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Correlation Between Transmission Power and Some Indicators Used to Measure the Knowledge-Based Economy: Case of Six OECD Countries

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Abstract In this paper, we study the correlation between the transmission power and some indicators used to measure the knowledge-based economy. For the case study, we select six OECD countries (USA, Canada, France, Germany, Japan and South Korea) and six indicators (gross domestic expenditure for research and development (GERD), number of researchers, gross domestic product (GDP) growth rate, GDP per capita, Human Development Index (HDI) and total factor productivity (TFP)). The time series of the transmission power over a 10-year period (2001–2010) are built on the basis of publication data collected from the Web of Science. The correlation between transmission power and the selected indicators is computed. Results show that Japan and South Korea exhibit a positive strong correlation between transmission power and GERD on one hand and transmission power and number of researchers on the other hand. These two countries have the same pattern as regarding the transmission power and each of the selected indicators; other countries do not show any comparable pattern. The study concludes that the transmission power computed at national level only is not sufficient to measure the extent to which an economy is knowledge-based, because it does not take into account the synergy contributed at international level by a nation innovation actor.

Keywords Transmission power · Mutual information · Triple Helix · Research collaboration · Knowledge-based economy

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Introduction

A knowledge-based economy is the one which is 'directly based on the production, distribution and use of knowledge and information' (OECD 1996, p. 7); it implies that economic growth, wealth creation and employment are driven essentially through the production, distribution and use of knowledge (e.g. APEC Economic Committee 2000). Even though the term has been used to characterize nowadays' economies, there are not yet any consensual indicators used to measure a knowledge-based economy,[1] so that publications used range of indicators that varies from one edition to another or from one institution to another.[2] Recently, Mêgnigbêto (2014a) proposed the transmission power as an indicator for measuring the knowledge-based economy.

This study seeks to answer the following research question: Does the transmission power measure the extent to which an economy is knowledge-based? We aim to test any correlation between the transmission power and some indicators used to measure knowledge economy. Any correlation found could mean that the transmission power measures the same things as the considered indicator; the absence of correlation could mean that the transmission power really captures a dynamic that is missing from other indicators. The article is organized as follows: First, the literature is reviewed; then, the selected countries and indicators are dealt with; in a third step, we discuss the data source and collection. Results are presented, and a discussion follows in subsequent sections.

Review of Literature

The initiatives towards measuring the knowledge-based economy were mainly taken by international organizations like the OECD,[3] the World Bank,[4] the European Union,[5] the Asia-Pacific Economic Committee[6] or the United Nations.[7] Some nations also have

[1] Since the term has been coined, conferences were held (e.g. by the European Union, cf. European Commission - EUROSTAT 2006; or OECD, cf. OECD & National Science Foundation, 1999) to discuss its measurement. Frameworks were set up to provide the concept with indicators (APEC Economic Committee 2000; Chen and Dahlman 2005; OECD 1996) and enable its measurement. Strategies and plans were formulated at international, regional and national levels (e.g. APEC Economic Committee 2000; Australian Bureau of Statistics and Trewin 2002; European Commission 2010a).

[2] cf. Godin (2006) for the case of OECD and Karahan (2012) for an overview of the indicators used by international organizations like OECD, the World Bank, the Asia-Pacific Economic Cooperation and the European Union.

[3] The OECD published several reports related to the knowledge-based economy (e.g. OECD 1996, 1999, 2013). It used up to 60 indicators with variations from one publication to another.

[4] The Word Bank established the Knowledge Economy Framework which built two indicators: the Knowledge Economy Index (KEI) and the Knowledge Index (KI) (Chen and Dahlman 2005).

[5] In the 2010 innovation scoreboard, the European Commission (2010b) published 26 statistics, but more recently, it has set up a composite index, the Summary Innovation Index—which summarizes the performance of a range of 25 different indicators (cf. European Commission 2014, p. 8).

[6] The Asian-Pacific Economic Cooperation defined the idealised knowledge-based economy under the name of Nikuda and fixed its characteristics (APEC Economic Committee 2000, pp. 3–16). The statistics are recognized as too idealistic.

[7] The United Nations Economic Commission for Europe (2002) suggested the Global Knowledge-Based Economy Index (GKEI) as a measure.

contributed to the debate; for example, the Australian Bureau of Statistics and Trewin (2002) defined a framework following the same methodology as the OECD, the World Bank, the Asia-Pacific Economic Committee and the European Union. All these frameworks used a 'suite of indicators'. Godin (2006) noted that none of the indicators intended to contribute to the measurement of the knowledge-based economy is new really; they all exist before the concept and have been used to measure a particular aspect of the 'traditional economy for decades'. In fact, the economy has been always based on knowledge; indeed, even in the so-called industrial economy (or traditional economy), human being had needed knowledge in order to transform natural resources and contribute to economic growth, 'because everything we do depends on knowledge' (World Bank 1999, p. 16).

Researchers at individual level also proposed indicators. For example, Arvanitidis and Petrakos (2011, p. 25) developed the Economic Dynamism Indicator, a composite index. The Centre for International Development (CID) at Harvard University proposed 19 indicators in five areas.[8] Leydesdorff (2003) on one hand and Leydesdorff and Ivanova (2014) on the other hand, respectively, proposed the mutual information or transmission and the mutual redundancy as a measure of the interactions among innovation system actors and hence of a knowledge-based economy. These two measures are derived from the Shannon's information theory (Shannon 1948; Shannon and Weaver 1949). Some studies used the mutual information to assess the extent to which an economy is knowledge-based (e.g. Leydesdorff et al. 2015; Leydesdorff and Zhou 2013; Mêgnigbêto 2013; Park et al. 2005; Park et al. 2005). (Mêgnigbêto 2014a) proposed the transmission power as the efficiency of the mutual information and affirmed that it is more suitable for comparison purpose. The transmission power was used to assess the knowledge flow within the West African innovation systems, both at national and regional levels (Mêgnigbêto 2014b, 2014c), and to compare the knowledge production profiles of six OECD countries (Mêgnigbêto 2015). Jointly with other indicators, it helped in studying the Norwegian innovation system both at national and county level, based on data including the number of establishments in geographical, organizational and technological dimensions over a 13-year period (Ivanova et al. 2014).

In summary, even though frameworks are produced by international or national institutions or researchers about the knowledge-based economy, there is not yet an internationally accepted indicator to capture the concept. The studies referred to above used the mutual information or the transmission power to measure the knowledge-based economy, but they did not seek for any correlation between these indicators and those used by international organizations for the same purpose. This paper aims at bridging this gap.

[8] The areas are networked access, networked learning, networked society, networked economy and networked policy. See http://www.readinessguide.org.

Methods and Data

Selected Countries and Indicators

For the purpose of this article, we collect data on six countries over a 10-year period (2001–2010). All the countries are members of the OECD: two from the American continent (USA and Canada), two from Europe (France and Germany) and two from Asia (Japan and South Korea). This choice is guided by the fact that the OECD has been playing a crucial role in the dissemination of the term knowledge-based economy (Godin 2006) and also regularly provides statistics on different aspects of its member states' economy. The APEC Economic Committee's (2000, p. 19 Table I-3-1) matrix of indicators was used as a starting point of the process of indicator selection; indeed, this matrix distinguishes indicators according to the knowledge chain (acquisition, creation, uses and dissemination).

As far as our research is concerned, the mutual information is derived from research output and research collaboration data. By doing research, researchers produce information and knowledge; by collaboration means, they increase their productivity (Katz and Martin 1997) and share information and knowledge (Guns and Rousseau 2014; Katz and Martin 1997; Olmeda-Gómez et al. 2008). Therefore, we can consider mutual information as an indicator of information and knowledge production on the one hand and information and knowledge sharing on the other hand. According to Liu (2011, p. 87 ff. and Liu et al. (2013), knowledge diffusion starts with the 'the act of publication' and the citations of publications received. Clearly, the mutual information, and therefore, the transmission power, does not intervene at the diffusion side of knowledge or information. It intervenes on neither the acquisition side nor the use side but rather in the production and sharing side only.

The Asia-Pacific Economic Cooperation (APEC) matrix retained four indicators in four categories for the knowledge production. They are the gross domestic expenditure for research and development (GERD) as percentage of gross domestic product (GDP), the natural science graduates per annum, the business expenditure for research and development (BERD), the number of researchers per capita and the patents awarded in the US per annum. Hence, from the APEC's matrix, we retain the GERD as percentage of GDP and the number of researchers; these indicators are also present in the framework proposed by the OECD, the World Bank and the European Union. Karahan (2012) distinguished them as input indicators. Some indicators are usually used to measure economic and social development. From them, we add three that Karahan (2012) considered as output indicators; they are (i) the Human Development Index (HDI), (ii) the gross domestic product growth rate and (iii) the gross domestic product per capita. The last two indicators measure the growth in the domestic wealth production in a given area. Finally, we select the total factor productivity (TFP) also called multifactor productivity (MFP) because it represents the 'part of GDP growth that cannot be explained by changes in labour and capital inputs'.[9]

[9] https://data.oecd.org/lprdty/multifactor-productivity.htm.

In summary, the six selected indicators we are comparing the transmission power to are GERD (OECD 2014a), number of researchers (OECD 2014b), GDP growth rate, GDP per capita (OECD 2015a), HDI (UNDP 2014, Table 2)[10] and TFP (OECD 2015b).

Research Data Collection

Research collaboration is recognized as crucial for knowledge production and innovation (OECD 2010, p. 98); it may cover several aspects. Even though research collaboration does not always yield publications, hereby, we consider co-authorship as its indicator because it has been widely used in Academia (Bordons and Gomez 2000; Katz and Martin 1997). It entails the tacit transfer of information and knowledge and ensures ideas' diffusion and knowledge circulation (Guns and Rousseau 2014).

We collect data over a 10-year period (2001–2010) on the selected countries' university, industry and government research output and collaboration through the Web of Science.[11] The search strategy consists of 11 steps for each country, adapted from Ye et al. (2013), based on the search strings previously developed and tested, Leydesdorff (2003, p. 458) and Park et al. (2005, p. 13 ff):

1. CU = COUNTRY and PY = 2001–2010: selection of all the scientific output of COUNTRY over the period 2001–2010;
2. PY = 2001–2010 AND AD = (COUNTRY SAME (UNIV* OR COLL* OR ECOLE)): selection of all university output of COUNTRY over the period 2001–2010;
3. PY = 2001–2010 AND AD = (COUNTRY SAME (GMBH* OR CORP* OR LTD* OR AG*)): selection of all industry output of COUNTRY over the period 2001–2010;
4. PY = 2001–2010 AND AD = (COUNTRY SAME (NATL* OR NACL* OR NAZL* OR GOVT* OR MINIST* OR ACAD* OR NIH*)): selection of all governmental output of COUNTRY over the period 2001–2010;
5. PY = 2001–2010 AND AD = (COUNTRY SAME (NATL* OR NACL* OR NAZL* OR GOVT* OR MINIST* OR ACAD* OR NIH*) SAME (UNIV* OR COLL* OR ECOLE)): selection of output of COUNTRY government and university share over the period 2001–2010;
6. PY = 2001–2010 AND AD = (COUNTRY SAME (NATL* OR NACL* OR NAZL* OR GOVT* OR MINIST* OR ACAD* OR NIH*) SAME (GMBH* OR CORP* OR LTD* OR AG*)): selection of output of COUNTRY government and industry share over the period 2001–2010;
7. #4 NOT #5 NOT #6: selection of governmental output only over the period 2001–2010;
8. #2 AND #3: selection of university and industry collaboration output over the period 2001–2010;

[10] The HDI time series cover only the period 2005–2010. Indeed, the indicator is provided by interval of 5 years from 1980 to 2000 and for each year from 2005 to 2013 in the recent Human Development Report (UNDP 2014). So, for methodological reasons, we restrict data to the period 2005–2010 for the HDI.

[11] The databases searched were Science Citation Index Expanded (SCI-EXPANDED), Social Sciences Citation Index (SSCI), Arts & Humanities Citation Index (A&HCI), Conference Proceedings Citation Index-Science (CPCI-S) and Conference Proceedings Citation Index-Social Science & Humanities (CPCI-SSH).

9. #2 AND #7: selection of university and government collaboration output over the period 2001–2010;
10. #3 AND #7: selection of industry and government collaboration output over the period 2001–2010;
11. #2 AND #3 AND #7: selection of university, industry and government collaboration output over the period 2001–2010.

The results of each stage were entered into a worksheet, and on a second worksheet, formulas are entered to compute university, industry and government sectorial output and other bilateral and trilateral collaboration data. We coded a PHP programme that computes the sectorial entropies, the bilateral entropies and transmission and the trilateral entropies and transmission and the transmission power.

Results

Analyses are presented following two levels: mutual information and transmission power level and selected country level.

Mutual Information and Transmission Power of Selected Countries

The mutual information and the transmission power of the selected countries over the period of study (2001–2010) are computed in Table 1. It shows that the mutual information values are negative for all the countries meaning that synergy exists within the selected national innovation system. All the countries except South Korea present a 'decreasing' trend with regards to the mutual information (Table 2). But because higher is the absolute value of the mutual information, the more there is synergy, we consider the absolute values of the time series. It results that the South Korean innovation system has gained in synergy over time and that the five other countries' innovation systems have lost synergy. Germany is in the lowest position, followed by South Korea, Canada and USA, the systems of which exhibit approximately the same values over the period. The French mutual information is higher than that of Japan until 2007 where the two countries display an equal value; then, the synergy into the Japanese innovation system became higher.

Regarding the transmission power, Japan keeps the first place, far ahead the five remaining countries; France is still the second well-performing system but reduces the gap with its successors; Canada also keeps the third place. Even though the USA begins the period with the fourth place, it has been caught up by South Korea in 2004 which competed with it until 2007 where it took the fourth place lagging the USA at the fifth position. Over all the period, German keeps the rear with respect with the transmission power. Whereas the two Asian countries exhibit an increasing trend with respect to the transmission power, the other countries show the reverse (Table 2).

To summarize, the synergy within the innovation systems operates largely in Japan and France than elsewhere; the USA and Canada present likely similar pattern; the South Korean innovation system has gained in synergy, while the five others have lost. Germany seems to have the less integrated innovation system as measured by the indicators we used.

Table 1 Mutual information (T_{UIG}, in millibits of information) and transmission power (τ, as percentage) of selected countries (2001–2010)

Years	USA		Canada		France		Germany		Japan		South Korea	
	T_{UIG}	τ	T_{UIG}	τ	T_{UIG}	τ	T_{UIG}	τ	T_{UIG}	τ	T_{UIG}	τ
2001	−53.2	23.33	−51.259	24.96	−118.9	26.76	−25.494	9.49	−102.733	35.2	−23.301	18.07
2002	−54.148	23.56	−49.842	25.77	−123.529	27.73	−22.601	8.33	−98.907	34.84	−23.268	18.67
2003	−52.892	23.02	−49.437	25.82	−120.995	27.48	−20.999	7.62	−99.917	36	−29.877	21.77
2004	−49.091	22.56	−47.542	25.63	−115.757	27.32	−23.962	8.79	−95.809	36.35	−28.221	22.23
2005	−46.591	22.12	−45.574	25.9	−116.14	27.81	−23.476	8.96	−94.173	36.58	−30.537	22.42
2006	−43.453	21.72	−43.228	25.17	−107.999	27.87	−22.265	8.78	−95.602	36.98	−28.419	20.71
2007	−43.01	21.82	−40.607	25.46	−99.124	28.13	−24.713	9.77	−95.031	37.2	−31.649	22.24
2008	−41.316	21.96	−37.338	24.33	−86.299	27.39	−16.281	6.95	−99.057	38.56	−31.072	22.99
2009	−36.773	20.72	−36.724	25.04	−74.621	26.02	−13.17	5.76	−94.637	37.41	−28.412	22.69
2010	−31.938	19.57	−31.093	23.83	−72.583	27.06	−15.046	6.62	−88.644	37.25	−26.941	22.1

Table 2 Trend in the six countries' mutual information and transmission power series ($t = 1$ in 2001)

	USA	Canada	France	Germany	Japan	South Korea
Mutual information	$y = 2.38t - 58.32$ $R^2 = 0.95$	$y = 2.16t - 55.16$ $R^2 = 0.96$	$y = 6t - 136.62$ $R^2 = 0.88$	$y = 1.11t - 26.88$ $R^2 = 0.59$	$y = 0.98t - 101.85$ $R^2 = 0.58$	$y = -0.5t - 25.41$ $R^2 = 0.27$
Transmission power	$y = -0.37t + 24.1$ $R^2 = 0.87$	$y = -0.145t + 26$ $R^2 = 0.42$	$y = -0.04t + 27.6$ $R^2 = 0.05$	$y = -0.27t + 9.58$ $R^2 = 0.38$	$y = 0.32t + 34.9$ $R^2 = 0.76$	$y = 0.42t + 19.1$ $R^2 = 0.55$

Table 3 Summary of the correlation coefficient of transmission power with the selected indicators

	GERD	Number of researchers	GDP growth rate	GDP per capita	HDI	TFP
USA	−0.26	−0.69	0.25	−0.83	−0.75	−0.98
Canada	0.78	−0.56	0.11	−0.57	−0.8	−0.31
France	−0.75	−0.23	0.68	−0.15	−0.61	0.57
Germany	−0.9	−0.74	0.54	0.52	−0.60	−0.13
Japan	0.85	0.4	−0.17	0.91	0.59	0.81
South Korea	0.64	0.66	−0.49	0.73	0.36	0.72

Country-Level Analysis

Table 3 summarizes the correlation coefficients of transmission power with the selected indicators for the selected countries. It informs that USA exhibits negative correlations between transmission power and five of the indicators and a positive moderate correlation between transmission power and GDP growth rate. Whereas the correlation between transmission power and GDP per capita on the one hand and transmission power and HDI are negative and strong ($r = -0.83$ and $r = -0.75$), it is moderate with GERD and the number of researchers. In the case of Canada, four indicators present a negative correlation with the transmission power; they are number of researchers, GDP per capita and HDI. These correlations are moderate (GDP per capita and number of researchers) or strong (HDI). The Canadian transmission power has however a strong positive correlation with this country's GERD and a weak one with GDP growth rate but has no correlation with TFP.

France has a negative strong correlation between transmission power and GERD but a negative moderate correlation between transmission power and number of researchers on one hand and transmission power and GDP per capita on the other hand, but negative moderate correlation between transmission and HDI. Conversely, it shows a positive moderate correlation between transmission power and GDP growth rate and transmission power on the one hand and transmission power and TFP on the other hand. As far as Germany is concerned, transmission power shows a negative correlation with GERD, numbers of researchers, HDI and TFP and a positive correlation with GDP growth rate and GDP per capita. Japan and South Korea show the same patterns. The correlations are positive or negative with regards to the same indicator; the difference is only on the strength of the correlation.

Discussion

The Triple Helix indicators we computed from scientific publication data reveal different patterns of the dynamics of the national innovation systems of the selected countries. Globally, the Japanese national innovation system exhibits the largest synergy, followed by France, USA, Canada, South Korea and Germany.

Globalization Erodes Synergy at National Level

The leading position of Japan with regards to the mutual information was yet recorded by Leydesdorff (2003) and that of Japan and France by Ye et al. (2013) for the year 2011, while the latter study computed the mutual information of a set of countries including the selected ones. Our results globally confirm the ranking of countries (Ye et al. 2013) obtained after calculation of mutual information based on data from Web of Science, except that Canada and South Korea interchange their ranking. They also conform to the findings that for most countries, the mutual information's absolute value is decreasing (Ye et al. 2013). This trend is due to globalization that erodes the synergy between national innovation actors (Leydesdorff and Park 2014; Leydesdorff and Sun 2009; Ye et al. 2013). Indeed, globalization gives opportunities to research institutions to cooperate largely regardless the distance separating their home countries; it has enlarged worldwide partnership. Therefore, a university in one country has the opportunity to collaborate with an industry or a governmental body, each located in different countries. This form of collaboration, even though linking the three innovation actors of the Triple Helix, escapes to be accounted for the synergy at the national level, as the present research paper measures it. Hence, the synergy at national level diminished.

The decrease in the absolute value of the mutual information and its small values is therefore a consequence of the internationalization of the science in the selected countries (namely Germany, South Korea, Canada and USA). Japan's performance is driven by domestic activity (Adams et al. 2010); this country's national innovation system is less internationalized than that of Canada; the latter is more integrated to the Anglo-American system (Leydesdorff and Sun 2009). Before globalization,[12] USA had the highest share in the international papers of almost countries (Glänzel 2001, p. 87; Zitt et al. 2000, p. 641); therefore, it should be expected that its mutual information and transmission power show a lower value over the chosen period. In the case of South Korea, the gain of synergy, even slow over the time, may be interpreted as the consequence of strengthening of its national innovation system after years of benefiting from international collaboration. This situation is a consequence of changes in these countries' policies over decades (cf. Kwon et al. 2012).

Strengthening Domestic Co-Authorship Explains the Performance of South Korea and Japan

Table 4 shows the time series of the entropies of the selected countries' innovation systems and the equation of their linear trend. Except Japan and South Korea that have an increasing trend, all the remaining countries have a negative one. The same trend is registered as regarding the bilateral entropies.[13]

The entropy of a system is the quantity of information or knowledge produced within the system. In other words, the quantity of information or knowledge produced by the Japan and the South Korean information systems is growing, whereas in the other countries, it is diminishing. Therefore, it is unsurprised that the share that circulated between actors (the transmission power) at the domestic level also decreases.

[12] Globalization after the end of the Cold War between 1990 and 2000 (cf. Leydesdorff and Sun 2009).

[13] The bilateral entropy values are not presented in this article.

Table 4 Trilateral entropies (in millibits of information) of the selected countries' innovation system (2001–2010)

Year	USA	Canada	France	Germany	Japan	South Korea
2001	729.851	819.975	1190.616	638.752	1424.249	526.043
2002	754.738	819.719	1211.682	653.975	1457.269	547.451
2003	741.297	807.656	1228.321	658.823	1447.158	587.428
2004	726.235	815.338	1222.301	657.701	1475.7	606.483
2005	718.794	805.235	1222.675	654	1469.972	594.532
2006	705.919	800.221	1188.216	660.75	1478.722	589.696
2007	703.591	787.627	1181.216	671.309	1471.127	606.704
2008	693.485	760.854	1137.709	631.379	1514.607	615.654
2009	668.871	758.015	1087.766	624.111	1490.306	606.096
2010	656.345	751.627	1098.313	630.187	1490.864	615.483
Linear trend	$y = -9.59t + 762.66$	$y = -8.30t + 838.27$	$y = -14t + 1253.8$	$y = -2.28t + 660.62$	$y = 7.05t + 1433.2$	$y = 8.20t + 544.48$

That explains the negative correlation of the transmission power with the selected indicators in the American and European selected countries.

The system's entropy has a positive relation with the bilateral entropies. In order words, the bilateral entropies add to the system entropy, e.g. an increase in the bilateral entropies engenders an increase in the system's entropy. That is the case of Japan and South Korean. Conversely, the four other countries' bilateral entropies have decreased; consequently, the system's entropy decreases. This emphasizes the role of collaboration in knowledge production and sharing for innovation.

The decreasing trend of bilateral entropies in USA, Canada, France and Germany innovation system should not be interpreted as lack of collaboration between university, industry and government; it may have result from the widen of collaboration abroad; we have concluded that international collaboration has eroded the mutual information at domestic level. We should recall that this study does not include foreign innovation in the computation of the indicators and that the Japanese co-authorship is domestic and that South Korea has engaged strengthening its domestic science.

Investment in R&D Feeds Synergy at National Level

The GERD as percentage of the GDP of the countries over the period of study (Fig. 1) and the number of researchers per thousand inhabitants (Fig. 2) bring new enlightenment to the gain of synergy within the South Korean innovation system. Indeed, at the beginning of the period, South Korea's GERD is equal to 2.59 and ranked South Korea third countries after Japan and USA; it rises to 3.06 in 2006 and reaches 3.56 in 2009 making South Korea having the highest GERD as percentage of GDP within the set of the six selected countries starting from 2009. The same trend is recorded as far as the number of researchers per thousand inhabitants. This steady investment in research and development may have strengthened collaboration between innovation actors at national level. It explains the performance of the country with regards to mutual information and transmission power; it illustrates the efforts South Korea has made to catch up with leading economies (OECD 2009, p. 13). We should underline that Japan and South Korea have the highest GERD as percentage of GDP meaning that these two countries have been investing heavily in research and development

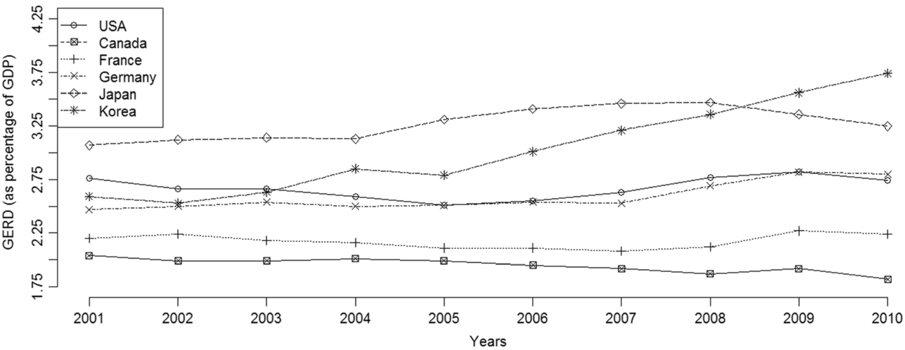

Fig. 1 GERD (as percentage of GDP) of the selected countries (2001–2010). Source: OECD (2014a)

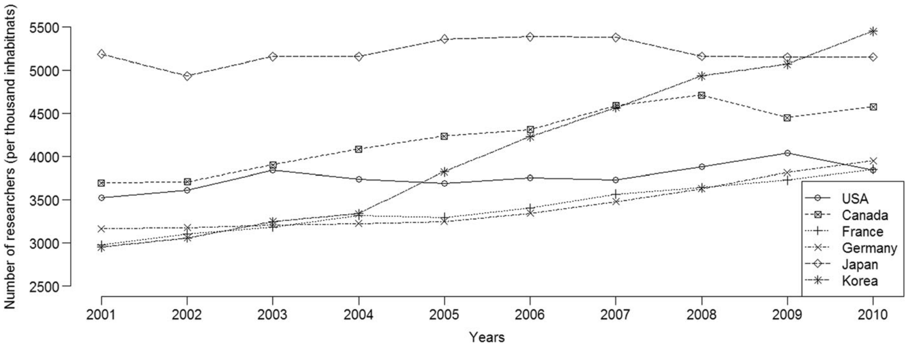

Fig. 2 Number of researchers per thousand inhabitants of the selected countries (2001–2010). Source: OECD (2014b)

and, hence, in human capital. If Japan has this tradition (its GERD equaled 2.9 % GDP in 1990 and has reached 3 % since 2000, cf. data in (OECD 2014a), South Korea has prioritized strengthening its economy towards a developed one (cf. Kwon et al. 2012; OECD 2009).

These results illustrate that investing in research and development (e.g. GERD and research personnel) strengthens the innovation system research and extends research collaboration. Therefore, opportunities for doing research and research collaboration between innovation actors are widened; knowledge could then be created and shared by and among innovation actors at national level. Indeed at the origin, the mutual information, borrowed from the (Shannon 1948)'s information theory, indicates the quantity of information common to two variables. In the case of more than two variables (the three actors of an innovation system, in our case), it measures the synergy within the system if it is negative, or the control one actor exerts on the others if it is positive (cf. Leydesdorff 2003). The transmission power is the normalization of the mutual information; it is obtained by dividing the mutual information by the maximum value it may reach according to the variables' value (Mêgnigbêto 2014a); it is the efficiency of the mutual information. In other words, the transmission power is the fraction of the quantity of the 'sharable information' that is shared within the system actually. It indicates the extent to which the produced information and knowledge flow between innovation actors (cf. Mêgnigbêto 2014b, 2014c).

South Korea Has Gained Profit More than Other Countries

Figure 3 plots the TFP (base = 100 in 2005) of the selected countries. It shows that before 2005, the South Korean TFP was the lowest but has become the highest after 2005. The OECD states that TFP is the part of GDP growth that cannot be explained by changes in labour and capital inputs. According to the World Bank (1999, p. 19 Tables 1 and 2), at least 70 % of growth rate is explained by intangible factors like knowledge, not by labour and capital. Indeed, the other countries have attained a certain level of development; a country like South Korea which 'suddenly' starts investing should have a shift in its output. That is why even though South Korea's GERD equals that of Japan

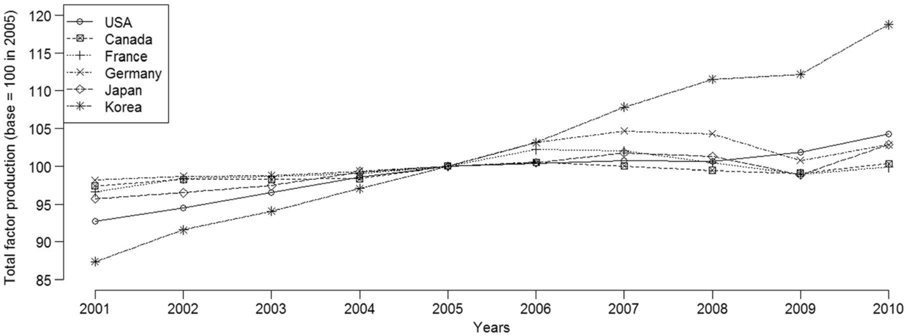

Fig. 3 Multifactor productivity of the selected countries (2001–2010). Source: OECD (2015b)

only in 2007 and its numbers of researchers that of Japan only in 2009, the TFP (base = 100 in 2005) has risen. In conclusion, the investment in R&D by South Korea since early 2000 as the result of changes in the country's research and innovation policy may have influenced the TFP time series.

Conclusion

This paper aimed to study the correlation between the transmission power and some selected indicators used to measure the knowledge-based economy, taking the case of six OECD countries namely USA, Canada, France, Germany, Japan and South Korea. The results show that the selected countries do not have the same pattern with regards to the selected indicators. Indeed, while some countries exhibit a positive correlation regarding the transmission power and a particular indicator, others show a negative correlation between the transmission power and the same indicator. However, Japan and South Korea exhibit a positive strong correlation between the transmission power and GERD on the one hand and the transmission power and the number of researchers on the other hand; they also have the same pattern as regarding the correlations studied. The particular situation of these two countries is due to the domestication in co-authorship in the Japanese science and the efforts of strengthening the national innovation system at the South Korean level. On the opposite, the four remaining countries are affected by the international collaboration they are involved in.

The results did not allow drawing any evident relation between the transmission power and the selected indicators, certainly because the transmission power captures a dynamic that is missing from other indicators. However, the study showed that the transmission power as measured by the method used informs only at the country level and does not measure the added value university, industry and government relationships create at the international level. Therefore, reasonably, it could not be used for absolute comparison of countries unless the synergy created abroad is taken into account with the inclusion of university-industry-government relationships at international level. This study shows that investments in research and development, particularly a constant increase in GERD and research personnel or equipment, strengthen domestic collaboration and give more opportunity for knowledge sharing at the country level. There is however a need for innovation system actors both to favour collaboration between innovation actors at the domestic level and enlarging collaboration at the international level in order to contribute to knowledge sharing abroad.

From this study, we could conclude that if collaboration sustains innovation and contributes to economic growth, mutual information and transmission power may be means for measuring the advances attained.

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