

**NATIONAL INNOVATION AND KNOWLEDGE PERFORMANCE:
THE ROLE OF HIGHER EDUCATION TEACHING AND TRAINING**

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ABSTRACT

This paper investigates the role of the higher education system (HES) in the production of national innovation. We specifically intend to focus on the issue of institutional diversity of HESs and its impact on national innovation systems. We identify four key HES characteristics and hypothesize their influence on the production of national innovation. The empirical evidence presented in this paper suggests several conclusions which have relevance for policy makers. In particular, there should be focus upon increasing access to and investment in higher education, and lowering subsidies. The latter is found to have an adverse effect on patent production.

1. INTRODUCTION

The role of the Higher Education System (HES) as the main provider of human capital through teaching and training is well known. This 'first mission' has traditionally been seen as a function of the HES which is recognized as one of the pillars of any system of innovation (Fagerberg & Shrolec, 2008). The innovation literature suggests that Higher Education Institutions (HEIs) play a significant role within the National Innovation System (NIS) through two main channels. The first channel is the high level of interdependency between the NIS and the research activities of HEIs (also known as the 'second mission'). The second channel is the exploitation of HEI teaching and research activities (known as the 'third mission') (Etzkowitz & Leydesdorff, 2000; Gulbrandsen & Slipersaeter, 2007). While the second and third missions' role in the NIS is relatively well explored, the HE policy issues related to the development of human capital through education (i.e. the first mission) and their relationship to the development of NIS remain under-explored, especially across the developing and emerging economies.

There is a general consensus within the HE policy literature on the heterogeneity of HESs across countries (Ansell, 2008). Policy choices relate to, for example, the extent of government control of HEIs (Etzkowitz, 1998), the adoption of elitist versus open HE System (HES) (Ansell, 2008), and the level of subsidies and public funding to HEIs. Given the institutional variety of HESs around the world, this paper intends to explore the relationships between key "institutional characteristics" of a country's HES and its performance in innovation and knowledge production. This paper also intends to provide empirical evidence which can contribute to the emerging policy debate

regarding the appropriate model of a national HES and its relationship with national innovation and knowledge performance.

We empirically examine four hypotheses. The results strongly support our first hypothesis that the size of the HES has a positive influence on innovation output. The tests fail to reject our prediction that it matters little whether the HES looks more like an 'Ivory Tower' or an 'Application Driven' system. However, we find less conclusive evidence on our remaining two hypotheses. The prediction of a positive association between investment in higher education and national innovation performance holds for patents but not for publications. On the other hand, our expectation of no impact of the level of public subsidies on innovation output is only confirmed for publications. Unexpectedly, highly subsidised systems seem to significantly underperform in terms of patent output.

The remainder of this paper comprises six sections. Section 2 reviews the literature on the multiple roles of HEIs in national economic and innovation development. We also review the literature on national HES characteristics and propose four hypotheses on how these characteristics may be associated with the country's future innovation and knowledge performance. Section 3 describes the methodology, data, and models adopted in this study. Section 4 presents the main empirical results. These results, and their implications for policy makers, are discussed in Section 5. The final section concludes.

2. LITERATURE REVIEW

The role of higher education institutions in innovation development

The HE sector contributes to the development of innovation through two main mechanisms. Firstly, HE provides a supply of human capital. Enhancing human capital leads to highly skilled human resources and better individual and organisational performance (Furman, Porter & Stern, 2002). Secondly, HE produces *useful* knowledge that supports innovation and economic and social development (Martin & Etzkowitz, 2000).

According to the systemic approach of national innovation production (Edquist, 2005), the innovation performance of a country depends on the existence of a highly effective National Innovation System (NIS) (Lundvall, 1992). This system consists of four interacting sub-systems: (i) the production sub-system; (ii) the research sub-system; (iii) the financial sub-system; and (iv) the education teaching and training sub-system. The first three sub-systems have been relatively well explored (Nelson, 1993). The HEIs' involvement in these three subsystems has also been sufficiently investigated (Perkmann & Walsh, 2007). However, there is little research on the teaching and training subsystem involvement in supporting innovation. Importantly, most of the economics and innovation system literature appears to have neglected the possible heterogeneities that may exist in the HESs around the world.

The characteristics of the HE teaching and training system and their effects on national innovation performance

The education policy literature identifies a variety of HESs around the world (Conner & Rabovsky, 2011). HESs differ in such characteristics as governance (Amaral et al., 2002), accountability (Huisman and Currie, 2004), funding (Titus, 2009), and government intervention (Neave and Van Vught, 1994). These studies have shown that HESs around the world are institutionally diverse and their effects on national innovation and knowledge production performance are not yet fully understood.

Most empirical studies focus on the effect of human capital on economic growth. However, some work has been undertaken on the effect of human capital on the innovation outputs. Chi and Qian (2010) found that the level of higher education attainment facilitated the level of innovation activity within a given region. Others, like Simonen and McCann (2008) showed that high mobility of human capital between regions can enhance the innovation performance of firms. Finally, using panel data from a sample of 29 countries, Varsakelis (2006) found that the investment in quality education¹ is associated with higher output of innovation activity. However, none of these works has considered the ‘institutional diversity’ of HESs and their impact on national innovation performance.

Our work is closely related to Trow (2005) and Ansell (2008). Based on their studies, we identify four main HES characteristics: (i) the capacity of the HES and number of students enrolled; (ii) the level of funding/investment allocated to the HES; (iii) the

¹ The quality of education is measured as the score in mathematics at the Third International Mathematics and Science Study)

amount of total public investment (or subsidies) to the HES; and (iv) the matching between HES activity and societal needs.

The level of student enrolment and national innovation performance

One important characteristic of a HES is the ability to absorb the growing demand for HE places (Trow, 2005). Some systems are specifically designed to cope with a high influx of students, while others are more focused (Ansell, 2008).

The innovation literature suggests that the availability of skilled human resources can facilitate the production of a substantial amount of technological knowledge and thus enhance innovation performance (Nightingale, 2000). In contrast, some scholars argue that in a globalized world, size is not necessarily positively associated with performance (Murphy, 1993). Dore (1976) posits that expanding higher education often leads to a poorer quality of that education, and to a quest for diploma rather than true skill.

Empirical evidence on the effect of HES scale on a country's performance is inconclusive. Seetanah (2009) found a positive effect of the primary and secondary education enrolment ratio on per capita GDP growth. Benhabib and Spiegel (1994) showed a positive association between the number of graduates and per capita GDP growth. However, the growth in the number of graduates was found to be negatively associated with GDP growth. Although these studies are not concerned directly with innovation, they do suggest a positive relationship between HES capacity and innovation. A more relevant study by Varsakelis (2006) found no significant correlation

between students enrolment in HE with scientific orientation and the national innovation outputs of a sample of mainly OECD countries.

The cited theoretical arguments and empirical results are clearly mixed. However, there seems to be a case that while the relationship between HE enrolment and national innovation performance is not strong in the developed world, there is empirical evidence in favour of a significant and positive association between enrolment and innovation performance in developing countries. Unlike developed economies, developing countries lag behind in terms of human capital and suffer from severe shortages in qualified and educated manpower. From this discussion we propose the following hypothesis:

H1: There is a positive relationship between HE size and national innovation performance.

The impact of funding

The effect of investment in education on economic growth has been widely researched in economics. The literature suggests that the quality and improvements in knowledge and research delivered by HEIs is fundamentally related to their resource levels and funding (Greenaway & Haynes, 2003). However, while there is strong evidence in the developed world, the results for the developing countries are mixed. Some scholars found no significant relationship (Temple, 2001), while others observed a strong

relationship between education expenditure and national economic growth (Neycheva, 2010).

Increased capacity and high quality teaching and learning require a higher level of investment per student (Barr, 2004; Greenaway & Haynes, 2003). Thus, the investment in HE leads to better quality of human capital and to higher levels of innovation performance as proposed in the following hypothesis

H2: There is a positive association between investment in higher education and national innovation performance

Higher education subsidies

One important characteristic of HE is the level of public subsidies and its impact on innovation performance. The extant literature reflects a significant divergence of views related to subsidising HE (Archibald & Feldman, 2008; Greenaway & Haynes, 2003). There are two distinct schools of thought. The first school advocates a greater involvement of the public sector with high levels of subsidies to support HE (Cheslock & Gianneschi, 2008). Subsidies are viewed as critical for the enhancement of access to HE equity (Heller, 2001) and efficiency (Jongbloed and Vossensteyn, 1998). However, a subsidised system is usually very expensive, putting increased pressure on government budgets (Barr, 2004; Doyle et al., 2009). More importantly, Liefner (2003) claims that subsidised HEIs face the risk of running unsuccessful projects.

A second school of thought places a greater emphasis upon market intervention mechanisms (Ansell, 2008; Barr, 2004). These new forms of funding from private actors (for example: fees, tuitions, gifts, grants etc.) are aimed at enabling HEIs to enhance their performance and be more responsive to changes in demand (Greenaway & Haynes, 2003). Liefner (2003) also suggests that the competitive approach can strengthen accountability and transform new knowledge into marketable products. However, the role of market orientation in HE is neither sufficiently investigated (Caruana et al., 1998) nor well understood (Barr 2004). For Jongbloed & Vossensteyn (2001) the market in which HEIs operate is not perfect and can fail. The strong use of competitive and performance based approaches can generate an attitude of risk-avoidance that can be counterproductive as HEIs will be more interested in outputs and objectives that can be easily achieved (Jongbloed & Vossensteyn, 2001).

In spite of their significant differences, these two types of funding mechanisms have both been successfully used by HEIs (Liefner, 2003). Such a success is fundamentally dependent upon the effective use of these resources by HEIs, regardless of the type and source of funding. This view is supported by examples of OECD countries whose growth has been linked to the increased and satisfactory level of funding allocated to their HES through the adoption of different policies and strategies of funding (Barr, 2004; Liefner, 2003). Thus, based on the above discussion, we propose the following hypothesis

H3: There is no association between the level of HE subsidies and national innovation performance

Alignment of HES

The final institutional characteristic is associated with the relationship between HESs and their surrounding societal environment. There is an interesting debate surrounding the relationship between knowledge and innovation developed by universities and their economic and social environment (Etzkowitz, 2008). Some HESs are deliberately designed to directly serve the needs of their surrounding society while others are not particularly established to support any particular societal need other than the advancement of scientific knowledge and critical thinking. In the HE literature, the latter is sometimes called an 'Ivory Tower' system. Under this model, knowledge is mainly initiated and produced by disciplinary academics, separated from society and usually based on the autonomy of scientific investigation (Gibbons et al., 1994).

In the alternative 'application driven' model, knowledge is carried out in the context of application. It is usually interdisciplinary and initiated by practical, societal problems (Gibbons et al., 1994). Examples of this knowledge production are the modern 'entrepreneurial' universities (Etzkowitz & Leydesdorff, 2000).

The merit of 'Ivory Tower' versus 'Application Driven' HESs for supporting national innovation performance has been the subject of intense debate. Nelson (2004) and Ziman (2000) argue that scientific knowledge produced by basic research and curiosity-driven knowledge production activities constitutes indispensable elements for future long term innovation performance. On the other hand, many scholars contend that having to serve societal needs will create new avenues for useful research which in turn will be useful to drive innovation performance (Schulte, 2004).

Empirical studies in this area have reached conflicting conclusions. One group of scholars report positive impacts from engagement with industry. For example, Van Looy et al. (2004) noticed that researchers' involvement in contract research stimulates scientific productivity, and Jensen and Thursby (2001) showed that the active pursuit of commercialisation could actually promote basic research and scholarly education. However, Mansfield (1991) estimated that 11% of new products and 9% of new processes could not have been developed without the support of basic academic research. Anselin & Varga (1997) found that firms' patenting activities were higher in a region where the universities were publishing high amount of academic publications. Given the conflicting views discussed above, and based on the inconclusiveness of the empirical evidence, we propose our fourth hypothesis:

H4: there is no difference between the 'Ivory Tower' and 'Application Driven' HES in supporting national innovation performance.

3. METHODOLOGY

Our empirical investigation relies on several databases. Patent data was collected from the World International Patent Office (WIPO). Country publication data was taken from the SCImago Journal & Country Rank database, available from Scopus database. Although similar, we chose Scopus over the ISI Web of Science because the former is less biased in favour of English speaking journals (Archambault et al., 2009). It also tends to cover more scientific and interdisciplinary publications than the ISI Web of Science.

The higher education data is from the World Bank Country Education Survey database, while the population data is obtained from US Bureau of Census (USBC). The distinction between developed and developing countries is based on the IMF World Economic Outlook 2004. The innovation performance of a country is measured by the annual average of patent family between 2005 and 2008. Patents may not necessarily be an accurate measure of innovation as they measure inventiveness and do not always lead to innovation (Crosby, 2000). More importantly, it could take a long time to transform an invention into a successful innovation. With this in mind, we nevertheless rely on patents as a proxy for innovation because of lack of directly measured innovation data. Because patent output is correlated with innovation, we argue that patents are the best available indicator of the relative innovation performance of a nation (Pavitt, 1998).

Knowledge performance is proxied by the annual average of academic publications between 2005 and 2008. Again, this is a rather noisy measurement of knowledge performance as publications have varying quality and impacts. Unfortunately, such a detailed data is not available across disciplines.

Data on education is generally fraught with missing and incomplete information. Apart from the mainly OECD countries, which have full dataset available, the majority of the remaining countries have sparse or inexistent data. Our aim is to focus on the international variation in the education system rather than the variation within the OECD countries. We are therefore obliged to make use of an incomplete dataset. The

literature has long considered methods on how to deal with missing data.² Rather than dropping the missing cases, or replacing missing observations with sample averages, we use instruments to approximate missing observations. Using sample averages biases the results in favour of OECD countries. However, using data from similar countries (based, for example, on per capita GDP) provides us with a more representative sample. In our empirical application we use 5 instruments to estimate missing observations, namely (i) average GDP between 2005 and 2008; (ii) average per capita GDP (2005-2008); (iii) average GDP growth (2005-2008); (iv) average GDP growth (2001-2004); and (v) average gross expenditure on research and development to GDP (2001-2004).

Proximity is based on the nearest neighbour. For each case, we rank the instrument in ascending order. Then, the country available on either side of the missing country is identified as neighbour. Then the missing observation of the missing country is equated with that of the neighbouring country. However, this method does not fill all missing observations because the nearest neighbours may themselves have missing observations (in which case we keep the observation as missing).

The estimation is carried out using simple OLS as well as a censored regression model (TOBIT). Our dependent variables are the average number of patents and publications between 2005 and 2008. Both of these have possible values of zero as some countries may have no patents or publications during the period 2005 to 2008. In this situation a censored regression estimation is more appropriate than the simple OLS since the latter

² For a brief review of how to deal with missing observations see Drukker (2011).
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method does not allow for variables with a mixture of discrete and continuous distributions.

The TOBIT model is given by

$$\log(O_i^*) = \beta'X_i + \epsilon_i$$

$$O_i = 0 \text{ if } O_i^* = 0$$

$$O_i = \log(O_i^*) \text{ if } O_i^* > 0$$

where β is a vector of parameters, O_i^* is the dependent variable for country i , and X_i is the vector of explanatory variables for the same country i . This is a non-linear model, which is usually estimated via maximum likelihood method (Amemiya, 1973)

We adopt is a production function type

$$O_i^* = H_{1i}^{\beta_1} H_{2i}^{\beta_2} H_{3i}^{\beta_3} H_{4i}^{\beta_4} \exp(\alpha_0 + \text{Control}_i + \epsilon_i)$$

where O_i^* is country i 's output (patents or publications), ϵ_i is the disturbance term, and H_{1i} to H_{4i} are the main inputs to the production function and are related to the four hypotheses proposed in the previous section. All data related to these hypotheses are four year averages (2005-2008). Ex penditure figures are in constant 2005 international \$.

For the first hypothesis, we proxy size by the gross enrolment ratio of students, which is the percentage of the number of the students enrolled in higher education to the total number of the population within the higher education age group. Thus, the gross enrolment ratio for country i is given by

$$H_{1i} = \frac{\text{Number of Students}}{\text{Population with HE age}} \times 100$$

This variable underpins the assumption that the greater the number of students enrolled in HES, the higher the potential to improve the innovation and knowledge performance of a country. We use relative, rather than absolute, size in order to avoid the scale effect problem (heterogeneity of, say, economic output and population may distort the results).

For the second hypothesis we proxy investment in higher education by 'relative support'. Thus, the relative support for country *i* is given as follows:

$$H_{2i} = \frac{\text{TotalExpHE/GDP}}{\text{TotalEnrol/Pop}}$$

This proxy is the ratio of relative expenditure to relative enrolment. The numerator equals total education expenditure for higher education (tertiary educational level) as a percentage of GDP. The denominator represents relative enrolment (enrolment ratio). The relative support is a better measure than absolute funding measures (such as total education expenditure for HE) because different countries have different population sizes as well as different levels of economic output. The second hypothesis implies a significant and positive relation between relative education support and innovation output.

The third hypothesis relates to the level of subsidies, which we measure as the ratio of public expenditure (in HE) to total expenditure (in HE), and is given as follows:

$$H_{3i} = \frac{PubExpHE}{TotalExpHE} \times 100$$

Finally, the last hypothesis relates to the impact of HES alignment with its surrounding economic and social environment on innovation performance. We measure this variable by a mismatch measure, which is the ratio of unemployed HE graduates to total population. Thus, the mismatch for country *i* is given by

$$H_{4i} = (UHE/POP) \times 100$$

Our choice of this measure is based on three considerations. First, it is not obvious how to identify whether a specific country belongs to an application driven or an ivory tower system. Second, even if there was a way of identifying some characteristics by which one can make a judgement as to the nature of the adopted system, it may well be the case that a country chooses a combination of both. Thus, given the possibility that countries may not adopt pure systems, a continuous measure would be preferable. Finally, we expect the number of unemployed higher education graduates to be correlated with how deep a system is within one system or another. For example, with an extreme 'Ivory Tower' system we expect H_{4i} to be at its highest value because none of the graduated students gets employment (unemployed higher graduates equal the number of graduates). On the other hand, an extreme 'Application Driven' system will produce the lowest value for H_{4i} of zero. In this extreme case, all graduated students find employment.

The control variables are defined as follows

$$\text{Control}_i = \alpha_1 D_i^{\text{OECD}} + \alpha_2 D_i^{\text{High}} + \alpha_3 D_i^{\text{Medium}} + \alpha_4 D_i^{\text{Missing}} + \alpha_5 G_i + \alpha_6 M_i \\ + \alpha_7 \text{LogPop}_i$$

where D_i^{OECD} , D_i^{High} , D_i^{Medium} and D_i^{Missing} are dummies equalling one if country i is an OECD member, has high level of output, has medium level of output, or has missing observations, respectively. G_i is the ratio of Gross Expenditure on Research and Development (GERD) to GDP; and M_i is a perception variable on the quality of math and science education in country i (MATH). Finally, to control for the possible effect of country size on output we use log population for country i (LogPop_i).

We define ‘high’ patent output countries as those exceeding 10,000 patents during the period of study, and ‘medium’ patent output countries as those between 1000 and 10,000 patents. High publication output countries are defined as those exceeding 50,000, while medium publication output is defined as between 10,000 and 50,000 publications. Although these cut-off points are necessarily arbitrary, our choice seems to fit the pattern shown in Table2.

Summary of Data

The initial dataset contains 208 countries. Of these, 11 countries have virtually no data and were removed.³ The remaining 197 countries are mixed. Only 30 countries, of which 21 are OECD countries, have complete data sets while the remaining 167 countries have sparse data. Table 1 shows the main variables for a selection of countries with full and missing information. The non-missing data set is dominated by OECD countries and shows some obvious outliers (US and Japan in terms of patents and US, UK and Japan in terms of publications). The incomplete data countries are mostly developing countries. Within this group there also appear to be outliers (China, Canada and India).

The summary statistics are shown in Table 2. There are few missing observations for the dependent variables (Patents and Publications). The large standard errors for these two variables indicate the presence of outliers on both sides of the distribution. The information on enrolment (H1) is fairly acceptable with 142 countries having information on this dependent variable. However, the remaining independent variables (H2, H3 and H4) have less available information. Finally, the control variables show fewer missing observations.

[Insert Table 1 about here]

[Insert Table 2 about here]

³These are: Curacao, Gibraltar, Kosovo, Puerto Rico, San Marino, Somalia, South Sudan, Taiwan, Turks and Caicos Islands, Tuvalu, and The Vatican.

4. RESULTS

We begin our analysis with the full information sample. This sample, which is dominated by OECD and industrialised countries, is not representative of the rest of the world. Nevertheless, these results will help us gauge the possible difference between the developed and developing countries as illustrated in Table 3. Since there are no zero values (for the dependent variables) in this set, we use OLS.

The F probability values suggest that the overall fit is significant. The R-squared is very high, suggesting appropriateness of the control variables. It is clear that the two types of output have different outcomes. First, the high and medium output dummies are highly significant for patents. The scale of the coefficients of these two dummy variables indicates two clear (structural) breaks in innovation even within this mainly developed nation sample. Roughly speaking, a typical high output nation produce $e^{3.515} = 33.62$ times more patents than an average low output nations, whereas a typical medium output nation produces 10.14 times more patents than a low output nation. These two dummies contribute about 6% to explaining patents.⁴ Given that these are dummy variables, this contribution suggests that there is a substantial portion of patents that cannot be explained by the model. Population and expenditure on research and development are also highly significant and explain about 5% and 2% of the variation in patents output, respectively. Finally, given the high and medium dummies and population, the perception on quality of education does not contribute to explaining

⁴ We approximate the contribution of one of more variables by carrying out two regressions, one of which excludes the variable(s) of interest. The difference in the R-squares gives the required partial contribution.

patents output. The OECD dummy is insignificant suggesting no difference in outputs between OECD and non-OECD countries once we control for relevant explanatory variables.

[Insert Table 3 about here]

Analysis of the Extended Set

As our focus is international, we aim to assess our four hypotheses in light of the extended sample containing all possible countries. Table 4 shows the TOBIT results for the extended set.⁵ The results for the extended set are generally different compared with the non-missing set. First, the control variables have more impact on patents. The gross expenditure on R&D is surprisingly negative, suggesting that, other things equal, countries with higher gross expenditure on R&D have marginally lower patent outputs. The remaining control variables are all highly significant. First, note that the coefficient of log population is significant but low (compared with the non-missing data case), suggesting that population size has a significant but less important role in determining the patent output. Second, the missing variable dummy is negative, implying that countries with missing variables are almost four times ($e^{-1.276} = 0.28$) less productive (in terms of patents) than a similar country without missing variables. Third, and most important, the OECD, medium and high dummies reveal a large unexplained gap between the high output and low output countries. The results suggest that on average,

⁵ For comparison, OLS estimation of the two models gave relatively low R-squares (82%-83% in the extended sample against 98%-96% in the smaller set).

an OECD country has $e^{2.623} = 13.78$ times more patents than a non-OECD. A high output country has 210 times more output than an average non-OECD and low output country; while a medium output country has more than 26 times more patents.

Our first hypothesis of a positive relationship between HE size and innovation is strongly supported. The coefficients for H1 are both positive and highly significant, suggesting that larger HE sectors produce higher levels of output, even after controlling for expenditure and population factors. There is also a strong support for our fourth hypothesis. Indeed, the coefficients for H4 are insignificant for both patents and publications, implying that there is no connection between mismatching and innovation output.

The results on our second and third hypotheses are less conclusive. The coefficient on relative support (H2) for patents is positive and highly significant, but the coefficient for publications is insignificant. So the second hypothesis is confirmed for patents, but rejected for publications. The roles are reversed when we consider the third hypothesis. This hypothesis is supported by the publication results but rejected by the patents results.

(Insert Table 4 about here)

5. DISCUSSION

Our findings indicate that our four hypotheses can be substantiated. The level of HE capacity and the level of funding to HE students, are shown to be associated with the level of national innovation and knowledge performance. Our findings confirm that

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there is no difference between the 'Ivory Tower' and 'Application Driven' approaches, in supporting the national innovation performance of a country. These findings support the view conveyed by a large body of the literature, that the ability of a country to build up a knowledge society and to innovate, is related to the development of its human capital (Barr, 2004; Chi & Qian, 2010).

The importance of the capacity of the HE sector for HE policy aimed at supporting national innovation and knowledge performance, is perhaps somewhat unsurprising, as it seems sensible to assume that an increase in educated human resource opens up the possibility for the creation of innovative undertakings or ventures. It is, however, worth noting that the scale of the capacity on its own can be counterproductive if it is not associated with the quality of education as suggested by an important branch of the literature (Hanushek & Woessmann, 2008).

The impact of funding of human capital production on national innovation performance is investigated through two hypotheses. H2 asserts that knowledge required for the production of innovation is dependent on the level of total funding invested in HE. H3 is focused on the impact of public funding (subsidies) on the national innovation performance. Although both of these hypotheses are less conclusive than H1 and H4, our empirical investigation still provides partial evidence of links between funding and national innovation performance, that is, relative support (H2) impacts patents. Moreover, our prediction that subsidies do not impact innovation is supported for publications only. On the other hand, countries with higher levels of subsidy tend to underperform in terms of patents.

Our results correspond to the on-going debate on HEI funding systems and the lack of clear consensus with regards to their effectiveness and impact on national innovation performance (Muscio et al., 2013). This lack of consensus and the continuing emergence of contrasting views between the two main schools (public funding versus market mechanisms) can be explained in part by the heterogeneity of the HE system (Ansell, 2008). This result provides evidence that both approaches and policies can be combined (Arclean & Schiopu, 2010) and when properly implemented, can lead to improved levels of innovation and knowledge performance (Muscio et al., 2013). This also explains the emerging view which places emphasis upon the complementarities between the different types of funding strategies (Arclean & Schiopu, 2010). It is also worth noting that expecting to secure immediate results from simply increasing HE funding can be misleading; an effective, high quality HE teaching and learning system is also required (Geuna & Muscio, 2009)

The objective of our last hypothesis (H4) was to investigate whether there were any differences between the 'Ivory Tower' and 'Application Driven' approaches in supporting the national innovation performance of a country. Our empirical findings show a strong support for H4 which unambiguously indicates a lack of relationship between the extent of matching graduates to labour demand and innovation output. Our results also confirm the absence of prior conclusive empirical evidence favouring one system over the other. Thus, we provide further evidence supporting the view that neither the 'Ivory Tower' nor the 'Application Driven' is a universally better approach in all applications.

The scale of HE capacity, the support per HE student and subsidy are likely to be amongst the main drivers for a country's future innovation performance. Thus, our findings suggest that these three elements should be the main constituents of HE policies aimed at supporting national innovation and knowledge performance. On the other hand, we find no difference between the 'Ivory Tower' and 'Application Driven' systems. Consequently, a greater emphasis should be placed on complementing the two systems.

6. CONCLUSIONS

The importance of knowledge and human capital and their impact on innovation and growth are widely recognised, and so is the role of the HES in the production of this knowledge. However, most of the innovation literature attributes this production to the second and third mission of HESs which includes the research and production functions of NIS. The role of the first mission has received noticeably less attention in this literature. This paper has been motivated by the existence of an apparent gap in the innovation literature concerning the appropriate HE policy to support national innovation and knowledge performance, specifically within the domain of the first mission.

In this paper, we show that the capacity of the HE sector, and the support available to HE students are positively correlated with the level of national innovation and knowledge production. On the other hand subsidisation is either neutral (for publications) or harmful (for patents). Finally, the adoption of any particular strategy with regards to the alignment between the HES and its external environment does not

seem to be relevant. Indeed, once we control for other HES characteristics, we could not find any statistical discrepancy between 'Ivory Tower' and 'Application Driven' systems.

Our empirical evidence suggests these key institutional characteristics should form the foundation of HE policies aimed at supporting national innovation and knowledge performance. In particular, policy makers should focus on greater access to HE as it is key to promoting both innovation and knowledge production. They should also be aware of the trade-off that exists in other characteristics. For example, higher investment in HE is good for patents but higher subsidies have an adverse effect on patent production. On the other hand neither of these policy tools seems to impact publication production.

The results of this paper are based on a cross-country analysis. This leads to two main limitations. First, we view the relation between HE characteristics and innovation production as an aggregate phenomenon. Thus, we do not consider within country heterogeneity of HESs. If such heterogeneity could be approximated, the empirical relevance of our results could be improved by including it as an additional HE characteristic. The second limitation stems from our choice to extend the sample beyond those countries that have complete data sets. This choice makes our study interesting because we avoid the limitation of drawing conclusions that are specific to the (mainly OECD) developed world. Unfortunately, this results in a thinner dataset, with a substantial number of missing observations. Although we partially mitigate this problem, we feel that until a fuller data set is made available, conclusions drawn on partial datasets like ours should be treated with caution.

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Table 1: Dependent and Independent Variables for a Selection of Full and Missing Data Countries.

| Country | PATENTS | PUBLICATIONS | H1 | H2 | H3 | H4 |
|--------------------------------------|----------|--------------|-------|-------|-------|------|
| Selected Countries with Full Dataset | | | | | | |
| Japan* | 65298.33 | 106821.75 | 51.77 | 37.99 | 41.37 | 1.43 |
| USA* | 61538.33 | 373854.50 | 77.29 | 52.12 | 39.32 | 2.54 |
| South Korea* | 19335.33 | 40958.00 | 87.35 | 33.45 | 17.58 | 1.05 |
| France* | 8915.67 | 76834.75 | 54.56 | 35.57 | 83.65 | 1.66 |
| UK* | 5539.00 | 117650.00 | 61.14 | 29.75 | 70.70 | 0.67 |
| Italy* | 4903.33 | 61485.00 | 56.90 | 27.68 | 72.49 | 0.71 |
| Austria* | 1537.67 | 13315.25 | 49.68 | 40.11 | 93.15 | 0.34 |
| Spain* | 1215.67 | 48859.50 | 63.12 | 26.85 | 76.11 | 2.48 |
| Israel | 1184.67 | 14164.25 | 55.74 | 43.00 | 53.26 | 5.68 |
| Belgium* | 1145.67 | 19139.50 | 60.37 | 35.93 | 85.03 | 1.39 |
| Selected Countries with Missing Data | | | | | | |
| China | 4923.00 | 193774.25 | 13.94 | | | |
| Canada* | 3475.00 | 64790.00 | 61.23 | | | 2.16 |
| India | 1444.67 | 44529.00 | 10.58 | 89.49 | 79.15 | |
| Singapore | 710.33 | 10105.75 | | | | 1.66 |
| Ireland* | 458.67 | 7096.25 | 54.46 | | | 0.96 |
| New Zealand* | 383.33 | 8361.00 | 72.73 | | | 0.76 |
| Malaysia | 201.00 | 4522.00 | 28.86 | | | 0.64 |
| Croatia | 31.33 | 3470.00 | 36.10 | | | 1.51 |
| Romania | 29.33 | 5196.00 | 34.27 | | | 0.40 |
| Iceland* | 29.00 | 663.25 | 58.40 | | | 0.34 |

Notes: (*) indicates that the country is OECD. PATENTS and PUBLICATIONS are, respectively, the average number of patents and academic publications between 2005 and 2008. H1, H2, H3, and H4 are defined in Section 3.

Table 2: Summary Statistics.

| Series | Observation | Mean | Std Error | Minimum | Maximum |
|----------------------------|-------------|----------|-----------|---------|----------|
| PATENTS | 181 | 1309.162 | 7285.666 | 0 | 65298.33 |
| PUBLICATIONS | 197 | 8929.871 | 34053.48 | 0 | 373854.5 |
| Gross Enrolment Ratio (H1) | 142 | 28.332 | 23.409 | 0.922 | 87.353 |
| Relative Support (H2) | 35 | 43.087 | 23.375 | 16.246 | 122.866 |
| Subsidy (H3) | 41 | 71.454 | 22.609 | 17.478 | 100.000 |
| Mismatching (H4) | 76 | 1.422 | 1.145 | 0.003 | 5.684 |
| Log Population 5-8 | 192 | 15.357 | 2.276 | 7.382 | 20.999 |
| Log GDP 5-8 | 183 | 24.321 | 2.249 | 19.201 | 30.193 |
| Log Per Capita GDP 5-8 | 183 | 8.713 | 1.307 | 5.652 | 11.187 |
| GERD to GDP 1-4 | 93 | 0.880 | 0.937 | 0.014 | 4.443 |
| GDP growth 5-8 | 190 | 5.367 | 3.405 | -6.737 | 24.187 |
| GDP growth 1-4 | 192 | 4.166 | 4.040 | -7.789 | 33.329 |
| MATH 3-4 | 101 | 4.127 | 1.130 | 1.900 | 6.500 |

Notes: PATENTS and PUBLICATIONS are, respectively, the average number of patents and academic publications between 2005 and 2008. H1-H4 are defined in Section 3. 'Log Population 5-8', 'Log GDP 5-8', 'Log Per Capita GDP 5-8' are average values across the years 2005 to 2008. GERD to GDP 1-4 is the average value of the ratio of Gross Expenditure on Research and Development (GERD) to GDP between 2001 and 2004. 'GDP growth 1-4' and 'GDP growth 5-8' are percentage growth in GDP for the years 2001-2004 and 2005-2008 respectively. 'MATH 3-4' is the average perceived quality of math and science education between 2003 and 2004.

Table 3: OLS results for the non-missing observations sample.

| | PATENTS | | | PUBLICATIONS | | |
|----------------------------|-------------|--------|-------|--------------|--------|-------|
| | Coefficient | t-stat | p-val | Coefficient | t-stat | p-val |
| Constant | -2.224 | -0.695 | 0.495 | -10.564 | -3.044 | 0.007 |
| Gross Enrolment Ratio (H1) | -0.153 | -0.448 | 0.659 | 1.045 | 3.004 | 0.007 |
| Relative Support (H2) | -1.273 | -4.105 | 0.001 | -0.090 | -0.286 | 0.778 |
| Subsidy (H3) | -0.407 | -1.474 | 0.157 | 0.316 | 1.338 | 0.197 |
| Mismatching (H4) | -0.497 | -3.011 | 0.007 | -0.099 | -0.611 | 0.549 |
| GERD to GDP 1-4 | 0.649 | 4.841 | 0.000 | 0.286 | 2.196 | 0.041 |
| MATH3-4 | 0.127 | 0.965 | 0.346 | 0.152 | 1.122 | 0.276 |
| OECD Dummy | 0.245 | 0.860 | 0.401 | 0.623 | 2.069 | 0.052 |
| HIGH Output Dummy | 3.515 | 6.834 | 0.000 | 0.625 | 1.343 | 0.195 |
| MEDIUM Output Dummy | 2.316 | 7.603 | 0.000 | 0.274 | 0.857 | 0.402 |
| Log Population 5-8 | 0.735 | 7.406 | 0.000 | 0.783 | 6.319 | 0.000 |
| N | 30 | | | 30 | | |
| R-sq | 0.98 | | | 0.96 | | |
| F(p-val) | 0.000 | | | 0.000 | | |

Notes: See Table 2 for definitions.

Table 4: TOBIT results for the extended set.

| | PATENTS | | | PUBLICATIONS | | |
|----------------------------|-------------|---------|-------|--------------|--------|-------|
| | Coefficient | t-stat | p-val | Coefficient | t-stat | p-val |
| Constant | -11.669 | -19.578 | 0.000 | -12.719 | -4.820 | 0.000 |
| Gross Enrolment Ratio (H1) | 1.002 | 3.496 | 0.000 | 0.644 | 4.654 | 0.000 |
| Relative Support (H2) | 1.496 | 55.285 | 0.000 | 0.389 | 1.080 | 0.280 |
| Subsidy (H3) | -0.325 | -2.073 | 0.038 | 0.160 | 0.418 | 0.676 |
| Mismatching (H4) | 0.327 | 0.974 | 0.330 | 0.254 | 1.226 | 0.220 |
| GERD to GDP 1-4 | -0.663 | -1.987 | 0.047 | -0.063 | -0.339 | 0.735 |
| MATH3-4 | 0.798 | 4.944 | 0.000 | 0.236 | 1.448 | 0.148 |
| OECD Dummy | 2.623 | 3.525 | 0.000 | 1.742 | 3.637 | 0.000 |
| HIGH Output Dummy | 5.347 | 2.940 | 0.003 | 0.721 | 0.898 | 0.369 |
| MEDIUM Output Dummy | 3.278 | 3.647 | 0.000 | 0.343 | 0.603 | 0.546 |
| Missing Observation Dummy | -1.276 | -2.605 | 0.009 | -1.263 | -3.136 | 0.002 |
| Log Population 5-8 | 0.195 | 7.600 | 0.000 | 0.907 | 12.141 | 0.000 |
| N | 110 | | | 110 | | |
| Log-Lik | -152.514 | | | -187.859 | | |

Notes: See Table 2 for definitions. The dummies are explained in Section 3.