The Effects of Innovation Policies on Business R&D: A Cross-national Empirical Study

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We thank Walter Park for generously providing data on patent rights through 1995 and offering helpful comments. We would also thank David Richardson, John Yinger, William Duncombe, Larry Schroeder and two anonymous referees for their valuable comments on various drafts of this paper.

Abstract

This paper examines the effect of three major national innovation policies (patent protection, R&D tax incentives, and government funding of business R&D) on business R&D spending. Unlike previous work, we also consider the effect of openness to international trade. We use data from nine OECD countries (Australia, Canada, France, Germany, Italy, Japan, Spain, UK, and USA) in 1985–1995. Our results show that all three innovation policies play a significant role in stimulating business funded and performed R&D. Among the components of patent rights, enforcement of patent legal regime and duration of protection term consistently have a positive effect on business R&D decisions. In addition, R&D performed by the government has a positive effect on business R&D, while R&D by the higher education sector has a negative impact on business R&D. We also find modest empirical support to the positive role of openness to international trade in business R&D investment.

Key words: Innovation policy, R&D, Tax incentive, Patent policy

J.E.L. Classification: E22, O31, O34, O57

1. INTRODUCTION

Many countries have employed innovation policies to encourage private research and development (R&D) with economic development and industrial competitiveness as the major objectives. Government interventions in industrial innovation are usually based on the belief that they are needed to stimulate innovative activities in the private sector and to promote long-term economic development. The key question is how effective the national innovation policy tools are in stimulating more business R&D spending within national borders.

Several scholars have assessed the effectiveness of government subsidies and tax incentives on private R&D investment at the national, industry or firm level (Hall and Reenen, 2000; David, Hall and Toole, 2000). Our study contributes to this strain of literature by conducting an integrated examination of three major national R&D policy instruments: government funding of business R&D, patent protection, and R&D tax incentives. We also include other important variables such as R&D performed in government and higher education sector, and openness to international trade.

Based on a panel of OECD countries, our results indicate that government funding of business R&D, patent protection, and R&D tax incentives all have positive effects on R&D financed and performed in business sector. Among the components of patent right, enforcement and duration positively affect business R&D spending decisions. In addition, R&D performed in government sector has a positive effect on business R&D, while R&D in higher education sector has a negative impact on business R&D. Finally, we find that openness to international trade also increases private R&D spending.

This paper is organized as follows: The first two sections present an overview of three major national innovation policies, and a brief review of empirical literature. Section four discusses modeling and methodology issues relevant to this research. The next two sections of the paper describe data sources and statistical results, followed by a concluding section.

2. THREE MAJOR NATIONAL INNOVATION POLICIES

Business R&D has long been believed to be a major determinant in economic growth (Mohnen, 1996; Link and Siegel, 2003). However, the characteristics of imperfect appropriability and imperfect excludability of innovation outputs lead to suboptimal level of innovation effort by the private sector, and therefore leave significant space for government intervention. In general, government's role in innovation falls into two major categories: (1) the creation and maintenance of a legal environment that encourages private sector investment in innovation (through patent, copyright, and trademark protection); and (2) the provision of incentives to overcome the natural inclination of private parties to consider only their private benefits when choosing the level of innovation in which to invest (governmental grants, contracts, and targeted tax incentives) (Leyden and Link, 1992).

Based on economics theory, private R&D decision-making is determined by the marginal rate of return (MRR) and the marginal cost of capital (MCC). Therefore, governments are capable of affecting private investment in R&D by shifting MRR, MCC or both of them. Next, we offer a brief discussion on how the three major national innovation policies work in such a conceptual framework.

R&D tax incentives include allowing R&D expenditures to be expensed rather than capitalized, depreciation allowance for R&D capital investment, and tax credits for eligible R&D expenditures. As one of the factors affecting MCC, R&D tax incentives are used to offset the inappropriability in innovation by reducing the cost of private R&D activities. The offer of tax incentives moves MCC curve downward, and thus increases private R&D investment level, other things being equal.

While the tax incentives reduce the cost of private R&D, the government funding of private R&D raise the profitability on private R&D investment and reduce the R&D cost. The government funding of private R&D, by relieving the company of some joint costs of research and development activity, shifts MCC curve downward, facilitating additional R&D activities using its own funds, other things being equal. Additionally, the government funding of private R&D shifts MRR curve upward in several ways. For instance, publicly subsidized R&D activity can yield learning and training effects in the performing firm, enhancing its efficiency in conducting other R&D projects. Where public funds are made available for some "infrastructure" construction (such as test facilities), the company involved may be able to conduct further R&D projects of its own at lower cost, and thereby derive a higher expected internal rate of return on its R&D investments. The decline of R&D cost and the increase in the marginal rate of return lead to additional business investment in R&D.

Patent protection is another important policy tool to encourage innovation by allowing inventors to capture some portion of the social value of their inventions. Granted by a national government, the patent right allows the owner (the patentee) to exclude others from making, using or selling the patented product in the country granting the patent for up to a certain period of time from the date the application is filed (or granted). The strength of patent protection is one important measure to protect the value of inventions and thus a positive sign for the inventors. Patent protection shifts the MRR curve upward if it becomes stronger and downward if it turns weaker.

The effect of patent law on private innovation investment is twofold. On the one hand, strong patent rights are likely to stimulate more private R&D investment either because the profitability of innovations can be significantly increased, or because the strong patent right triggers potential duplicative and hurried R&D in a race to be the first to patent an invention. On the other hand, strong patent rights may boost the cost of innovations by limiting the dissemination of knowledge under protection. The restricted use of innovation imposes additional cost to the society in taking advantage of the current knowledge stock. These conflicting effects suggest that different dimensions of the patent right (coverage, duration, breadth of claim, etc.) have to be structured properly to create a socially efficient patent legal regime.

3. EMPIRICAL LITERATURE ON R&D POLICIES

There is a large body of empirical literature addressing the effect of government policies on private R&D. One strain of R&D literature focuses on the impact of fiscal incentives for R&D. Another set of empirical studies explores the effect of government R&D subsides on private R&D investment – whether the government funding of private R&D is a complement or substitute for private R&D. Some recent assessments include multiple policy instruments in a single empirical model. It is noteworthy that one important policy tool, patent protection, remains largely unexplored in the empirical literature.

In the literature on tax incentives, the basic model is constructed to predict the level (or stock) of business R&D spending as a function of the "user cost of R&D" and some other control variables such as the economic output. Leyden and Link (1993) provide an early review of the empirical evidence on the effectiveness of R&D tax credits. In a recent review, Hall and Reenen (2000) conclude that a dollar in tax credit for R&D stimulates a dollar of additional private R&D investment.

Compared with literature on tax incentives, empirical studies on the impact of public funding of private R&D business R&D rely on a much simpler method. They model the private R&D financed by companies themselves as a function of public financing of private R&D and some control variables that influence R&D effort by companies. The findings overall are ambivalent. Results where public R&D funds and private R&D expenditure are complementary occur more frequently in aggregate macro econometric studies than when examining a single industry or country (David, Hall and Toole, 2000).

Patent protection has also been identified as a major determinant of R&D investment in the empirical literature (Yang and Maskus, 1999; Varsakelis, 2001). Varsakelis (2001) contributes a cross-national empirical study on the effect of patent protection on R&D investment in a sample of 50 countries. The empirical results show that countries with strong patent protection framework invest more in R&D. Another recent study explores the effect of patent protection by estimating the premium of patenting innovations (Arora, Ceccagnoli and Cohen, 2003). They find that an increase in the patent premium clearly stimulates industrial R&D investment although the responsiveness of R&D to patent premium varies across industries. While these studies analyze the impact of patent protection framework on R&D, patent protection has not been examined in line with other innovation policies such as government funding of business R&D and fiscal incentives on R&D.

Very few scholars have attempted to systematically assess the effectiveness of various R&D policy tools across countries. Bloom *et al* (2000) examine the impact of tax incentives on the level of business R&D investment in nine OECD countries (Australia, Canada, France, Germany, Italy, Japan, Spain, U.K. and U.S.A.). They find that tax incentives play a significant role in business R&D investment. After including government-financed R&D in the business sector, the elasticity estimates for the tax incentives variable (user cost of R&D) drop but are still significant, as the long-run elasticity of business R&D investment with respect to the user cost of R&D drops from about -1.1 to -0.745.

Guellec and Van Pottelsberghe De La Potterie (2003) contribute the most recent and integrated cross-country study. They explore the effect of several major policy instruments (direct government funding on business R&D, R&D tax incentives, and direct performance of research in government laboratories and universities) on a panel of seventeen OECD countries over the period 1981-1996. The results suggest that both direct government funding of R&D performed by the business sector and R&D tax incentives on business R&D have a positive impact on business R&D. They also find that research performed by the government sector crowds out private R&D, while research conducted by higher education institutions has no significant impact.

This brief review suggests some caveats in the current empirical literature on innovation policy. First of all, comprehensive assessment of major national innovation policies is rare. In particular, while patent protection may play an important role encouraging innovation, its effect on private R&D at the national level has not been fully examined in a comprehensive way.

In addition to the policies mentioned above, other policy factors are likely to influence private R&D decisions. In particular, several recent papers have discussed the links between trade and international R&D spillovers. Coe and Helpman show that both the level and composition of imports play a significant role in international R&D spillovers (Coe and

Helpman, 1995). Keller confirms the importance of international trade in technology diffusion, and further finds that the import composition does matter if countries receive a relatively high share of its total imports from one particular country (Keller, 2000). It is expected that domestic R&D can benefit from foreign R&D spillovers either through direct learning from foreign technological knowledge (active spillovers) or through employing advanced intermediate products that have been invented abroad (passive spillovers).[1] We hypothesize that the openness of a country to international trade would have a positive impact on the domestic R&D investment.

This study follows the recent effort of analyzing the effect of major government R&D policies in an integrated framework. Among the direct policy instruments, R&D tax incentives and government funding of private R&D have been the targets of empirical research. The inclusion of patent protection makes it distinct from previous work. In addition, unlike previous work, we also include the variable of openness to international trade to recognize the importance of foreign knowledge spillovers.

4. THE MODEL AND METHODOLOGY

The purpose of this cross-national empirical study is to assess the effect of three major national innovation policies simultaneously. The policies to be examined include R&D tax incentives, patent protection, and government funding of business R&D. The model is set up as follows:

$$BRD_{i,t} = \beta_0 + \delta_t + \gamma_i + \beta_1 BRD_{i,t-1} + \beta_2 GDP_{i,t-1} + \beta_3 TP_{i,t-1} + \beta_4 PR_{i,t}$$
$$+ \beta_5 BRDG_{i,t-1} + \beta_6 URD_{i,t-1} + \beta_7 GRD_{i,t} + \beta_8 OT_{i,t} + \varepsilon_{i,t}$$

[1] For a detailed discussion of the trade-related international R&D spillovers, please see Keller (2004).

The dependent variable *BRD* refers to the business funded and performed R&D in each country in a particular year. *TP*, *PR* and *BRDG* are policy variables for tax incentives, strength of patent right, and government funding of business R&D. The variables *URD* and *GRD* refer to R&D performed by universities and government respectively; *OT* represents openness to international trade. The model also includes the business funded and performed R&D with one-year lag to account for dynamism of R&D projects.[2] Considering that business R&D spending, like other major business outlays, may be affected by the overall economic situation, we include *GDP* – Gross Domestic Product – with a one-year lag in the model. In addition, we control for time and country fixed effects via δ_i and γ_i. The countries are indexed by *i* (from 1 to 9) with the years by *t* (from 1985 to 1995). As is standard in the literature, all variables are in logarithm of real values.

We employ the "user cost of R&D" as the measure of R&D tax policy (*TP*). The "user cost of R&D", which integrates the effect of depreciation allowances, tax credits, corporate income tax rates, and personal income tax rates, derives the pre-tax real rate of return on the marginal investment project that is required to earn a minimum rate of return after tax. This variable is likely to be endogenous because the R&D investment level and the tax price faced by the firm may be simultaneously chosen. To deal with the simultaneity between R&D investment level of a firm and the tax policy variable, one-year lagged rather than contemporaneous "user cost of R&D" is used in the model.[3]

The establishment and enforcement of patent rights is an important national policy to protect the value of inventions and thus increase the expected return to the inventors. To quantify the strength of patent right (*PR*), we use the Ginarte and Park (1997) patent right

[2] The work by Bloom *et al* (2000) includes the same variable in their estimation. A similar measure was also used by Stern *et al* (2002) to account for the cluster-specific conditions for private sector R&D investment.

index (GP Index). The GP Index applies a coding scheme to national patent laws. Five categories of national patent laws are examined: (1) extent of coverage, (2) membership in international patent agreements, (3) provisions for loss of protection, (4) enforcement mechanisms, and (5) duration of protection. Each of the categories (per country, per year) is scored a value ranging from 0 to 1, depending on the strength of protection. Rather than using the overall GP Index, we employ one variable for each of the five categories.

In theory, the government funding of business R&D may have a delayed effect on business R&D activities because it takes time for the private sector to benefit from it. In particular, the training and learning effect can only be beneficial to private R&D projects conducted later. Therefore, we will employ government funding of business R&D with one-year lag in the model (*BRDG*). An extra advantage of using lagged government funding of business R&D is that it also helps to alleviate the potential endogeneity issue associated with public subsidies to private R&D. As pointed out by David *et al.* (2000), the public subsidy to industrial R&D could be an endogenous variable because some omitted latent variables may be correlated with both the public and private R&D investment decisions. Although the fixed effect model controls for some of the omitted factors, the one-year lagged variable of public funding of business R&D may still be helpful in easing the endogeneity concern.

Similar to the work by Guellec and Van Pottelsberghe De La Potterie (2003), we introduce two variables for research performed in government and higher education sector. R&D performed by universities (*URD*) is relevant for two reasons. First, companies may contract out some R&D projects to universities, so that university-performed R&D may substitute for business funded and performed R&D. Secondly, while a significant part of R&D performed by universities are not funded by business sector, companies can benefit

[3] Bloom *et al* (2000) used a similar method to deal with the simultaneity issue.

from R&D spillovers from universities by hiring science and engineering graduates. Since the business sector benefits from university R&D primarily through spillover and diffusion mechanisms, there may be a time lag between the performance of university R&D and its effect on business R&D. Therefore, we use one-year lagged *URD* in the estimation. The lagged *URD* also helps to deal with the endogeneity concern.[4]

R&D performed in the government sector (*GRD*) is also included because government R&D activity may benefit private R&D through channels of technology diffusion. The primary goal of government research is to satisfy public missions such as defense. However, government performed research may still offer indirect benefits to business R&D because the diffusion of government technology could reduce R&D cost for private companies.[5] Moreover, private companies are also motivated to increase their R&D absorptive capacity to better take advantage of the dissemination and utilization of government-developed technologies.

Besides the variables discussed above, we add one new variable to reflect the spillover effects from foreign knowledge: openness to international trade (*OT*). We expect added accessibility to foreign technology through international trade to have a positive impact on domestic R&D investment. Additionally, access to foreign markets helps to address the issue of “inappropriability” of innovation outputs because exports can increase the size of market for new or enhanced products resulting from R&D efforts, thus improving the appropriability of innovation outputs.

[4] To industrial R&D performers, universities are a major competitor for both government and industrial R&D funds. As the universities intensify the effort for seeking external funding for R&D projects, the substitute effect will become more significant.

[5] For instance, in the United States, several laws were passed, and various cooperative R&D initiatives such as R&D consortia were launched to emphasize the role of government in promoting dissemination and utilization of government-developed technologies in private sector in pursuit of industrial competitiveness and economic prosperity.

5. MEASUREMENT AND DATA

We estimate the model using a 9-country panel with data from 1985 to 1995. The panel includes Australia, Canada, France, Germany, Japan, Italy, Spain, United Kingdom and United States. Such a panel is chosen primarily based on the availability of data for variables being included in the analysis. In this section, we will describe the measurement and data sources. The summary of variables and descriptive statistics are offered in Table 1, Table 2-1 and Table 2-2 at the end of this section.

In this study, all R&D data (*BRD*, *BRDG*, *URD* and *GRD*) are from *Basic Science and Technology Statistics* (OECD, 2000). The OECD has been collecting R&D data on a regular basis since the early 1960s through retrospective surveys of the units actually carrying out or performing R&D projects. This publication contains the most comprehensive R&D statistics, which are based on the sum of performers' reports of their R&D investment on national territory while excluding payments to international organizations and other performers abroad. The data are widely used for empirical studies on R&D topics for OECD countries.

From *Basic Science and Technology Statistics*, we use data on Business Enterprises R&D Financed by Business Enterprises for the variable of business funded and performed R&D (*BRD*), data on Business Enterprises R&D Financed by Direct Government for government funding of business R&D (*BRDG*), data on R&D Investment Performed in Government Sector for R&D performed by government (*GRD*), and data on Higher Education R&D Performance for R&D performed by universities (*URD*). All R&D data are converted to millions of constant 1995 U.S. dollars using purchasing power parities.

The design of R&D tax policy varies across countries. One type of cross-country comparable measurement of R&D tax policies – user cost of R&D – is used as the measure for R&D tax policy (*TP*). Since the "user cost of R&D" is a composite measure of effects of depreciation allowance, tax credit, corporate income tax rate, and personal income tax rate, there are very little data of such kind published for research use. We use the B-index data constructed recently by Guellec and Van Pottelsberghe De La Potterie (2003).[6]

Our measures of patent rights are based on the Ginarte and Park index (GP index). We use an index for each of the five elements rather than the composite GP index. Therefore, the variable *PR* (strength of patent right) is replaced with five component variables including COV (Coverage), DUR (Duration), MEM (Membership in international treatises), ENF (enforcement) and RIG (Loss of protection). Since the GP indexes are quinquennial data, we construct annual data for each of the PR components.[7] As there is no change in the element of RIG during 1985 – 1995, only four variables (COV, DUR, MEM, and ENF) are included.

Following Ginarte and Park, the numeric values for each component are computed from the raw data of national patent laws. COV (Coverage) measures the patentability of the following 6 categories: utility models, pharmaceuticals, food products, chemical products, plant & animal products, and micro-organisms. The value of COV is the fraction of these six categories which are patentable in national patent laws. For the variable DUR (Duration), we use the standard duration of patents – 20 years from date of application or 17 years from time of grant. The magnitude of DUR is the division of the real term of protection by the standard terms. The GP index includes three measures of patent enforcement – preliminary injunctions,

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[6] We thank Bruno Van Pottelsberghe De La Potterie for generously providing the B-index data.
[7] The sources of information on national patent laws we checked include Baxter, J.W. (1968-2002), Meller, M.N. (1983-2002), and Vanhees, H. (1997-2000).

contributory infringement pleadings, and burden-of-proof reversals.[8] The total number of the enforcement measures available in patent laws divided by 3 gives the value of enforcement variable ENF. Lastly, MEM (Membership) refers to the membership status of the countries in three major international patent treatises: the Paris Convention of 1883 (and subsequent revisions), the Patent Treaty of 1970, and the International Convention for the Protection of New Varieties of Plants of 1961. The magnitude of MEM is the number of international treaties in which a country participates divided by the total of 3.

As shown in Table 2-2, there is not much variation across time within the countries in some indices like duration and enforcement. Only one and two changes happened over this period for the index of duration and enforcement respectively. However, additional variation across countries may help to improve the statistical analyses. There is more cross-country and cross-time variation in the index of coverage and membership than that of duration and enforcement.

As discussed before, we expect both exports and imports of international trade to have positive effects on R&D investment by reducing the problem of inappropriability and generating spillovers in R&D activities. The data for openness to international trade (*OT*) is from the *Penn World Table 6.1*, which offers a set of internationally comparable national accounts economic time series for about 160 countries (Heston, Summers and Aten, 2002). Openness is defined as the sum of imports and exports divided by total GDP. This "Openness" variable fits for our need well because it accounts for both imports and exports. Besides the openness variable, GDP data are also from *Penn World Table 6.1*.

[8] By definition, the preliminary injunctions are pre-trial actions that require individuals to cease an alleged infringement. Contributory infringement refers to actions that do not in themselves infringe a patent right but cause or otherwise result in infringement by others. Burden-of-proof reversals are procedures that shift the burden of proof in process patent infringement cases from the patentee to the alleged infringer.

[Insert Table 1 here]

[Insert Table 2-1 here]

[Insert Table 2-2 here]

6. RESULT AND DISCUSSION

We estimate the model using several empirical techniques on the 9-country panel in the period of 1985-1995. First, we estimate a fixed effect model without correcting autocorrelation. Since the estimations are based on time series level data, we expect autocorrelation to exist in the errors. Another fixed effect model with standard first-order autocorrelation adjustment is presented.[9] Because the model includes a lagged dependent variable, we use the Arellano-Bond dynamic panel data estimator (Arellano and Bond, 1991). The Arellano-Bond technique is theoretically preferable for our model, as it provides an unbiased estimate of the autocorrelation. However, because the Arellano-Bond technique uses first differences of the data, it suppresses the effects of some variables, such as openness, which vary across country but do not vary much within a single country. Finally, we run the Parks model with time and country dummies to correct the autocorrelation problem. The Parks method assumes both first-order autoregressive errors within each section, and contemporaneous correlation between cross sections (Parks, 1967). As we demonstrate, correcting for correlation between cross sections can result in some efficiency gains.

To check the sensitivity of the statistical results, we also analyze different specifications for each of the four empirical models. The results of all estimations are presented in Table 3-1 to Table 3-4.

[Insert Table 3-1 here]

[Insert Table 3-2 here]

[Insert Table 3-3 here]

[Insert Table 3-4 here]

We begin our discussion by looking at the results of the base specification using the complete set of explanatory variables. One obvious observation is that most of the coefficients in the four empirical models are consistent and in the direction as expected. First, we find statistically significant estimates for the variables of one-year lagged business funded and performed R&D (BRD_{t-1}), duration component of patent right (DUR_t), government funding of business R&D ($BRDG_{t-1}$), and R&D performed in higher education sector (URD_{t-1}). The enforcement component (ENF_t) has significant effect in all estimators except for the Arellano-Bond dynamic model, while B-index ($BINDX_{t-1}$) is statistically significant in all estimators but the fixed effect model without AR correction. We find mixed results for openness to international trade (OT_t), which is significant only when using the Parks method.

[9] This is done using the xtregar command in Stata.

Next, we investigate whether our results change when removing openness from the model. The significant estimates mostly remain when we exclude the openness variable. The results for one-year lagged business funded and performed R&D (BRD_{t-1}), government funding of business R&D ($BRDG_{t-1}$), R&D performed in higher education sector (URD_{t-1}), and B-index ($BINDX_{t-1}$) are not affected by the change of specification. One noticeable change happens in the relative importance of patent right components. While the duration component (DUR_t) lose some statistical power, only being significant in two estimators, the enforcement component (ENF_t) remains highly significant in the three empirical models as in the base specification.

We also present results for specifications without the patent component variables. We do this both with the openness variable (third column of each table) and without openness (fourth column). We believe that these models are not solidly supported by theory because they miss one important policy instrument, and inevitably suffer missing variable bias. Several abnormal results occur in these two specifications. For instance, the estimate for GDP turns negative while the estimate for B-index becomes significantly positive in one Parks estimation. These results are contrary to the theoretical expectations. An interesting observation is that we still get expected estimates for one-year lagged business funded and performed R&D (BRD_{t-1}), government funding of businesses R&D ($BRDG_{t-1}$), and R&D performed in higher education sector (URD_{t-1}) in the two biased specifications.

Since there is evidence to suggest that autocorrelation exists, the following discussion will focus on the three empirical models used to handle this problem.[10] The Arellano-Bond method first differences the data, thus removing any fixed effects. Lags of both the dependent variable and the differenced exogenous variables are used as instruments to obtain an unbiased estimate of autocorrelation. The results are generally consistent with the other models, while the increased efficiency from correcting for autocorrelation results in additional significant coefficients. For example, the coverage and membership component of patent rights (COV_t and MEM_t) are now significant. However, we find that the effect of the enforcement component (ENF_t) and openness (OT_t) on private R&D spending is no longer significant as they are in the other models. This result is not surprising given that the enforcement and openness measure varies across countries, but is relatively stable across time. Thus, the first-differencing used in the Arellano-Bond model eliminates most of the variation in the two variables.

Because first differencing the data does reduce variation in some key variables, we also report results correcting for autocorrelation without first differencing – fixed effect model with AR adjustment. Because this technique does not account for endogeneity between the lagged dependent variable and the autocorrelated error, the first-stage estimation of autocorrelation may be biased.

Finally, we consider the Parks method, which assumes both first-order autoregressive errors within each section, and contemporaneous correlation between cross sections (Parks, 1967). The Parks results corroborate most of the estimates from the fixed effect with AR adjustment, and the Arellano-Bond method. In particular, the variables of one-year lagged

[10] In Arellano-Band dynamic estimator, the hypothesis tests reject the null hypothesis of no first-order

business funded and performed R&D (BRD_{t-1}), B-index ($BINDX_{t-1}$), duration component (DUR_t), enforcement component (ENF_t), government funding of business R&D ($BRDG_{t-1}$), and R&D performed in higher education sector (URD_{t-1}) are consistently significant. Note that we do find some efficiency gains when using the Parks method partially because of correcting for cross-sectional correlations of the errors.

Turning to magnitudes, we find that the estimated coefficients of one-year lagged business funded and performed R&D are highly significant with magnitude of 0.55 ~ 0.74. Thus, a 10 percent increase in business R&D will generate roughly a 5 ~ 7 percent increase in the same measure next year. The high significance of the estimates indicates the dynamic nature of R&D activities that the conduct of R&D projects may spread over several years.

The results also suggest that tax policies that lower the user cost of R&D stimulate additional business R&D spending. A 10 percent drop in the user cost of R&D results in roughly 2 percent increase in business funded and performed R&D. With everything else being equal, the companies are likely to locate new R&D projects or to expand existing research and development facilities in a jurisdiction where the government fiscal policies favor industrial R&D activities.

For patent right components, enforcement and duration are consistently significant in the estimations with elasticity of 0.10 ~ 0.13 and 0.48 ~ 0.71 respectively. It suggests that the enforcement of patent law does matter to private investors. It coincides with the idea that the value of inventions is not protected effectively unless some legal safeguards are built in the patent law to make it easier for patentees to secure their legal right. The results also indicate

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autocorrelation in the differenced residuals, but do not reject the null hypothesis of no second-order autocorrelation, making usage of the technique appropriate.

that the term of protection, as the most visible symbol of patent regime, also matter to R&D spending by and in business sector.

The other two consistently significant variables are government funding of business R&D (*BRDG*) and R&D performed by higher education sector (*URD*). This study adds to the literature supporting a complementary relationship between public- and private-funded R&D performed in business sector.[11] The values of coefficients for government funded business R&D range from 0.10 ~ 0.16. Thus, a 10 percent increase in government subsidies generates a bit more than 1 percent additional business funded and performed R&D. On the contrary, university R&D acts as a substitute for business funded and performed R&D because the estimated coefficients are highly significant and negative in all estimations. The estimates are between 0.23 and 0.34 in absolute value. A 10 percent increase in R&D performed by higher education sector leads to a roughly 3 percent decrease in the R&D funded and performed by business sector. This reflects the trend that university R&D funded by industries has been increasing, and some companies just contract out their R&D projects to universities in order to take advantage of the intensive knowledge and R&D human resources available in the higher education sector.

As discussed before, openness to international trade may have a positive effect on private R&D investment by raising appropriability and generating spillovers in R&D activities. We get modest evidence to support this proposition. While the elasticity of openness is positive in all models, it is only significant in the Parks estimation. We find that a

[11] This result should be interpreted with caution. Since we do not distinguish the price effect in the business R&D investment, it is hard to say whether there exist a complementary relationship between public R&D and "real" private R&D effort. Nevertheless, the business investment data have been adjusted to some extent because they are in constant $ (1995 prices and PPPs).

10 percent increase in openness measure results in about a 3 percent increase in business funded and performed R&D spending.

Finally, we provide a brief comparison of our analysis with other previous studies. The most recent and closest research is reported by Guellec and Van Pottelsberghe De La Potterie (2003), who examine the effects of government funding of business R&D, tax incentives, and R&D performed in government or universities on a panel of 19 OECD countries. They estimate a model similar to our regressions in the fourth column of each table, where openness and patent rights are omitted. For common variables included in both studies, we find similar estimates for tax incentives (B-index) and government funding of business R&D. While R&D performed in higher education sector is insignificant (with negative values) in their analysis, we find significant negative estimates for this variable.

However, it is important to note that we obtain similar results to Gullec and Van Pottelsberghe de la Potterie only when using our completely specified model. Our model differs from the model of Guellec and Van Pottelsberghe de la Potterie because we add patent right variables as well as variable for openness to international trade. With these variables omitted, we only find a positive effect of tax incentives when using the Parks method. As demonstrated in the theory part and empirical results, the exclusion of these variables is not only conceptually unjustifiable but also produces abnormal empirical results (for example, for GDP and B-Index).

7. CONCLUSION

This study contributes to the literature by simultaneously examining the effectiveness of several major national innovation policies on R&D investment funded by and performed in the business sector. Our analysis shows support for both government funding of business R&D and tax incentives in stimulating business funded and performed R&D spending. The government funding of business R&D has the additional benefit of directing public research funds to where they are more valuable to the whole society. However, this advantage is compromised to some extent by the possible efficiency loss due to the interference by governments into the market economy. The positive effect of tax incentives also shows up. One caveat is that tax incentives come with a cost of lost revenue for the government. The net effect should be based on the comparison between the induced private R&D and the tax money foregone.

As a major contribution, the effect of patent right is evaluated in this paper. Among the components examined, enforcement and duration seem to affect R&D spending funded and performed by businesses the most. Due to the data limitation, we cannot provide strong evidence for the positive impact of the components of coverage and membership in international patent treaties on innovation effort by business enterprises. The results generally support the conventional view that patent protection is important to increase the amount of R&D expenditure generated by private markets.

While it is not easy to find significant effect of R&D performed in government on business funded and performed R&D, the negative impact of R&D conducted in higher education sector is obvious and consistent. The positive impact of government R&D activity comes from the possible diffusion of government technology to business sector, which has been a major policy focus since 1990s. However, there is still a long way to go for private companies to benefit from government R&D outputs because of the mission-driven nature of government research projects as well as the high threshold of absorbing capacity. On the other hand, the negative effect of R&D performed in higher education sector is understandable when more and more industrial R&D projects are contracted out to universities.

Finally, as a major channel of knowledge and rent spillover as well as an extension of market, international trade matters to private R&D investors. Our empirical study provides modest evidence to support this view.

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Table 1: Variables and Definitions

Variable	Definition	Data Source
BRD	Business funded and performed R&D	OECD publication: *Basic Science and Technology Statistics* (2000)
GDP	Gross domestic product	Heston, Summers and Aten: *Penn World Table* 6.1 (2002)
BINDX	B-Index (user cost of R&D)	Guellec and Van Pottelsberghe De La Potterie (2003)
COV	Coverage element – ratio of patentable categories divided by 6	International legal literature on patent laws, national patent laws, and Ginarte and Park: "Determinants of patent rights: A cross-national study" (1997)
DUR	Duration element – ratio of terms of protection divided by standard terms	International legal literature on patent laws, national patent laws, and Ginarte and Park: "Determinants of patent rights: A cross-national study" (1997)
MEM	Membership element – ratio of international treaties participated divided by 3	International legal literature on patent laws, national patent laws, and Ginarte and Park: "Determinants of patent rights: A cross-national study" (1997)
ENF	Enforcement element – ratio of enforcement measures available divided by 3	International legal literature on patent laws, national patent laws, and Ginarte and Park: "Determinants of patent rights: A cross-national study" (1997)
BRDG	Government funding of business R&D	OECD publication: *Basic Science and Technology Statistics* (2000)
URD	R&D performed in higher education sector	OECD publication: *Basic Science and Technology Statistics* (2000)
GRD	R&D performed in government sector	OECD publication: *Basic Science and Technology Statistics* (2000)
OT	Ratio of the total value of imports and exports over the GDP	Heston, Summers and Aten: *Penn World Table* 6.1 (2002)

Table 2-1: Descriptive Statistics

Variables	N	Maximum	Minimum	Median	Mean	Std Dev
BRD	99	108652.0	961.0	9582.4	21858.0	28743.8
GDP	99	7473804.8	290280.4	1041282.7	1700388.3	1846500.3
BINDX	99	1.0536	0.5851	0.9206	0.9097	0.1299
COV	99	1.00	0.33	0.83	0.72	0.21
DUR	99	1.00	0.75	1.00	0.95	0.094
MEM	99	1.00	0.33	1.00	0.93	0.17
ENF	99	1.00	0.33	1.00	0.84	0.26
BRDG	99	38919.5	47.1	1024.7	4628.9	9588.3
URD	99	28019.0	486.9	3297.0	6658.9	7662.3
GRD	99	18392.0	571.7	3019.2	5000.8	4932.2
OT	99	70.9	14.4	36.1	36.3	13.6

Table 2-2: Summary of changes in PR components (1985-1995)

Country	Coverage (COV)	Duration (DUR)	Membership (MEM)	Enforcement (ENF)
Australia	1985-1990: 0.33 1991-1995: 0.83	1985-1994: 0.80 1995: 1.00	1985-1988: 0.67 1989-1995: 1.00	1985-1990: 0.33 1991-1995: 1.00
Canada	1985-1992: 0.50 1993-1995: 0.67	1985-1995: 1.00	1985-1989: 0.33 1990: 0.67 1991-1995: 1.00	1985-1995: 0.67
France	1985-1993: 0.67 1994-1995: 0.83	1985-1995: 1.00	1985-1995: 1.00	1985-1995: 1.00
Germany	1985-1995: 0.83	1985-1995: 1.00	1985-1995: 1.00	1985-1995: 1.00
Italy	1985-1991: 0.83 1992-1995: 1.00	1985-1995: 1.00	1985-1995: 1.00	1985-1995: 1.00
Japan	1985-1995: 1.00	1985-1995: 0.75	1985-1995: 1.00	1985-1995: 1.00
Spain	1985-1992: 0.33 1993-1995: 0.83	1985-1995: 1.00	1985-1989: 0.67 1990-1995: 1.00	1985: 0.33 1986-1995: 1.00
U.K.	1985-1995: 0.67	1985-1995: 1.00	1985-1995: 1.00	1985-1995: 0.33
U.S.A.	1985-1995: 0.83	1985-1995: 1.00	1985-1995: 1.00	1985-1995: 1.00

Note: COV (Coverage): ratio of patentable categories (utility models, pharmaceuticals, food products, chemical products, plant & animal products, and micro-organisms) over total number of categories (6); DUR (Duration): ratio of real term of protection over the standard terms (20 years from date of application or 17 years from time of grant); MEM (Membership in three major international patent treatises): ratio of number of treaties joined over total number of treaties (3); ENF (Enforcement measures such as preliminary injunctions, contributory infringement pleadings, and burden-of-proof reversals): ratio of number of enforcement measures available over total number of major enforcement measures (3).

Table 3-1: Summary of Statistical Results – Fixed Effect Model without AR (1)

Variable	FE without AR adjustment – Base model	FE without AR adjustment – Model without OT	FE without AR adjustment – Model without PR elements	FE without AR adjustment – Model without PR elements or OT
$BRD_{i,t-1}$	0.664[a]	0.700[a]	0.783[a]	0.915[a]
	(7.67)	(8.61)	(9.57)	(13.58)
$GDP_{i,t-1}$	0.142	0.055	0.036	-0.302
	(0.51)	(0.20)	(0.12)	(-1.12)
$BINDX_{i,t-1}$	-0.186	-0.175	-0.050	0.030
	(-1.53)	(-1.44)	(-0.43)	(0.26)
$COV_{i,t}$	0.057	0.054		
	(0.97)	(0.91)		
$DUR_{i,t}$	0.503[c]	0.426		
	(1.66)	(1.44)		
$MEM_{i,t}$	0.041	0.046		
	(1.24)	(1.37)		
$ENF_{i,t}$	0.084[c]	0.092[b]		
	(1.69)	(1.88)		
$BRDG_{i,t-1}$	0.133[a]	0.147[a]	0.119[a]	0.134[a]
	(3.21)	(3.71)	(2.95)	(3.33)
$URD_{i,t-1}$	-0.304[a]	-0.272[a]	-0.263[a]	-0.192[a]
	(-3.31)	(-3.09)	(-3.61)	(-2.82)
$GRD_{i,t}$	-0.044	-0.115	-0.019	-0.070
	(-0.39)	(-1.22)	(-0.19)	(-0.77)
$OT_{i,t}$	0.214		0.136	
	(1.17)		(0.72)	
N	99	99	99	99
Hausman	40.87	44.29	34.97	26.38
Overall R2	0.90	0.94	0.96	0.97

1) The dependent variable is Business enterprise R&D financed by business enterprises in country i at time t: $BRD_{i,t}$.
2) 1, 2, 3 and 4 refer to different specification of the model: 1-base specification with all explanatory variables; 2- specification with patent right components but without openness variable; 3- specification with openness variable but without patent right components; 4-specification with neither patent right components nor openness.
2) N refers to the total number of observation. T-statistics are in parenthesis. a, b, and c refer to significance level at 1% and below, 5%, and 10%.

Table 3-2: Summary of Statistical Results – Arellano-Bond Dynamic Model

Variable	AB dynamic – Base model	AB dynamic – Model without OT	AB dynamic – Model without PR elements	AB dynamic – Model without PR elements or OT
$BRD_{i,t-1}$	0.732[a]	0.744[a]	0.846[a]	0.957[a]
	(9.88)	(10.61)	(12.43)	(16.44)
$GDP_{i,t-1}$	0.141	0.151	-0.020	-0.259
	(0.60)	(0.65)	(-0.08)	(-1.10)
$BINDX_{i,t-1}$	-0.172[b]	-0.168[b]	-0.067	-0.011
	(-1.88)	(-1.85)	(-0.75)	(-0.12)
$COV_{i,t}$	0.106[b]	0.113[c]		
	(2.01)	(2.12)		
$DUR_{i,t}$	0.519[b]	0.482[c]		
	(1.97)	(1.88)		
$MEM_{i,t}$	0.065[b]	0.069[b]		
	(2.22)	(2.34)		
$ENF_{i,t}$	0.037	0.031		
	(0.88)	(0.73)		
$BRDG_{i,t-1}$	0.104[a]	0.112[a]	0.082[a]	0.091[a]
	(3.08)	(3.53)	(2.62)	(2.90)
$URD_{i,t-1}$	-0.339[a]	-0.347[a]	-0.236[a]	-0.189[a]
	(-3.91)	(-4.03)	(-3.71)	(-2.99)
$GRD_{i,t}$	-0.006	-0.013	-0.018	-0.019
	(-0.07)	(-0.16)	(-0.21)	(-0.23)
$OT_{i,t}$	0.051		-0.053	
	(0.32)		(-0.33)	
N	99	99	99	99
Arellano-Bond Order 1	-2.73	-2.77	-2.73	-3.19
Arellano-Bond Order 2	0.83	0.87	0.58	0.70

1) The dependent variable is Business enterprise R&D financed by business enterprises in country i at time t: $BRD_{i,t}$.
2) 1, 2, 3 and 4 refer to different specification of the model: 1-base specification with all explanatory variables; 2- specification with patent right components but without openness variable; 3-specification with openness variable but without patent right components; 4-specification with neither patent right components nor openness.
2) N refers to the total number of observation. T-statistics are in parenthesis. a, b, and c refer to significance level at 1% and below, 5%, and 10%.

Table 3-3: Summary of Statistical Results – Fixed Effect Model with AR (1)

Variable	FE with AR adjustment – Base model	FE with AR adjustment – Model without OT	FE with AR adjustment – Model without PR elements	FE with AR adjustment – Model without PR elements or OT
$BRD_{i,t-1}$	0.554[a] (6.11)	0.610[a] (7.07)	0.609[a] (6.73)	0.879[a] (12.13)
$GDP_{i,t-1}$	0.267 (0.84)	0.137 (0.44)	0.238 (0.72)	-0.271 (-0.94)
$BINDX_{i,t-1}$	-0.262[b] (-2.07)	-0.249[b] (-1.95)	-0.165 (-1.33)	-0.001 (-0.01)
$COV_{i,t}$	0.040 (0.66)	0.043 (0.69)		
$DUR_{i,t}$	0.530[c] (1.83)	0.441 (1.53)		
$MEM_{i,t}$	0.053 (1.32)	0.061 (1.53)		
$ENF_{i,t}$	0.111[b] (2.11)	0.119[b] (2.26)		
$BRDG_{i,t-1}$	0.145[a] (3.14)	0.160[a] (3.52)	0.153[a] (3.32)	0.145[a] (3.35)
$URD_{i,t-1}$	-0.295[a] (-2.94)	-0.258[a] (-2.63)	-0.297[a] (-3.50)	-0.192[a] (-2.64)
$GRD_{i,t}$	0.003 (0.03)	-0.084 (-0.81)	0.054 (0.49)	-0.062 (-0.65)
$OT_{i,t}$	0.331[c] (1.67)		0.274 (1.33)	
N	99	99	99	99
Hausman	54.97	50.11	46.73	26.34
Durbin-Watson	1.53	1.57	1.53	1.72
Overall R2	0.86	0.93	0.92	0.97

1) The dependent variable is Business enterprise R&D financed by business enterprises in country i at time t: $BRD_{i,t}$.
2) 1, 2, 3 and 4 refer to different specification of the model: 1-base specification with all explanatory variables; 2- specification with patent right components but without openness variable; 3-specification with openness variable but without patent right components; 4-specification with neither patent right components nor openness.
2) N refers to the total number of observation. T-statistics are in parenthesis. a, b, and c refer to significance level at 1% and below, 5%, and 10%.

Table 3-4: Summary of Statistical Results – Parks Model

Variable	Parks – Base model	Parks – Model without OT	Parks – Model without PR elements	Parks – Model without PR elements or OT
$BRD_{i,t-1}$	0.585[a]	0.699[a]	0.785[a]	0.918[a]
	(11.83)	(17.36)	(17.66)	(28.67)
$GDP_{i,t-1}$	0.241[c]	-0.083	-0.012	-0.376[a]
	(1.79)	(-0.70)	(-0.11)	(-5.87)
$BINDX_{i,t-1}$	-0.225[a]	-0.157[a]	-0.047	0.091[b]
	(-4.24)	(-3.01)	(-0.89)	(2.05)
$COV_{i,t}$	0.018	0.007		
	(0.60)	(0.23)		
$DUR_{i,t}$	0.709[a]	0.563[a]		
	(6.50)	(5.10)		
$MEM_{i,t}$	0.009	0.017		
	(0.35)	(0.70)		
$ENF_{i,t}$	0.122[a]	0.134[a]		
	(4.54)	(4.97)		
$BRDG_{i,t-1}$	0.100[a]	0.125[a]	0.115[a]	0.125[a]
	(5.14)	(7.32)	(6.91)	(8.56)
$URD_{i,t-1}$	-0.291[a]	-0.227[a]	-0.316[a]	-0.211[a]
	(-6.03)	(-4.57)	(-9.18)	(-6.64)
$GRD_{i,t}$	0.023	-0.068[b]	0.103[a]	0.042[c]
	(0.42)	(-1.97)	(2.67)	(1.65)
$OT_{i,t}$	0.290[a]		0.335[a]	
	(3.27)		(4.47)	
N	99	99	99	99
MSE	1.19	1.15	1.18	1.12

1) The dependent variable is Business enterprise R&D financed by business enterprises in country i at time t: $BRD_{i,t}$.
2) 1, 2, 3 and 4 refer to different specification of the model: 1-base specification with all explanatory variables; 2- specification with patent right components but without openness variable; 3-specification with openness variable but without patent right components; 4-specification with neither patent right components nor openness.
2) N refers to the total number of observation. T-statistics are in parenthesis. a, b, and c refer to significance level at 1% and below, 5%, and 10%.