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Exploring the cross-country gap in patenting: A Stochastic Frontier Approach

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ABSTRACT

This paper benchmarks the patent activities of a sample of OECD countries against the world frontier and explores the sources of the cross-country differences in patenting (regarded as a proxy for innovation). A patent production frontier is estimated for a panel of 21 OECD countries over the 1990–2002 period using Stochastic Frontier Analysis. Patenting performance for each country is decomposed into basic patenting capacity and patenting efficiency. The gap between Europe and the world leaders in terms of basic patenting capacity remains substantial with little sign of convergence over the sample period. In terms of patenting efficiency, Japan, Germany and Italy have improved their relative position in recent years. The gap in patenting performance between the UK and the world frontier is due to relative underperformance in both patenting capacity and efficiency in patent production. Institutional factors are found to be significantly associated with the patenting efficiency of an economy.

1. Introduction

The gap in innovation between European Union (EU) countries and the USA has been well documented. Recent publications by the European Commission and the UK Department of Trade and Industry on international research and development (R&D) expenditure show that Europe lags behind the USA and some Asian economies in R&D investment (DTI, 2005; EC, 2005). Hall (2004) and other studies have also suggested an increasing gap between Europe and the USA. There are numerous academic and government studies investigating the factors affecting national innovation performance and quantifying national innovative capacity, which have identified gaps between the OECD economies and the USA as the lead economy in this respect (e.g. EC, 2002, 2005; Porter and Stern, 1999; Furman et al., 2002; DTI, 2003a,b,c, 2005; Mairesse and Mohnen, 2002; Faber and Hesen, 2004; Furman and Hayes, 2004; Jaumotte and Pain, 2005).

One of the most influential contributions to this literature has been based on a particular notion of innovation capacity. This is defined as "the ability of a country – as both a political and economic entity – to produce and commercialise the flow of new-to-the-world technologies over the long term" (Furman et al., 2002, p. 900). This notion of innovative capacity is "not the realised level of innovative output per se, but reflects more fundamental determinants of the innovation process" (Furman et al., 2002). This notion, operationalised by the authors as a "production function" for international patents, is – they argue – readily captured by a small number of observable factors that describe a country's national innovative capacity. These are the *common innovation infrastructure* including overall science and technology policy, basic research support mechanisms, higher education and the stock of cumulative technological knowledge; *specific innovation environments* such as industrial clusters of the kind identified by Porter in his work on the sources of national competitive advantage; and *linkages* between the common innovation infrastructure and the clusters influenced, among other things, by the nature of the university system and the nature of funding sources for new ventures linked to the particular industrial clusters.

In most developments of this approach innovation output is proxied by US PTO patenting per capita. The contribution or 'weight' of each of the potential drivers is then derived from a regression analysis. This analysis attempts to explain the cross-country patterns of patenting in terms of proxy variables designed to capture infrastructure, cluster and linkage variables On the basis of these estimated 'weights' and the value of the underlying innovation drivers, countries may then be ranked in terms of per capita national innovation capacity (for a recent review of developments using this approach, see Gans and Hayes, 2008).

Other multivariate regression approaches to the analysis of cross-country patterns of innovation outputs have used different estimation procedures and have augmented or moved away from patents as a proxy for innovation output. Jaumotte and Pain (2005), for example, model the determinants of business sector R&D and then separately model the determinants of patenting. They then model the determinants of R&D employment and real wages in an attempt to assess the potentially adverse impacts that an increased

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demand for R&D employees might have on the cost of R&D to the private sector. Faber and Hesen (2004) and Mairesse and Mohnen (2002) replace or augment patents as an indicator of innovation with more direct measures arising from the European Community Harmonised Innovation Surveys. These more direct variables include measures of the share of innovative products in final sales. Unfortunately there are no comparable data for the US or Japan or other non-EU countries which can use these more direct measures of innovation, so broader OECD comparisons continue to be primarily based on patenting data (Gans and Hayes, 2008).

Each of these approaches has provided important insights into cross-country patenting and innovation performance differences. However, they fail to distinguish explicitly between the extent to which innovation output differences across countries are due to the lack of innovation input *per se*, and the efficiency with which those inputs are converted into innovation outputs. The innovation performance of an economy depends not only on how much it invests in innovation, e.g. R&D investment and manpower, but also on how efficiently it manages the innovation process and successfully transforms the innovation inputs into useful innovation outputs, such as patents. With low innovation efficiency, an increase in investment in, say, R&D or the Science Base may not produce the expected increase in "outputs". The importance of such inefficiency is implicit in many policy discussions. The EC (1995) *Green Paper on Innovation*, for instance, states that "Europe suffers from a paradox. Compared with the scientific performance of its principal competitors, that of the EU is excellent, but [. . .] its technological and commercial performance in high-technology sectors such as electronics and information technologies has deteriorated. One of Europe's major weaknesses lies in its inferiority in terms of transforming the results of technological research and skills into innovations and competitive advantages."

Whilst the innovation capacity approach includes innovation system variables which one might expect to influence the translation of inputs into innovation outputs, it is not able to systematically distinguish and account for the relative contribution of these system effects which influence 'efficiency' compared to inputs *per se*. In this paper we attempt to do this by decomposing each country's gap in patenting compared to an estimated world patenting frontier into basic patenting capacity based on innovative inputs and the efficiency with which those inputs are used. We employ the Stochastic Frontier Analysis (SFA) approach to estimate the world patenting frontier. SFA is a widely used standard efficiency estimation approach in productivity analysis,[1] which we apply in the new context of knowledge production. The advantage of the SFA approach lies in that it explicitly decomposes the observed patent performance into two separate components: the patenting potential of a country given the best practice use of inputs, and an "efficiency gap" relative to the best practice patenting frontier. This is different from the traditional total factor productivity (TFP) approach that defines productivity as the residual of the patenting production function. In contrast SFA takes account of measurement error and decomposes a country's deviation from the frontier into inefficiency and a random error.

An alternative approach to SFA in the evaluation of cross-country patenting efficiency would be to apply Data Envelopment Analysis (DEA). Using this approach, and with R&D capital stock and manpower as inputs and patents and academic publications as innovation outputs, Wong and Huang (2007) evaluate the relative efficiency of the R&D activities of 30 countries. They find that less than one-half of the countries are fully efficient in R&D activities. Similarly, Hollanders and Esser (2007) carry out a DEA analysis using scores from the European Innovation Scoreboard (EIS) for the year 2007. Their model includes three categories of innovation inputs, namely innovation drivers, knowledge creation and innovation and entrepreneurship, and two broad categories of outputs which they term applications and intellectual property. Applications include, *inter alia*, the CIS based direct innovation measures and indirect measures based on high-tech activity. Their study also shows a variety of efficiency in innovation across countries. Both studies focus on the estimation of innovation efficiency, and say relatively little on innovation capacity. Moreover, the DEA method attributes all the deviation from the frontier to inefficiency (see for example the discussion in Cosh et al., 2005; Fritsch and Slavtchev, 2007); whilst SFA has the advantage of controlling for statistical noise in the estimation of innovative efficiency.

Using USPTO patenting as our innovation output proxy, we define a country's patenting capacity as its predicted patent output if it were located on the estimated patenting frontier. We define patenting efficiency as the ratio of observed patenting value to estimated patenting at the frontier. The use of patents allows direct comparability with the previously cited major studies of comparative international patent performance. We recognise that the use of the USPTO imparts a country bias when comparing any one country's performance relative to the US, but there is no reason for this bias to vary across countries when comparing each to the US.

This paper contributes to the literature as the first attempt to apply the SFA approach to the analysis of cross-country innovation activity provided by patents. In addition we attempt to allow for structural differences between economies which may affect the incidence of patenting. Since patenting varies significantly across industries, we include industry structure as one of the explanatory variables affecting observed patenting gaps. Given the pressure of home country patent data bias, we focus relatively more on the comparison of non-US economies with each other relative to the US. However, given the fact that the US is widely regarded as one of the leading economies in innovation we include the US in the construction of the world patenting frontier.

The rest of the paper is organized as follows. Section 2 discusses the theoretical framework. Section 3 presents some stylized facts. Section 4 discusses the model, data and methodology. Section 5 reports the estimated results, and Section 6 concludes.

2. Determinants of national innovation performance

In this paper we seek to identify sources of differences in national innovation performance as proxied by patenting, in terms of differences in their innovation systems. Following existing work in this field we define a national innovation system as a set of agents, the institutional framework within which they operate, and the networks and interrelationships among them. The national systems approach argues that taken together these system elements determine national innovation performance. The institutional framework and patterns of relationships condition, and co-evolve with, the motivation and abilities of firms to invest in R&D and human capital and to develop and commercialize product designs and service activities and manufacturing and service production processes that are new to them (Freeman, 1987; Lundvall, 1992; Nelson, 1993). The innovation performance of a nation is determined not only by the quantity of human and capital factor inputs into innovation, but also by institutional and other system factors. These factors constitute constraints and/or incentives for innovation (Pavitt, 1980; Furman et al., 2002; Faber and Hesen, 2004). They also influence the direction and nature of innovation decisions taken by firms and hence determine the 'efficiency' of the national innovation system (Mairesse and Mohnen, 2002).

Within an innovation system perspective we seek to estimate the innovation capacity of a country based on its basic innovation

[1] For examples of the application in traditional productivity analysis, see Banker et al. (1987), Lovell (1996), Hofler and Payne (1993) and Hiebert (2002).