% of total innovative enterprises)
4	COcompet	Share of enterprises that co-operate with competitors or other enterprises of the same sector (% of total innovative enterprises)
5	COconsult	Share of enterprises that co-operate with consultants, commercial labs, or private R&D institutes (% of total innovative enterprises)

Source: compiled by the authors.

Table 6. Multiple regression models describing the shaping of the innovation co-operation of enterprises under influence of synthetic components of innovation policy

	CO group	CO supplier	CO customer	CO competitor	CO consultant
Constant	12.722***	23.733***	19.676***	12.211***	13.639***
	(0.393)	(0.620)	(0.463)	(0.376)	(0.342)
C1: Level of public support to the education	1.786***	3.259***	3.087***	1.217***	2.525***
	(0.395)	(0.623)	(0.465)	(0.378)	(0.344)
C2: Development level of institutional environment for innovation	1.308***	–2.641***	–0.550	–1.649***	–1.092***
	(0.395)	(0.623)	(0.465)	(0.378)	(0.344)
C3: Level of the government sector R&D financing	–1.012**	–0.173	0.624	0.759**	–0.220
	(0.395)	(0.623)	(0.465)	(0.378)	(0.344)
C4: Share of central government in the financing of the innovation activities of firms	0.233	1.586**	0.322	0.948**	2.154***
	(0.395)	(0.623)	(0.465)	(0.378)	(0.344)
C5: Level of co-operation between public and enterprise sector	3.222***	6.471***	6.555***	4.942***	4.983***
	(0.395)	(0.623)	(0.465)	(0.378)	(0.344)
C6: Level of the higher education sector R&D financing	–0.651*	–0.916	–0.753*	–0.645*	–0.450
	(0.395)	(0.623)	(0.465)	(0.378)	(0.344)
C7: Level of the enterprise sector R&D financing by public sector	–0.405	–0.974	–1.354***	–1.255***	–0.165
	(0.395)	(0.623)	(0.465)	(0.378)	(0.344)
R^2	0.475	0.578	0.682	0.652	0.725
Adjusted R^2	0.445	0.554	0.664	0.632	0.708
No. of observations	128	128	128	128	128

In brackets is presented the statistical error of coefficient assessment.
*, **, *** – statistically significant on the level accordingly 0.1, 0.05, 0.01.
Source: calculated by the authors using SPSS.

Very few indicators characterise directly the innovation performance in the business enterprise sector, three are presented in Table 7. In Table 8 the multiple regression models of shaping innovation performance indicators under the influence of innovation policy components are presented.

In the models presented in Table 8 the variation description rate (46.3–53.8%) shows that about a half of differences of innovation performance in the enterprise sector in the countries observed could be explained through the differences in innovation policy of these countries. Another half of innovation performance disparities are the result of influence by specific factors in these countries. Innovation policy definitely needs a more thorough analysis from this perspective, in order to find other significant factors influencing innovation performance in the enterprise sector, in addition to the innovation policy components included in this analysis.

Table 7. Indicators characterising innovation performance in the enterprise sector

No.	Abbrev.	Description
1	innov	Share of innovative enterprises in total enterprises (% of total enterprises)
2	newmar	Share of enterprises that have introduced new or significantly improved products or services that were new to the market (% of total innovative enterprises)
3	patEPO	Number of business enterprise sector patent applications to the European Patent Office (per million of inhabitants)

Source: compiled by the authors.

Table 8. Multiple regression models describing the shaping of innovation performance in the enterprise sector under the influence of synthetic components of innovation policy

	innov	newmar	patEPO
Constant	37.147***	15.217***	76.649***
	(0.741)	(0.453)	(5.643)
C1: Level of public support to the education	4.423***	2.224***	36.138***
	(0.744)	(0.455)	(5.666)
C2: Development level of institutional environment for innovation	6.822***	3.945***	56.608***
	(0.744)	(0.455)	(5.666)
C3: Level of the government sector R&D financing	–0.308	1.114**	–4.995
	(0.744)	(0.455)	(5.666)
C4: Share of central government in the financing of the innovation activities of firms	1.728**	0.722	6.599
	(0.744)	(0.455)	(5.666)
C5: Level of co-operation between public and enterprise sector	–1.196	0.105	15.779***
	(0.744)	(0.455)	(5.666)
C6: Level of the higher education sector R&D financing	0.970	1.258***	9.262*
	(0.744)	(0.455)	(5.666)
C7: Level of the enterprise sector R&D financing by public sector	–0.208	–0.533	8.192
	(0.744)	(0.455)	(5.666)
R^2	0.519	0.493	0.564
Adjusted R^2	0.491	0.463	0.538
No. of observations	128	128	128

In brackets is presented the statistical error of coefficient assessment.
*, **, *** – statistically significant on the level accordingly 0.1, 0.05, 0.01.
Source: calculated by the authors using SPSS.

From Table 8 it is evident that the differences between countries in the field of enterprise sector innovation performance are shaped through statistically significant influence of two innovation policy components (C2 – development

level of the environment for innovation, C1 – public sector support to education) and therefore originate from differences in the level of these policy components. For the patent application activity of the enterprise sector (*patEPO*) the co-operation between public and enterprise sector (policy component C5) is additionally important. On the proportion of enterprises that have launched a new or significantly improved product/service (*newmar*) the level of the higher education sector R&D financing (policy component C6) has also a statistically significant (at the level of 0.01) positive influence.

Based on the regression models, the following conclusions were made regarding the innovation policy impacts on the innovation performance of the enterprise sector:

- indirect factors – the development level of institutional environment for innovation (C2) and public support to education development (C1) – have a statistically significant and positive influence on all aspects of innovation activities in the enterprise sector. It seems that precisely through institutional and education development the effect of innovation policy is most efficient regarding the innovation performance of enterprises;
- the development level of institutional environment for innovation (C2) has generally the strongest influence on the level of R&D activities and the level of innovation performance in the business enterprise sector;
- the level of co-operation between public and enterprise sector (C5) has a positive influence on most aspects of the innovation activities investigated in the enterprise sector, and the latter influence is strongest on the co-operation between enterprises and on the share of enterprises developing R&D activities, it seem that the co-operation between enterprises is often generated through public sector finances;
- the share of central government in the financing of the innovation activities of firms (C4) has a positive influence on the proportion of innovative enterprises focusing on internal and outsourced R&D activities, as well as on the proportion of innovation co-operation between enterprises;
- the importance of other innovation policy components regarding the innovation activities in the enterprise sector is not clear enough, they have statistically significant influence only on a very limited number of indicators describing the innovation activities in the enterprise sector and the influence seems to be controversial.

Based on the analysis, it can be said that innovation policy has a significant influence on the indicators describing R&D activities and innovation performance in the enterprise sector. Therefore, in order to improve a country's NIS functioning, innovation policy must be made more efficient, directing resources to the instruments that have the strongest impact on the desired aspects in the business enterprise sector innovation activities.

3.4. Analysis of the shaping of enterprise sector innovation-related activities

The regression models of the indicators describing the enterprise sector's innovation-related activities highlighted a series of statistically significant dependencies on different aspects (synthetic components) of innovation policy. The influence of innovation policy enables to open up an analysis of the scope of influence of different factors in any country under observation; and in this analysis, regression coefficients brought out by the regression models will be connected with the specific values of innovation policy components (these measure the difference with the average of countries observed) in the country under analysis:

$$SIC_{i,j} = \alpha_i * k_{i,j},$$

where

$SIC_{i,j}$ – the scope of influence for component *i* (deviation from the average value of countries observed) in the country *j*;

α_i – the regression coefficient of component *i*;

$k_{i,j}$ – component score (value) of component *i* (deviation from the average) in country *j*.

The value of the indicator describing innovation-related activities in the enterprise sector, which is shaped by the influence of innovation policy in country *i* (IPI_i) is calculated by summing up the intercept of the regression model ($\alpha_{0,i}$) – average level of the indicator in the countries observed – and the scopes of influence of individual policy components:

$$IPI_i = \alpha_{0,i} + \sum SIC_i$$

whereas this is the prognostic value of the indicator based on the regression model; the actual value of this indicator differs from prognostic value by the influence of socioeconomic environment factors not included in the model.

3.5. Assessment of the situation in Estonia

Table 9 gives an overview of standardised IPI_{EE} values in Estonia, describing the difference between the values of the indicators characterising innovation-related activities in the enterprise sector in Estonia and the average level of countries observed due to the differences of innovation policy components (C1-C7) scores in Estonia from the average level of countries observed. Innovation policy component scores for all countries observed are presented in Annex 1. The table also shows the actual deviation of the indicator in Estonia, compared to the average in countries observed (in standard deviations) – AD_{EE}. The difference between the actual deviation of an indicator (AD_{EE}) and the deviation of prognostic value based on the model (IPI_{EE}) characterises the scope of influence on the analysed indicators by other socioeconomic environment factors not included in the model.

Table 9. The scope of influence of innovation policy and other factors in Estonia (deviation from the average of countries observed) on indicators describing innovation related activities in the enterprise sector, in standard deviations

Indicator	IPI_{EE}				AD_{EE}				$AD_{EE} - IPI_{EE}$			
	2004	2006	2008	2010	2004	2006	2008	2010	2004	2006	2008	2010
BESgdp	0.05	0.05	0.20	0.26	–0.81	–0.58	–0.51	–0.14	–0.86	–0.63	–0.70	–0.40
BESshr	–0.08	0.13	0.25	0.30	–0.87	–0.54	–0.61	–0.18	–0.80	–0.66	–0.86	–0.49
BEStoBES	0.14	0.09	0.20	0.21	–0.75	–0.55	–0.44	–0.13	–0.89	–0.63	–0.64	–0.34
empBES	–0.04	0.01	0.23	0.29	–0.84	–0.68	–0.61	–0.47	–0.80	–0.69	–0.84	–0.76
RDin	–0.67	–0.71	–0.94	–0.58	–0.14	–0.75	–0.19	0.39	0.53	–0.04	0.75	0.97
RDex	–0.59	–0.73	–0.98	–0.68	–0.03	–0.13	0.06	0.61	0.55	0.60	1.03	1.30
COgroup	0.19	0.04	–0.27	–0.38	0.48	1.30	1.69	1.50	0.29	1.26	1.96	1.88
COsupplier	–0.29	–0.51	–0.93	–0.83	–0.04	–0.09	0.05	0.02	0.25	0.42	0.97	0.85
COcustomer	–0.07	–0.33	–0.79	–0.84	0.35	0.54	0.28	0.23	0.42	0.86	1.07	1.07
COcompet	–0.29	–0.56	–1.12	–1.10	0.88	0.54	–0.01	–0.27	1.18	1.10	1.12	0.83
COconsult	–0.48	–0.67	–1.01	–0.78	–0.50	–0.40	–0.54	–0.28	–0.02	0.27	0.47	0.50
innov	0.33	0.30	0.87	0.89	0.97	0.92	0.90	0.80	0.64	0.62	0.03	–0.09
newmar	0.30	0.15	0.54	0.52	0.73	0.08	–0.40	–0.44	0.43	–0.06	–0.94	–0.96
patEPO	0.20	0.16	0.42	0.46	–0.78	–0.73	–0.63	–0.65	–0.98	–0.88	–1.04	–1.12

During the period 2004–2010, the influence of components characterising innovation policy on indicators describing innovation-related activities of enterprise sector in Estonia is controversial. Table 9 shows us improvement in the prognostic values (IPI_{EE}) of eight innovation-related indicators, while the prognostic values of six indicators worsened in the Estonian enterprise sector during this period. The decline has been in the prognostic values of all indicators describing co-operation between enterprises and also the prognostic value of *RDex* that characterises outsourcing of R&D work. The prognostic values of all other indicators have improved during the period 2004–2010 and have reached or exceeded the average level of a group of countries observed. It could be assumed that innovation policy has a positive influence on innovation-related activities of enterprise sector in Estonia, excluded co-operation of enterprises.

During the period of observation, the actual values (AD_{EE} in Table 9) of 13 indicators (out of 14) characterising innovation-related activities in Estonian enterprise sector have improved, but often to a smaller extent than the improvement predicted based on the regression models (the prognostic values). Such results show the contribution of innovation policy to the improvement of most innovation-related activities in the enterprise sector; but on the other hand, the socio-economic environment in Estonia was generally not favourable for many innovation-related activities during the period of observation. Only indicator *newmar* (i.e. the share of enterprises that have introduced new or significantly improved products or services that were new to the market – % of total innovative enterprises) has significantly worsened and fallen under the average level. It seems that after entering the markets at the first half of the 2000s the development of new products and services has declined in Estonian enterprises.

The last four columns of Table 9 characterise the influence of socio-economic environment on indicators describing the innovation-related activities in Estonian enterprise sector. As the result of this influence the actual values of indicators differ from the prognostic values. For 10 indicators the influence of socio-economic environment has improved in 2010 compared to 2004 – the negative values have declined or positive values increased. Regarding four indicators, foremost characterising the innovation performance in Estonian enterprise sector, the influence of socio-economic environment has worsened during the period observed. In 2010 the socio-economic environment has positive influence on 7 indicators (rises the actual value over the prognostic value) and negative influence also on 7 indicators (decreases the actual value under the prognostic value). Also, the socio-economic environment has significant influence on indicators describing innovation-related activities in the Estonian enterprise sector: in 2010 regarding four indicators the influence was strong (the difference between actual and prognostic value was over 1 standard deviation) and regarding six indicators, it was moderate (the difference was 0.5–1 standard deviation). Thus, it is evident that all indicators characterising innovation-related activities in the Estonian enterprise sector depend not only on the components of innovation policy but also on socio-economic factors not included in the regression models.

The Estonian innovation policy does not seem to favour co-operation related activities between enterprises, however the positive effect of the socio-economic environment brings the actual level of the indicators describing co-operation activities over the average level in the group of countries observed. Regarding the other indicators the situation is opposite: due to innovation policy efforts the prognostic value is over the average level, but the negative influence of socio-economic environment cancels out any efforts made in this policy direction in Estonia compared to the average level. These aspects demand serious attention in the future research. Estonian efforts in innovation policy may be more efficient when the negative influence of socio-economic environment on the important fields of innovation activities is excluded.

4. Summary

The public sector intervenes in innovation processes in order to eliminate market and system failures that hinder innovation. At the same time, public sector intervention requires careful analytical reasoning because this intervention could distort market processes and guide innovation processes towards economically harmful directions. Innovative activities of enterprises depend largely on the operational efficiency of the national innovation system. So far, innovation system approaches have been vague and have not been able to adequately characterise the role of the innovation policy in the system. In this article, a new comprehensive national innovation system model was synthesised, based on previous studies. In the centre of a national innovation system are various organisations, which

together generate, diffuse and use new and economically useful knowledge. Innovative activities of organisations evolve directly under the influence of national innovation policy that mediates relationships between formal and spontaneous institutions.

The public sector promotes innovation-related activities in the enterprise sector by implementing different innovation policy instruments. The choice of suitable instruments has to be based on the path dependence of development, economic policy goals and general factors affecting the implementation of national innovation policy.

There are large divergences in the theoretical discussions on the influence of innovation policy, as well as in its empirical analysis. The empirical study in this article is theoretically based on a comprehensive model of national innovation system presented in the first part of the article that characterises the role of innovation policy in this system. Innovation policy is a broad complex of governmental intervention methods. Therefore, the description of innovation policy needs a comprehensive sample of indicators describing all aspects of governmental intervention in this field. In this article, the problems highlighted in the existing empirical studies are analysed and the methodological basis of statistical modelling and analysis is improved. The solution for the robustness problem of statistical models describing the structure and influence of innovation policy is offered on the basis of principal component analysis (PCA) method.

The assessments of economic effect of innovation policy mostly rely on processing indirect indicators with the methods of statistical analysis, in which case the interpretation of the results must also take into consideration the peculiarities of the dataset and the specific characteristics of the data processing methods. The executers of innovation policy are mostly governments, therefore the macro-quantitative approach to empirical analysis of innovation policy indicators and the characteristics of the enterprise sector's innovation-related activities are used. In this article we evaluated the international position of Estonian innovation policy implementation within the group of EU member states and countries closely associated with the EU, based on the macro-quantitative analysis of data from years 2004, 2006, 2008 and 2010.

The macro-quantitative analysis of the innovation policy structure and influence highlights the complicated and even somewhat contradictory results of innovation policy implementation. At the same time, in the study the real dimensions of innovation policy and the specific influence structure of innovation policy on innovation-related activities in the enterprise sector are explored.

The innovation policy was characterised with 25 initial indicators. With the help of PCA method seven robust independent (non-correlated) dimensions (components) of innovation policy were underlined. The main part (more than 80%) of information (variation) contained in the set of initial indicators was described through these seven synthetic complex indicators (components) of innovation policy.

With these non-correlated components of innovation policy 14 robust multiple regression models were created to analyse the shaping of indicators describing innovation-related activities in the enterprise sector. The innovation policy components have explained 44–78% (adjusted R^2 of regression models) differences between countries observed on the basis of indicators describing the innovation-related activities in the enterprise sector. The indirect components of innovation policy have the most important influence – the development level of institutional environment for innovation (C2) and public support to education development (C1): these components have a statistically significant and positive influence on all aspects of innovation-related activities in the enterprise sector. The development level of institutional environment for innovation (C2) has generally the strongest influence on the level of R&D activities and the level of innovation performance in the enterprise sector. Other innovation policy components have statistically significant influence only on a limited number of indicators describing the innovation-related activities in the enterprise sector and sometimes the influence seems to be controversial.

Also, the prognostic values of indicators describing the innovation-related activities in the Estonian enterprise sector were brought out on the basis of regression models in order to analyse the influence of Estonian innovation policy in comparison to the average level of countries observed. The results reveal a complicated and sometimes controversial picture: the prognostic values of eight indicators have improved and six indicators worsened during the period 2004–2010. The prognostic values characterising the influence of innovation policy in Estonia have reached the average level of countries observed for seven indicators and stayed under the average level for seven indicators as well.

The actual values of 13 indicators (out of 14) improved during the period 2004–2010, which means that Estonia has improved its position in the group of countries observed. The development of the prognostic values has shown that for eight indicators the improvement was contributed by the innovation policy. The difference between actual and prognostic value measures the influence of factors not included in regression models (i.e. socio-economic environment). The influence of socioeconomic environment on innovation-related activities in Estonian enterprises is controversial: for eight indicators it causes improvement, but for six indicators it causes worsening during the period 2004–2010.

Multiple regression models based on the components of innovation policy, for indicators characterising innovation activities in the enterprise sector, enable to compile macro-quantitative evaluations regarding the average intensity of the influence of various factors in a group of countries under observation and to a specific extent in a particular country (e.g. in Estonia). This makes it possible to enhance the quantitative analysis of the efficiency of country's national innovation system from the aspect of innovation policy. That is also the starting point for an enhanced analysis of the influence of specific instrument groups of innovation policy.

Analogously to the analysis of the situation in Estonia, combining the values (component scores) of independent innovation policy dimensions (principal components) for each country (see Annex 1) and regression coefficients from the models presented in tables 4, 6 and 8, it is possible to empirically assess the influence of innovation policy on the shaping of enterprise sector innovation-related activities in all countries observed. Also, it is possible to create smaller groups of similar countries and investigate more thoroughly the situation of national innovation systems in and between these different groups of countries.

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ANNEX 1.

Innovation policy component scores for countries observed in standard deviation from the average value, as a mean of four years (2004, 2006, 2008, 2010)

	C1	C2	C3	C4	C5	C6	C7
BE	0.37	0.17	–0.47	–0.43	0.62	0.74	1.08
BG	–0.85	–0.42	1.51	–0.92	–0.97	–1.12	–1.17
CZ	–0.83	0.41	0.32	–0.44	0.20	–1.48	0.65
DK	1.97	0.90	–1.16	–0.79	0.25	–0.41	–0.72
DE	–0.34	0.94	1.07	–0.32	–0.87	0.53	0.29
EE	**0.43**	**0.42**	**–0.69**	**–0.68**	**–0.78**	**0.14**	**–0.72**
IE	0.33	0.71	–1.11	0.13	–0.58	–0.70	–0.57
GR	–1.05	–0.20	–0.78	0.81	0.24	1.01	–0.63
ES	–0.32	0.07	0.17	–0.07	–0.66	0.53	1.69
FR	0.23	0.63	0.57	0.41	–0.24	–0.79	1.13
HR	–0.78	–0.24	–0.39	0.53	–1.17	0.69	1.47
IT	1.87	–2.84	–0.31	2.08	–0.88	–0.81	0.05
CY	0.28	–2.56	–0.30	–1.35	1.01	1.03	–0.19
LV	–0.13	–0.51	–0.13	–0.75	0.53	1.27	–0.91
LT	–0.71	1.31	0.51	0.44	–0.25	–2.58	–1.43
LU	–0.77	–0.02	0.73	0.71	0.31	–0.27	–0.18
HU	0.53	–1.76	–1.47	–0.02	–0.81	–0.72	–0.98
MT	0.33	0.50	0.73	1.32	–0.54	1.57	–0.18
NL	–0.14	1.03	–0.95	1.23	0.18	0.16	2.14
AT	–0.10	–1.11	0.44	–0.70	–0.03	–0.06	0.25
PL	–0.19	0.42	–1.18	–0.54	–0.37	–0.64	–0.98
PT	–1.02	–0.81	0.41	–1.12	–0.64	–1.20	1.90
RO	0.04	–0.75	1.44	0.23	1.54	–0.61	0.29
SI	–1.07	–0.64	0.09	–1.22	1.12	–0.60	0.41
SK	0.68	0.67	0.68	0.93	3.55	0.10	–0.34
FI	1.25	1.17	–0.97	–0.87	0.14	0.05	0.83
SE	0.62	0.54	–0.61	–1.07	0.01	0.01	0.29
UK	1.66	0.57	3.07	–1.12	–1.07	1.55	–0.68
IS	1.15	0.32	0.73	2.41	0.03	–0.51	–0.36
NO	0.66	1.06	–1.14	–0.47	0.16	0.91	–0.42
CH	–1.79	–0.23	0.05	0.72	0.67	0.45	–1.20
TR	–2.30	0.24	–0.85	0.89	–0.72	1.72	–0.78