Losing the Edge at the Final Frontier: A Relative Decline in Scientific Inputs and its Consequences[*]

ATIN BASU CHOUDHARY[‡] AND MICHAEL REKSULAK[§]

[‡] *Department of Economics & Business, 345 Scott Shipp Hall, Virginia Military Institute, Lexington, Virginia 24450, USA*

[§] *School of Economic Development, Georgia Southern University, P. O. Box 8152, Statesboro, Georgia 30460, USA*

August 2006

Abstract

This paper proposes a model of scientific output utilizing a Cobb-Douglas production function. We employ a newly available panel dataset to analyze patterns of investment in research across countries and their consequences for research leadership. Results suggest some evidence that the demographic mix of a country may matter more than previously thought in determining scientific output relative to R&D spending and the existing stock of scientific output.

JEL Classification: H0, O3, O38.
Keywords: Technological Change, Public Policy, Demographics, R&D.

---

[*] We benefited from comments by Ann Battle, R. Morris Coats, John Conlon, Tinni Sen, and William F. Shughart II. Earlier versions of this paper were presented at the Annual Meetings of the Southern Economic Association in Washington, D.C., the Economics Seminar at the Virginia Military Institute, and at the meetings of the Virginia Association of Economists in Williamsburg,VA. The authors, as is customary, assume collective responsibility for any errors.

Losing the Edge at the Final Frontier: A Relative Decline in Scientific Inputs and its Consequences

> With innovative capacity rapidly spreading across the Pacific, the United States cannot simply assume that it will remain the epicenter of scientific research and technological innovation. [Segal, 2004, p. 8]

1. Introduction

Assuming that one could imagine scientific output as the engine in a *NASCAR* or *Formula I*-type racecar and the race itself as one for economic growth, then the United States would find itself far ahead of the pack. Cruising along at high speed, the leader could be confident of a win. Alas, that is where the analogy hits the first speed bump and the brakes have to be applied to the confidence of the frontrunner. The race in question is open-ended and, therefore, at any point in time it is the relative distance to the advancing stragglers that counts the most. Recently, it was *Foreign Affairs* that signaled a warning from the sidelines. The author cautioned of slippage in the gears of the US-based research engine and augured a relative shortfall in horse power compared with those who pour only the best oil into their machines:

> For 50 years, the United States has maintained its economic edge by being better and faster than any other country at inventing and exploiting new technologies. Today, however, its dominance is starting to slip, as Asian countries pour resources into R&D and challenge America's traditional role in the global economy. (Segal, 2004, p. 2)

Richard Freeman, in a widely publicized NBER working paper in the summer of 2005, traces the speed at which other countries have been and are catching up to the United States. While pointing out that America's leadership advantage is still enormous, he nevertheless sketches future difficulties and suggests means to ease the anticipated painful adjustments.

The "catching up" effect in terms of Research & Development (R&D)[1] expenditure as percentage of GDP is represented in Figure 1 for, arguably, the five largest actors in the area of science and technology. Russia, after the initial transitional shock brought about by the opening up of its economy, is posting impressive growth rates in this expenditure category. China has reached the same level and exhibits the highest growth rates – especially if one takes into account its gargantuan increase in GDP over the last decade. The European Union as a whole has dropped

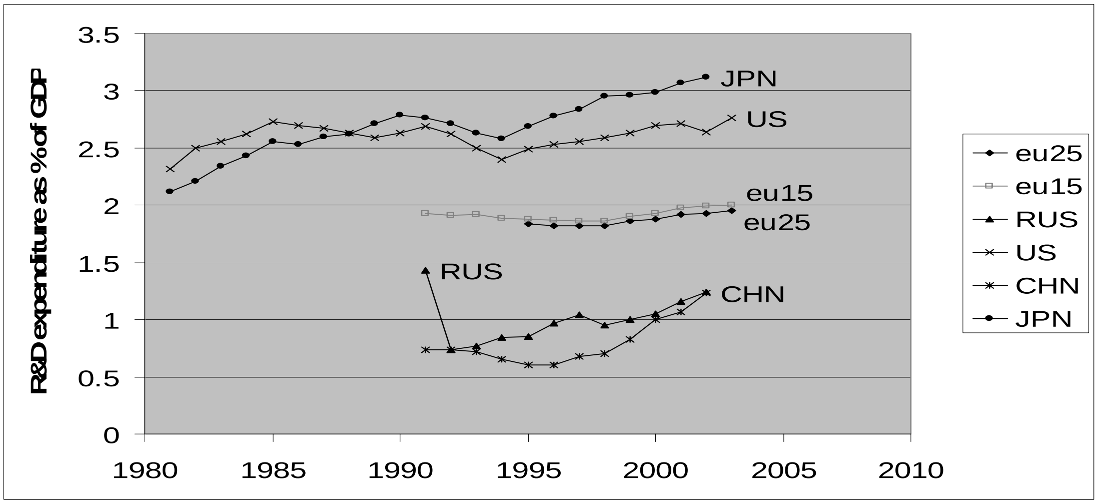
---

[1] This includes public and private expenditures on both fundamental and applied research in these countries.

somewhat in this measure after welcoming ten more countries. Japan and the United States of America – although far out in front – are losing ground in a relative sense.

The National Academy of Sciences, in October of 2005, published an extensive report on "Prospering in the Global Economy of the 21st Century" (The National Academy, 2005). In it, the authors profess concern "… that the scientific and technical building blocks of our economic leadership are eroding at a time when many other nations are gathering strength" (p. 2). The study warned that the American edge in science and technology has begun to erode and proposed that a concerted effort be undertaken at all levels of government to secure the competitiveness of the United States in this area. Without this, the report warns, "For the first time in generations, the nation's children could face poorer prospects than their parents and grandparents did." (p. 8).

Figure 1. Research and development expenditures as percentage of GDP



Source: Eurostat (2005)

There is still a significant disparity in the scientific output between scientifically advanced countries, especially the US, and scientifically developing countries. However, it seems that this gap is rapidly being closed not only in relative but also in absolute terms. Holmgren and Schnitzer (2004) make the astonishing assertion – accounting for different amounts of research funds available in the studied regions – that Latin America had outpublished both the US and Canada in 2000.

These changes in national expenditures on R&D and the effect on scientific output are important because of their potential impact on GDP growth (Grossman and Helpman, 1991) and the relative economic power of nations.

There exists ample evidence in the academic literature of positive economic returns (see Scott et al. 2001 for an extensive survey) to research and development investments. A recent RAND study asserts that “In advanced countries, S&T [Science and Technology] has been shown to contribute significantly to economic growth” (Wagner et al. 2001, p. ix). The authors distinguish between four types of countries: 22 “scientifically advanced countries” (SAC), 24 “scientifically proficient countries” (SPC), 24 “scientifically developing countries” (SDC), and 80 “scientifically lagging countries” (SLC). We use this classification to construct Table 1. Figure 2 depicts the global distribution of levels of scientific development based on the same classification.

It therefore seems of some interest to attempt to understand how the engine of science is built differently in different countries – and, indeed, if these differences can explain why some engines have less horsepower than others. Such an analysis could form the basis of policy decisions that will have an impact on economic growth.

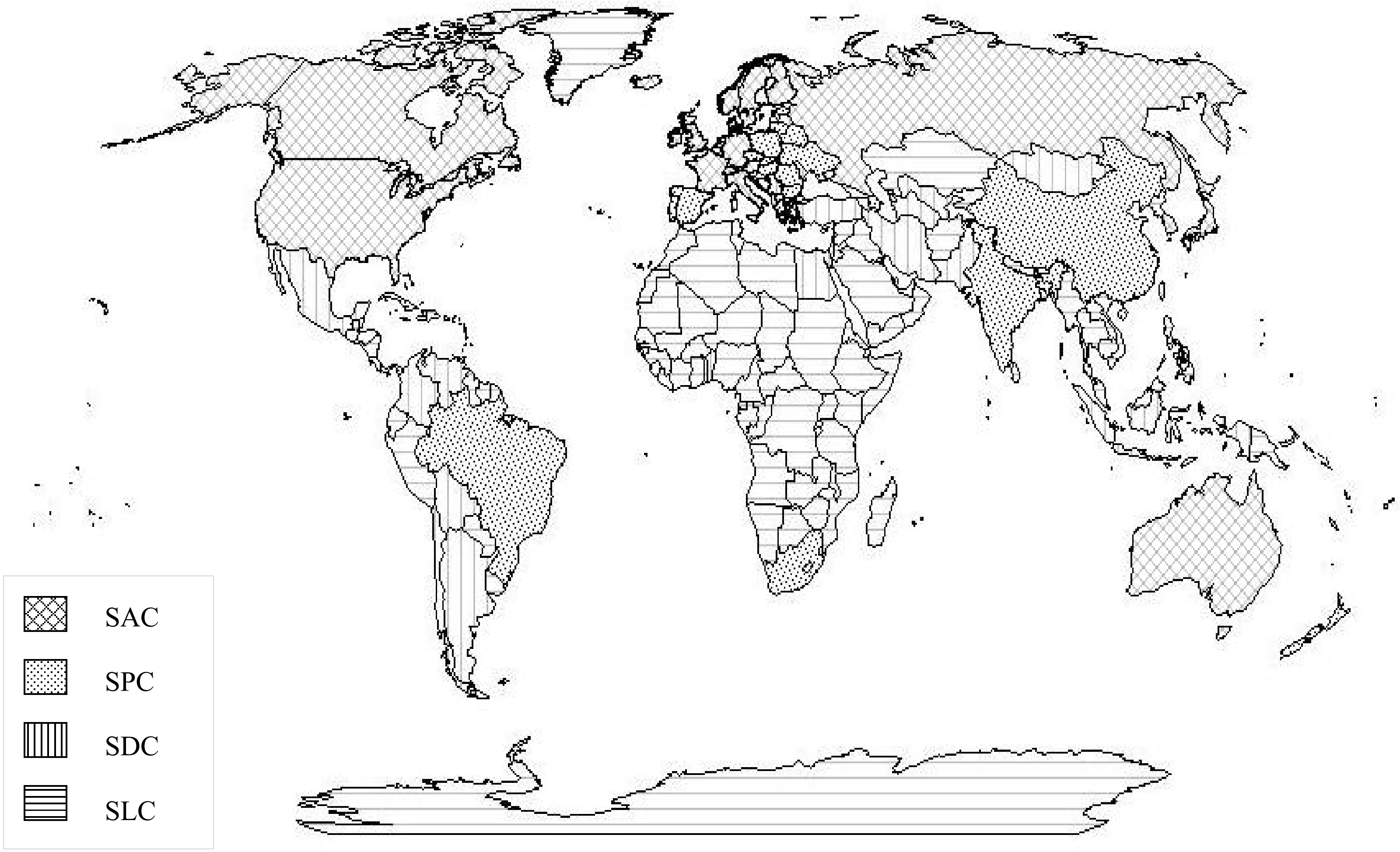
Nations can be distinguished by a plethora of characteristics regarding scientific activity. Those include the number of researchers employed, R&D expenditures, scientific and technical journal articles, expenditure per student at different levels of education, high-tech exports as a

Table 1. Country Index with respect to scientific development

SAC	SPC	SDC	SLC
United States, Japan, Germany, Canada, Taiwan*, Sweden, United Kingdom, France, Switzerland, Israel, Korea_Rep. of, Finland, Australia, Iceland, Denmark, Norway, Netherlands, Italy, Russian Federation, Belgium, Ireland, Austria	Spain, Singapore, Slovenia, New Zealand, Luxembourg, Slovak Republic, Ukraine, Belarus, Czech Republic, Croatia, Estonia, Poland, Lithuania, Bulgaria, Azerbaijan, Cuba, China, Brazil, Hungary, Portugal, Romania, South Africa, India Greece	Uzbekistan, Latvia, Argentina, Chile, Mexico, Moldova, Pakistan, Turkey, Armenia, Colombia, Macedonia, Venezuela, Mauritius, Iran, Benin, Yugoslavia_FR, Kuwait, Hong Kong_China, Costa Rica, Bolivia, Egypt_Arab Rep., Mongolia, Turkmenistan, Indonesia	Malaysia, Uganda, Thailand, Kyrgyz Republic, United Arab Emirates, Togo, Tajikistan, Jordan, Tunisia, Philippines, Uruguay, Kazakhstan, Gabon, Saudi Arabia, Sri Lanka, Nepal, Burundi, Guatemala, Congo_Dem. Rep., Iraq, Peru, Syrian Arab Republic, Central African Republic, Vietnam, Ecuador, Panama, Georgia, Burkina Faso, Guinea, Madagascar, Guinea-Bissau, Oman, Botswana, Jamaica, Lebanon, Nigeria, Libya, Trinidad Tobago, Kenya, Nicaragua, Bangladesh, Zimbabwe, Namibia, Senegal, Dominican Republic, El Salvador, Rwanda, Morocco, Papua New Guinea, Paraguay, Ghana, Zambia, Malawi, Honduras, Algeria, Tanzania, West Bank and Gaza, Côte d’Ivoire, Cameroon, Bosnia and Herzegovina, Lesotho, Albania, Gambia, Haiti, Congo_Rep., Ethiopia, Mali, Mauritania, Angola, Sudan, Yemen, Sierra Leon, Niger, Cambodia, Myanmar, Mozambique, Korea_Dem. Rep., Lao PDR, Chad, Eritrea

Source: Wagner et al. (2001, pp. 12–17) ranking within the categories suggested by the authors.
* not in our dataset

Figure 2. Geographic distribution of scientific development



percentage of manufacturing exports, information technology expenditure per capita, and university-based research, many of which we utilize in our data analysis and results section. Indeed, as has been discussed repeatedly (Jaffe, 1989; Bessette, 2003; Feller, 2004), university-based research plays a significant role in preparing the academic field for the harvest of scientific and technological advances; even if only in a more general sense of providing the necessary underlying infrastructure of knowledge (Florida and Cohen, 1999). Most recently, Jones (2002) demonstrated the importance of research intensity for economic growth and Mokyr (2002; Shughart, 2004, provides an in-depth summary) discussed the evolution of "useful knowledge" and the vital role played by applied science.

In section 2, we illustrate the theoretical framework that forms the basis for our hypothesis. We model scientific output utilizing a Cobb-Douglas type production function for the technology sector. The subsequent section describes the data sources and the variable definitions. We report the results of our empirical models in section 4 before concluding in section 5.

2. The model of scientific production

Adams and Griliches (1996) use a production function approach to estimate the *magnitude* of the scientific returns to changes in labor and capital inputs. They try to estimate scientific output embodied in scientific papers adjusted for citation frequency. Our focus is less on understanding the magnitudes of returns to inputs in the scientific production process and more on whether some inputs are more important than others. This approach can be used to understand whether cross-country differences in inputs may explain cross-country differences in scientific output. Since our focus is on technological output we estimate a "production function" for scientific output in the Adams and Griliches (1996) spirit.

Thus we estimate

$$y = b + \alpha k + \beta l + \gamma s \qquad (1)$$

where k is the log of the amount of capital allocated to research and development, l is the log of the amount of labor that could be engaged in research, and s is a control for the scientific infrastructure of a country. We look at l in two possible ways. One is to think of l as the log of the number of people actually engaged in research. However, Kremer (1993) suggests that the stock of knowledge rises with population. This seems innocuous enough – knowledge after all is created by people. Thus countries with larger populations should also generate more research. Thus l can represent the productive population of a country as well. Institutional and other differences between countries are tracked by b.[2] For example, differences in opportunities available for the pursuit of science or differences in the ability to retain the private benefits of scientific output in different countries could be captured by b.

The parameters represent the sensitivity of scientific output to changes in the inputs. Thus, α measures the sensitivity of scientific output to changes in the capital stock allocated to research, β represents the sensitivity of scientific output to changes in the amount of labor that could be allocated to research, and γ measures the sensitivity of current scientific research to changes in the infrastructural capability of a country. We estimate this model using a panel dataset.

3. Methodology and Variables

The model developed in the previous section provides a template for the analysis of the impact of various factors on the amount of scientific output in a country. We will assume fixed effects to estimate our pooled dataset which includes all countries for which data are available. The econometrics of this approach is straightforward and has been discussed extensively elsewhere (Barro and Sala-i-Martin 2004). The availability of data is a serious problem for this kind of analysis. However, as the growth literature demonstrates, panel estimation over short periods of time is not unusual. The period we will consider includes data for the largest subset of countries possible. We rely on the World Development Indicators (WDI) published by the World Bank Group. A number of variables pertinent to our model have recently been added to the data collected by the WDI. The number of scientific and technical journal articles, research and development expenditure, researchers in R&D, information and communication technology expenditure as well as the number of patent applications have now become available. Table 2 provides an overview.

Table 2. Variable Names and Definitions[3]

Variable Names	**Variable Descriptions** (yearly counts)
PATAPP	Total number of patent applications by residents and non-residents of a country.
STJOURN	Scientific and technical journal articles published in a country.
POP	Population ages 15-64 (% of total) of a country.
RESPERCA	Researchers in R&D (per million people) in a country
RANDD	Research and development expenditure (% of GDP) of a country.

---

[2] We do not make any assumptions about the returns to scale here. Doubling similar inputs could lead to similar discoveries. Thus, diminishing returns to scale are plausible (Romer 2001).

[3] See Table A2 in the appendix for complete definitions of these variables as they appear in the WDI database.

We have collected data on these variables for almost all the countries included in the aforementioned RAND study (Wagner et al. 2001) and listed in Table 1. Data are available for the years 1960–2003. However, measures for most of the variables listed in Table 2 do not start before 1980 and – for many countries – are only available for the years 1996–1999. We use STJOURN as the best available proxy for the scientific infrastructure in a given country in a given year. Generally journal articles cite the existing literature – i.e., each article can be interpreted as a marginal addition to human knowledge. However, these articles could not have been written without the accompanying scientific infrastructure and the resulting prior research. We lag STJOURN by a year to simulate the scientific infrastructure used as an input in the production of privately appropriable science.

Our other input variables, in accordance with the model developed in section 2, include measures of the capital investment in research and development across countries, namely RANDD (additional evidence for the connection between R&D expenditure and patent creations is provided by Prodan, 2005). The number of researchers employed in R&D per capita (RESPERCA), as well as a measure for the percentage of the population commonly thought of as the "productive" group (POP, defined by age), are proxies for the amount of labor allocated to research at a given time. Admittedly, the POP variable does not capture the human capital element of the population. Thus, RESPERCA would probably be a more accurate representation of the amount of labor allocated to research while capturing the human capital element in research. However, this variable "includes professionals engaged in the conception or creation of new knowledge, products, processes, methods, or systems and in the management of the projects concerned."[4] In other words it may "over count" the number of researchers because it could include secretaries, government "minders", and other staff members not directly related to the research process. While these members of a research team may facilitate the research process, too many of them may hinder the process. Rampant bureaucracies in the research process may have the same results as rampant bureaucracies anywhere. This negative effect may be most profound for developing nations with government led research programs particularly if these staffers substitute for "capital"; e.g., computer networking technology.

We measure scientific output by the total number of patent applications (PATAPP) in a given country in a given year. The usefulness of patent data in the analysis of knowledge production is highlighted in Jaffe and Trajtenberg (2002; see also Jaffe, 1989, and Jaffe and Lerner, 2004). We include patent applications by both residents and non-residents. Using patent applications as a proxy for scientific output is not without problems. First of all, basic scientific

---

[4] This is part of the definition available from the WDI database.

research is often not patented even though the results of such research are widely used. However, in our paper this may be an advantage. Since basic research is non-rival it is available to all countries and therefore unlikely to explain variations in scientific output across nations. Thus, patented scientific processes may be a more precise way of explaining national variations in scientific output. Further, since our interest in scientific output is rooted in a quest to explain cross-country variations in economic growth rates, a focus on scientific output that is privately appropriable by firms or individuals within a country seems more salient. Second, the globalization of property rights in ideas makes it difficult to focus on only patent applications by residents or only on patent applications by non-residents. For example a resident may file a patent in the home country as well as a number of foreign countries where the patent applications would be counted as non-resident applications. It is impossible to identify and extricate individual patents in our datasets. We therefore sidestep this problem by including patent applications by both residents and non-residents – a patent application by a foreigner allows the use of that intellectual property in the country concerned as much as does a patent application by a resident. Last, it is often argued that major scientific breakthroughs take place outside the formal patenting or even the "organized" R&D process (Mokyr, 2002). We do not account for these fundamental paradigm shifts in science – rather our approach focuses on the institutional approach to science.

4. Results and Discussion

Our production function approach suggests that variations in the scientific output among nations should be explained by variations in the availability of inputs. We find some evidence that the demographic mix of a country may matter more in determining scientific output than R&D spending and the existing stock of science.

Before starting our discussion we must state some caveats about our data. First, the data are spotty at best. More data are available for SAC countries than any other category. Moreover, more data are available for later years. Thus, if anything, our dataset is biased towards the more advanced countries. Given the dataset, however, RESPERCA and POP are not highly correlated though RANDD and RESPERCA are.

We report two sets of results – one set focuses narrowly on SAC countries (models 1a, 2a, 3a) while the other includes both SAC countries and all other countries for which data is available.

The results based on the SAC dataset provide evidence that demographics, along with the stock of scientific knowledge, and actual capital expenditures on research have a strong impact on privately appropriable scientific output. All of the independent variables (except for RANDD in model 3a) are significant at the 1% level.

There may be a number of problems with these results. For example, in models 2a and 3a, the POP variable may not capture the level or quality of education of the productive population of a country. Of course, the level of education ought to be captured by the RESPERCA variable – there are probably not too many researchers without any formal education! We note that RESPERCA significantly explains PATAPP in model 1a. Further, one may argue that scientific progress ought to be a function of the quality of human capital rather than sheer numbers. So what may the POP variable in model 2a and 3a be capturing, if anything? Countries with larger populations are more likely to produce talented individuals capable of advancing scientific knowledge. Indeed Kremer (1993) tests a direct link between population size and technological progress.[5] This suggests that the scientific advantage of a country may be dependent on the underlying demographics. From a policy perspective this makes a country's scientific progress somewhat deterministic in the short run and certainly difficult to influence in the long run. As a matter of geopolitics, it may also suggest that, ceteris paribus, "ageing" countries – particularly those in Europe – are more likely to lose their technological edge.

In all three model specifications for the SAC countries RANDD is significant. Clearly, capital expenditures on research and development matter. In model 1a we find that about 90% of the variation in scientific output is explained by RANDD, RESPERCA, and STJOURN. In fact, our model specification allows us to interpret the coefficients in terms of elasticities. Thus, e.g., in model 1a, a 1% increase in research and development spending as a percentage of GDP increases scientific output by about 1.04% keeping researchers per capita and the scientific infrastructure constant. Interestingly, in model 1a, increases in researchers per capita seem to have the biggest positive impact on the production of scientific output when compared to research spending and the scientific infrastructure. Technologically advanced countries with aging populations may thus be disadvantaged when it comes to maintaining their technological edge. Of course, a more direct measure of the "demographic" effect is captured in model 2a where a 1% increase in the "productive population" increases scientific output by 15.54%! This implies that countries which spend less on research and development and have a less extensive knowledge base than the US, may, by the sheer force of a younger population, counter the current technological advantage

---

[5] Kremer's (1993) test was based on the geographical separation of large land masses between the last ice age and the voyages of European travelers. Larger land masses would support larger population densities because their initial larger populations would innovate more and therefore allow faster population growth. Admittedly this is a very indirect test but the idea that innovations are endogenous is intuitively attractive – people after all are the innovators and more people should generate more innovations.

enjoyed by the US. However, this result does not bode well for countries that in addition to stagnant levels of R&D expenditures also have ageing populations. In fact, model 2a suggests that to compensate for a 1% decline in the productive population, R&D expenditures have to increase by more than 7%. Moreover, model 3a suggests that, long-run demographic trends notwithstanding, increasing R&D expenditures in combination with the number of researchers could significantly impact scientific output. Surprisingly, the scientific infrastructure, though significant in all three models (1a, 2a, and 3a), seems to have the smallest impact on new ideas. Intuitively this makes sense. Whatever the extent of the scientific infrastructure may be, its non-rival nature would have little impact in explaining cross-country variations in privately appropriable scientific output. Moreover, the internet has reduced the impact of "ownership" of such an infrastructure by countries. In fact, web engines such as Google Scholar may further reduce its role. Note that we are not claiming that the scientific infrastructure is unimportant – just that it is losing its importance in explaining cross country variations in the production of privately appropriable scientific output. Further, old science will have little impact on new science if people (POP, RESPERCA) are not paid nor have the capital (RANDD) to produce it.

The results discussed above are largely mirrored in the larger data set. The only exception seems to be the sign on RESPERCA. This is somewhat troubling and may be driven by the nature of the non-SAC countries. In fact we run model 1 with only SPC or only SDC countries and find that RESPERCA has a negative sign only for the SPC countries.[6] This suggests that the addition of the SPC countries to SAC and SDC countries is driving the negative sign on RESPERCA.[7] One possible explanation for the negative sign on RESPERCA may lie in the nature of the definition of that variable. This variable "includes professionals engaged in the conception or creation of new knowledge, products, processes, methods, or systems and in the management of the projects concerned." Thus managers and secretarial staff, and peons are all included in the RESPERCA variable. Since a number of the SPC countries belonged to the Soviet block or are developing nations that have undertaken recent market reforms it is plausible to suggest that their research establishments continues to be influenced by the state (Knack and Keefer, 1995). In that case a large state bureaucracy gets included in the number of researchers and these tend to hamper private research that results in patent applications. Another possibility may be a certain disregard for intellectual property rights that provides a disincentive for patentable research. Our focus on privately appropriable research in this paper may therefore be driving these perverse results. It would also be useful to run models with variables that show the public to private sector

---

[6] Results are available on request.

[7] An outlier check did not reveal any obvious outliers in terms of single data points.

ratio of researchers. To the best of our knowledge these data are not available consistently for the SPC, SDC, SLC countries though they may be constructed for the SAC countries. Since the results for the SAC countries are consistent with our hypothetical expectations we have not sought to differentiate between the public and the private sector in this paper. We should also note here that our discussion of the negative sign on RESPERCA may be consistent with the findings of Baumol (1990) and Murphy, Shleifer, and Vishny (1991). These papers suggest the importance of institutional factors that provide an incentive for the appropriability of the benefits of private effort that is essential for generating socially productive output like science and technology. These results would hold particularly true when the scientific output is privately appropriable, e.g., patents. Thus the lack of these institutional factors in SPC countries may be responsible for our results in models 1 and 3.

We present evidence that variations in R&D expenditures, number of researchers per capita, and the extent of the scientific infrastructure knowledge help explain variations in scientific output. In other words we appear to have some answers to the following questions:

1. Do research and development expenditures matter in producing scientific output?

Research and development expenditures matter. RANDD is robustly significant in all possible specifications. This suggests that, ceteris paribus, recent drops in R&D expenditure in the US relative to other countries may have a significant impact on scientific output in the US relative to other countries and thus have a negative effect on the US technological advantage.

2. Do demographics matter in producing scientific output?

It seems that demographics – having populations that are in the productive age group – may matter in explaining variations in scientific output. In fact, demographics, even if taken in conjunction with the number of researchers per million seems to have the biggest single impact on scientific output. This should be of particular interest to policy makers in developed (SAC) countries. First of all this may mean that developing countries with young populations may have a chance of “catching up” technologically with developed nations – particularly so since the existing stock of scientific knowledge has become widely available through the internet. Second, developed countries with ageing populations would have to compensate with higher and higher expenditures on research and development to maintain their edge. Such expenditures may be subject to diminishing marginal productivity. Indeed, models 1a through 3a indicate this for scientifically advanced countries (although not at a significant level), once a squared term for these expenditures is included. Coupled with the increasing dislike of foreigners in developed countries that impacts immigration decisions, such demographic effects may indeed shift the balance of world power to scientifically developing nations. In fact we note that the POP variable is positively significant when non-SAC countries are included in the regression (models 2 and 3).

3. Does the scientific infrastructure matter in determining scientific output?

The scientific infrastructure matters – though not as much as the other variables under consideration. These institutional foundations will continue to be needed to produce more scientific output, but they will be not be sufficient to generate a technological advantage over younger nations that spend more on R&D.

Our paper generates several policy prescriptions. The absolute importance of the number of researchers per capita in generating scientific output in the SAC countries underscores the importance of expenditures on science education in developed countries. The impact of researchers per capita when a wider mix of countries are included is complicated to say the least. This may be due to a number of reasons as stated above. Certainly our results seem consistent with work done by Baumol (1990) and Murphy, Shleifer, and Vishny (1991), who note that scientific research depends on whether talented people can be provided with the right incentives to pursue this research. Government policies that promote an environment where these incentives exist are therefore very important. At the most fundamental level the ability to capture the returns from such research would promote technological innovation. Talented people choose socially productive activities when markets with clearly defined property rights exist (Murphy, Shleifer and Vishny, 1991). Societies that generate incentives for smart people to choose socially productive activities over pure rent seeking (presumably smart people can excel at either!) tend to flourish (Baumol 1990). While these incentives often exist in developed (SAC) countries they may be less prevalent in the SPC countries and prevent them from attaining their full potential among nations. At the very least the perverse results in models 1 and 3 suggest future research that explicitly takes into account the incentives for doing research.

Moreover, the relative importance of a younger population compared to the existing body of knowledge and research spending suggests that technologically advanced nations with aging populations need not take their advantage for granted – especially with the entry of “younger” countries like Brazil and India into the global community. The advanced countries may be tempted to give in to the temporary panaceas of protectionism and xenophobia. However, such a temptation, if indulged, may not prevent this decline. One positive policy response could be to import a younger demographic with appropriate immigration policies – in fact it may be more useful to import young foreigners with potential rather than older foreigners with proven track records. In this regard developed countries like the US and the UK, which are destinations for foreign students, should do more to attract and retain these students.[8] At the very least technologically advanced countries need to resist declines in research and development spending since this would allow less developed but globally integrated countries to catch up even faster. At any rate, having an extensive scientific infrastructure compared to other countries may have a cushioning impact on scientific decline but will not guarantee preeminence. For example, model 2 suggests that a 1% decline in the percentage of people in the 15-64 age group would reduce scientific output by almost 17%. The scientific infrastructure in this country would have to be extended by more than 21% to offset this decline.

An analysis like ours may also have implications for foreign policy. For example, there is some evidence that the Chinese population is aging rapidly. If the “demographic” effect suggested by our model is valid then Chinese scientific output – not high to begin with – is set to decline in spite of higher R&D expenditures in China. One option for China would be to increase the number of researchers per capita. In fact, Freeman (2005) predicts that – at the current rate – China will produce more doctorates in science and engineering than the US by 2010. Indeed the US share of science and engineering PhDs will fall to about 15% of the world total. However, results that include more than just the SAC countries suggest that sheer numbers may not be enough. Somehow China will have to emulate the effectiveness of researchers in SAC countries (as reported in models 1a and 3a). Since the effectiveness of researchers seem to be tied to institutions such as property rights the Chinese would have to change their governance style fairly dramatically. China seems to have changed its constitution to provide some protection to property rights though the effectiveness of these changes is unclear. Moreover, an increase in researchers per capita in China might not be sustainable because of an aging population. This peculiar concatenation of circumstances may – in their quest for the technological advantage – reduce the Chinese incentive to protect intellectual property rights and foster more of an incentive to promote technological advance through “other means” like industrial espionage.

Needless to say this paper raises more questions that are candidates for future research. For example it would be interesting to see if variations in institutional variables like property rights, rent seeking opportunities, corruption levels, the rigidity of labor laws, and economic freedom have any effect on scientific output. Further, the quality and level of education may matter in the output of researchers that ought to be considered in a production function for researchers. For example, variations in math and science scores across countries may be

---

[8] There is some anecdotal evidence that the US has been less welcoming of foreign students since 9/11. Countries like Australia, Canada, and the United Kingdom have emerged as competitors for this important input in the production of scientific output.

indicators of the quality of education in science and therefore may serve as predictors of technological advancement.

A number of recommendations issued by the *National Academy of Sciences* report mentioned previously (The National Academy, 2005) are strongly supported by our findings. Specifically, “Action A-1” (attract 10,000 of our brightest students to enter the teaching profession each year), “Action B-1” – which suggests a 10% increase per year in the federal investment in long-term research for the next seven years – and “Action C-1”, a proposal to increase the number of US citizens with bachelor’s degrees in engineering and mathematics “…by providing 25,000 new 4-year undergraduate scholarships” each year (p. 6), are indicated by our results to be effective inputs in the technological production process. All of these proposals, if successful, would increase the number of researchers per capita. An increase in the number of researchers would also increase scientific output according to our model. Such efforts may counter the retarding effect of an aging US population on scientific output predicted by our model. These policy prescriptions are also applicable to many of the other scientifically advanced and scientifically developing countries with populations that are growing older.

5. Conclusion

Scientifically advanced countries such as the United States and Japan, which have enjoyed many economic rewards from their comparative advantage in the field of science and technology, are facing the challenge of how to keep this important engine of growth humming along while keeping former neophytes – which are starting to get closer – at bay. All the evidence points to an outcome where the struggle for supremacy in the areas of science and engineering will be more fierce than it has been in the past – and that the results will have a significant impact on a nation’s relative standing in the global economy.

This paper asks how central the different ingredients in this competition for research leadership are. The extent of the scientific infrastructure matters as well as demographics and investment in R&D. We do, however, find that there is a certain mix which will make these fuels most potent. That in turn presents suggestions to the policy-makers managing this contest about what tools they should employ to prolong and ease the transition from “one runaway champion” to “leaders of the pack.”

References

Barro, R.J. and X. Sala-i-Martin. *Economic Growth.* 2nd Edition. Cambridge, MA: MIT Press, 2004.

Baumol, William. “Entrepreneurship: Productive, Unproductive and Destructive.” *Journal of Political Economy*, 1990, 98, pp. 893-921.

Bessette, Russell W. “Measuring the Economic Impact of University-Based Research.” *Journal of Technology Transfer*, 2003, 28(3-4), pp. 355-61.

Feller, Irwin. “Virtuous and Vicious Cycles in the Contributions of Public Research Universities to State Economic Development Objectives.” *Economic Development Quarterly*, 2004, *18*(2), pp. 138-50.

Florida, Richard and Cohen, Wesley. “Engine or Infrastructure? The University? Role on Economic Development,” in Branscomb, Lewis; Kodama, Fumio; and Florida, Richard (eds)., *Industrializing Knowledge* (pp. 589–610). Cambridge: MIT Press, 1999.

Freeman, Richard B. “Does Globalization of the Scientific/Engineering Workforce Threaten U.S. Economic Leadership?” *NBER Working Paper 11457*, 2005.

Grossman, Gene M., and Helpman, Elhanan. *Innovation and Growth in the Global Economy.* Cambridge, MA: MIT Press, 1991.

Holmgren, Milena and Schnitzer, Stefan A. “Science on the Rise in Developing Countries.” *PLoS Biology*, 2004, *2*(1), pp. 10-13.

Jaffe, Adam B. “Real Effects of Academic Research.” *American Economic Review*, 1989, *79*(5), pp. 957-70.

Jaffe, Adam B, and Manuel Trajtenberg. *Patents, Citations, and Innovations*. Cambridge, MA: MIT-Press, 2002.

Jaffe, Adam B, and Josh Lerner. *Innovation and Its Discontents: How Our Broken Patent System is Endangering Innovation and Progress, and What to Do About It.* Princeton, NJ: Princeton University Press, 2004.

Jones, Charles I. “Sources of U.S. Economic Growth in a World of Ideas.” *American Economic Review*, 2002, *92*(1), pp. 220-39.

Knack, Stephen and Keefer, Phillip. "Institutions and Economic Performance: Cross Country Tests Using Alternative Institutional Measures." *Economics and Politics*, 1995, 7, pp. 207-227.

Kremer, Michael. "Population Growth and Technological Change: 1 Million B.C. to 1990." *Quarterly Journal of Economics*, 1990, 108, pp. 681-716.

Mokyr Joel. *The Gifts of Athena: Historical Origins of the Knowledge Economy.* Princeton and Oxford: Princeton University Press, 2002.

Murphy, Kevin M., Shleifer, Andrei, and Vishny, Robert W. "The Allocation of Talent: Implications for Growth." *Quarterly Journal of Economics*, 1991, 106. pp. 503-530.

Prodan, Igor. "Influence of Research and Development Expenditures on Number of Patent Applications: Selected Case Studies in OECD countries and Central Europe, 1981-2001." *Applied Econometrics and International Development*, 2005, 5(4). pp. 5-22.

Romer, David. *Advanced Macroeconomics.* 2nd Edition. New York, NY: McGraw Hill, 2001.

Scott, Alister; Steyn, Grové; Geuna, Aldo; Brusoni, Stefano and Steinmueller, Ed. "The Economic Returns to Basic Research and the Benefits of University-Industry Relationships." *SPRU - Science and Technology Policy Research*, 2001.

Segal, Adam. "Is America Losing Its Edge?" *Foreign Affairs*, 2004, *83*(6), pp. 2-8.

Shughart, II, William F. "Review of Joel Mokyr The Gifts of Athena: Historical Origins of the Knowledge Economy," *Economic History Services*, Mar 15, 2004, URL : http://eh.net/bookreviews/library/0748.shtml.

The National Academy of Sciences. *Rising Above The Gathering Storm: Energizing and Employing America for a Brighter Economic Future.* (prepublication copy) Washington, D.C.: The National Academies Press, 2005. [http://www.nap.edu/catalog/11463.html]

Wagner, Caroline S.; Brahmakulam, Irene; Jackson, Brian; Wong, Anny and Yoda, Tatsuro. "Science and Technology Collaboration: Building Capacity in Developing Countries?" *RAND Corporation Report.* 2001, 90.

Wooldridge, Jeffrey M. *Introductory Econometrics: A Modern Approach*. Cincinnati, OH: South-Western Publishing, 1999.

Appendix

Table A1.

Dependent Variable: lnPATAPP

Independent Variables	Model 1	Model 2	Model 3	Model 1a (SAC countries)	Model 2a (SAC countries)	Model 3a (SAC countries)
lnSTJOURN(–1)	1.5627*** (0.3385)	0.8084*** (0.2475)	1.2402*** (0.3072)	0.4752*** (0.0847)	0.8252*** (0.1134)	0.3884*** (0.0495)
lnPOP		16.8161*** (1.9410)	22.4136*** (5.2663)		15.5362*** (2.4776)	17.6945*** (2.6685)
lnRESPERCA	–1.0088* (0.5350)		–1.1598** (0.4568)	1.8744*** (0.4635)		1.9357*** (0.5165)
lnRANDD	1.0878*** (0.3289)	1.1005** (10.34)	1.2479*** (0.2895)	1.0415*** (0.2351)	2.2460*** (0.3743)	0.753304* (0.4473)
C	6.3521** (2.5344)	–65.8703 (9.0461)	–84.1637*** (23.2778)	–8.4870** (3.7901)	–62.8056** (11.1789)	–82.3883*** (12.5763)
Observation Information	Total Panel = 195 Number of Cross Sections included = 63	Total Panel = 234 Number of Cross Sections included = 65	Total Panel = 195 Number of Cross Sections included = 63	Total Panel = 73 Number of Cross Sections included = 21	Total Panel = 92 Number of Cross Sections included = 21	Total Panel = 73 Number of Cross Sections included = 21
F-statistic	36.416***	60.013***	40.795***	32.367***	32.037***	38.191***
Adjusted R^2	0.9222	0.9443	0.9312	0.9092	0.8869	0.9253

*** Significant at the 1% level.
** Significant at the 5% level.
* Significant at the 10% level.
(t-values are in parentheses)

Table A2

Variable definitions as they appear in the WDI database.

Variable	Definition
Research and Development expenditure (% of GDP) **RANDD**	Expenditures for research and development are current and capital expenditures (both public and private) on creative, systematic activity that increases the stock of knowledge. Included are fundamental and applied research and experimental development work leading to new devices, products, or processes.
Scientific and technical journal articles **STJOURN**	Scientific and technical journal articles refer to the number of scientific and engineering articles published in the following fields: physics, biology, chemistry, mathematics, clinical medicine, biomedical research, engineering and technology, and earth and space sciences.
Population ages 15-64 (% of total) **POP**	Population ages 15 to 64 is the percentage of the total population that is in the age group 15 to 64.
Researchers in R&D (per million people) **RESPERCA**	Researchers in R&D are people trained to work in any field of science who are engaged in professional R&D activity. Most such jobs require completion of tertiary education.
Patent applications **PATAPP**	Patent applications are applications filed with a national patent office for exclusive rights for an invention--a product or process that provides a new way of doing something or offers a new technical solution to a problem. A patent provides protection for the invention to the owner of the patent for a limited period, generally 20 years.