Knowledge spillovers in interdependent economies

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Abstract

In this paper, we improve upon Coe and Helpman's model of international R&D spillovers, using seemingly unrelated regression (SUR) to include interdependence among national economies and allow for variations in coefficients across countries. We find that the impact of knowledge spillovers on national productivity is context dependent: positive in some cases while negative in others. From our interpretation, the results suggest that both beneficial and competitive effects from foreign knowledge spillovers are important. We view the most important contribution of our work as simply providing evidence of this variation, and suggesting directions for future research to explain this phenomenon.

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1. Introduction

Since the emergence of endogenous growth theory in the late 1980s, there has been increased interest in the issues of technological advancement and economic growth. Because technological knowledge, as an input, is a nonrival, partially excludable good, technology spillovers are prevalent between firms, industries and nations. Although a great deal of work has been done addressing the impacts of technology spillovers at the firm and industry level, less has been done on international knowledge spillovers. Coe and Helpman (CH) (1995) provided the initial empirical contribution to this literature by exploring the effects of international R&D spillovers on national productivity. Their principal conclusion, shared by most economists, is that both foreign R&D spillovers and domestic R&D have significant positive effects in promoting national productivity.

In this paper, we make several modifications to CH's model. Most importantly, whereas CH use a fixed effects regression, we use a seemingly unrelated regressions (SUR) framework. SUR offers two important improvements to CH's basic model. First, through the error term, SUR incorporates interdependence among national economies, thus improving the efficiency of the regression results. Although Grossman and Helpman (1991) mentioned a similar point, none of the existing empirical work, including that of CH, captures this structure. More importantly, the SUR framework allows the effect of R&D to vary across countries. Our results show that, while domestic R&D efforts can promote national productivity universally, foreign knowledge spillovers do not always have positive impacts on national productivity, as in works of CH and many other scholars; on the contrary, they may be negative in some cases. From our interpretation, the results raise the possibility that knowledge spillovers offer not only positive externalities, but also competitive effects. For example, in our results, both the United States and Japan suffer negative impacts from foreign knowledge spillovers. The lack of variables measuring the competitive position of nations suggests misspecification of the CH's model.

In addition to using seemingly unrelated regressions, we also make other changes to the model that we think are important. First, whereas CH use contemporary stocks of R&D spending, we use lagged knowledge variables to account for the gradual diffusion of new knowledge. In addition, we also use foreign patents, rather than foreign R&D expenditures, as a measure of the foreign knowledge stock. Although we argue that these alternative data provide a better measure of foreign knowledge flows, we do show that the basic result of variation in the effect of foreign knowledge across countries holds even when using CH's data.

This paper is organized as follows: The next section presents our theoretical framework including a critical review of prior work. This is followed by a description of the data used to estimate our model. The fourth section of the paper presents our results, followed by a concluding section.

2. Theory

(1) Theoretical background

The role of technological advancement in economic growth has been of great interest for both academics and practitioners. Beginning with the work on endogenous growth models, a new theoretical and empirical literature recently emerged focusing on the importance of innovation efforts in promoting national economic growth. Frantzen (1998) summarized that this literature builds on four 'stylized' facts: (?) most innovations that are relevant for productivity growth are the result of purposive commercially oriented R&D effort; (??) innovators are driven by profit motives and subject to competition; (???) they dispose over sufficient market power to allow monopoly profits which make their innovation efforts worthwhile; and (?v) knowledge generated by innovations will eventually become available for use by others and contribute to further scientific research. Of these, we focus our discussion on points (ii) and (iv) – the competitive nature of R&D and the prevalence of knowledge spillovers.

Knowledge spillovers are an important theoretical assumption of endogenous growth models. Romer (1990) pointed out that the distinguishing feature of technology, as an input, is that it is neither a conventional good nor a public good; it is a nonrival, partially excludable good. Knowledge can be used by more than one entity (firm, industry, or country) at the same time, without the use by one entity prohibiting the use by others (non-rivalry), and others can often not be excluded from using the knowledge (non-excludability). The spillover of knowledge can be beneficial to economic output of one specific entity, because the entity can take advantage of both internal and external technological resources to strengthen its capacity to conduct R&D and enhance the performance of economic activities. On the other hand, spillovers discourage the R&D effort of any private entity, because it cannot obtain the total benefits that will be created by their R&D efforts in the existence of externalities.

Compared with the spillovers between firms or industries, international knowledge spillover is a relatively new academic focus.[1] Many models have been developed and tested on this topic recently. Most scholars conclude that both domestic and foreign sources of innovation act as engines of economic growth at the national level. For example, Eaton and Kortum (1997) found that growth is primarily the result of research performed abroad, and even the largest country, the United States, would have grown less than half as much if it had been isolated from the rest of the world.

Much of the empirical work on international spillovers has been based on the model presented by Coe and Helpman (1995). Their model uses data on domestic and international R&D to estimate the effect of R&D spillovers on economic growth, as measured by changes in total factor productivity (TFP) – the component of output growth that is not attributable to the accumulation of the conventional economic inputs. The basic assumption is that both domestic R&D and international R&D spillovers play important roles in promoting national economic performance. They argued, “The benefits from foreign R&D can be both direct and indirect. Direct benefits consist of learning

[1] Examples of research on knowledge spillovers across firms include Bernstein and Nadiri (1988, 1989) and Jaffe (1986, 1988).

about new technologies and materials, production processes, or organizational methods. Indirect benefits emanate from imports of goods and services that have been developed by trade partners. In either case, foreign R&D affects a country's productivity." (Coe and Helpman, 1995)

The basic model estimated by CH is:

$$\mathrm{LogF}_{it} = a_i^{\,0} + a^d\,\mathrm{LogS}^{\mathrm{d}}_{it} + a^f\,\mathrm{LogS}^{\mathrm{f}}_{it} + \mathrm{e}_{it} \qquad (1)$$

In the model, F represents TFP, S^d represents the domestic R&D capital stock, and S^f represents the foreign R&D stock.[2] CH define the foreign capital stock as the import-share-weighted average of the domestic R&D capital stocks of trade partners. To account for the role of international trade in the diffusion of knowledge, CH weight the log of the stock of foreign R&D by the fraction of imports, m_i, in GDP for each country. They use fixed-effect estimation on panel data from 22 countries (21 OECD countries and Israel), which imposes cross-country restrictions on the elasticities a_i^d and a_i^f.[3] CH find that foreign R&D has significant beneficial effects on domestic productivity, and that the effect is stronger the more open an economy is to foreign trade.

CH's initial work spurred several studies designed to more carefully examine the role of international spillovers in economic growth. A commonly cited methodological

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[2] In CH's paper, log*TFP* is defined as $\log Y - ß \log K - (1- ß) \log L$, where Y, K, L and $ß$ represent GDP, capital, labor, and the share of capital in GDP. In calculating log*TFP*, they use the average share of capital income from 1987-89 as value of coefficient $ß$.
[3] Although the equations in CH's model have country-specific coefficients a^d_{i} and a^f_{i}, they use fixed effect estimation by assuming that the coefficients for both domestic and foreign R&D are the same across countries. Variations across countries due to foreign R&D come from variations in the importance of imports, m_i.

drawback of CH's model is that, by concentrating exclusively on cointegrating equations estimated by OLS, they are unable to perform tests of significance on the parameter estimates (Frantzen, 1998). Another concern is that they use fixed-effect estimation, assuming that the coefficients of both domestic and foreign R&D are constant for all countries. This assumption is not plausible. For example, Frantzen (1998) demonstrated that the influence of foreign R&D was, on average, stronger than that of domestic R&D, although in the G7 economies the elasticity of TFP with response to domestic R&D was more important. Recent theoretical insights from various perspectives have stressed the differential impact that R&D might have in different countries (Verspagen, 1995). For example, work on national systems of innovation shows that the differences in technology institutions and policy might lead to differences in the efficiency of R&D and other technological activities (Nelson, 1993). In addition, Keller (2000) found that countries that import largely from high-knowledge countries should, everything else equal, import more technology than countries that import largely from low-knowledge countries. These results suggest that the effects of both domestic R&D and foreign R&D spillovers on economic growth may differ across countries.

An important point to note is that the impact of foreign knowledge on national economies may be multi-sided. Not only might a stock of foreign knowledge have direct and indirect benefits to recipient countries, it might also have negative effects resulting from technology-based foreign competition, which could threaten even interrupt the growth of national economies. For example, Engelbrecht (1997) modified CH's basic model by adding variables to represent the business cycle, TFP catch-up, and country specific dummies.[4] The empirical results show that there is a group of countries (such as US and Western Germany) for which international R&D spillovers have negative impact on TFP. Engelbrecht explained that some leading knowledge producers might have relatively less to learn from foreign R&D, whereas some smaller countries may be well placed to take advantage of foreign R&D. In addition, other researchers modified CH's work using a random coefficients specification, and found that the estimated elasticity of TFP with respect to foreign R&D stock is negative and even significant in some cases (Müller and Nettekoven, 1999). However, they did not give an explanation to the peculiar results.

Another important limitation of fixed effects analysis is that it ignores interdependence among economies. Although theoretical models have made note of the importance of this connection,[5] empirical work on knowledge spillovers has not taken advantage of this interdependence. Here we want to emphasize two points. The first is that, with the deepening and extensive process of globalization and regional economic integration, interdependence among individual economies has become stronger and stronger. The channels of connection between national economies include inter-flows of all other production factors such as capital flows and labor migration besides knowledge spillovers. There are many possible channels for knowledge spillovers, including patents granted to nonresidents, foreign direct investments, education and training received abroad, exchange of journals and books, international conferences, and electronic

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[4] By adding 21 interactive dummy variables, Engelbrecht obtained the estimates of country specific R&D spillovers using a generalized least-squares cross-sectionally heteroscedastic and timewise autoregressive model. Our approach is to estimate country specific coefficients by means of SUR.

[5] For example, Grossman and Helpman (1991) note that "(c)ountries that are integrated into the world economy interact with one another in several dimensions. They trade goods on world product markets, borrow and lend on world capital markets, and exchange information through market and nonmarket channels."

information transfers. The existence of those channels strengthens the interdependence among national economies that may not be picked up in the trade weighted knowledge spillover measurement alone.

Finally, it is important to consider the measurement of R&D output. CH use international trade to weight knowledge spillovers across countries. The use of trade-weighted R&D capital stocks implies either that all international knowledge flows are embodied in traded goods, or that such goods are an acceptable proxy for the many other mechanisms by which knowledge is transferred between countries. Keller (1996) found that the role played by the composition of imports is limited: alternatively weighted R&D stocks, in which import shares are created randomly, also led to a positive correlation between foreign R&D and the importing country's productivity. This finding sheds doubt on the claim that patterns of international trade are important in driving R&D spillovers.

Second, the time lag structure used by CH to model the impact of R&D efforts on productivity growth is important. The research and development processes takes time, so that we would not expect current research and development to have an effect on measured productivity until several years have elapsed.[6] In constructing a stock of knowledge, it is necessary to make assumptions about the relevant lag structure. CH assume instant diffusion and a constant decay rate. Nonetheless, they use contemporary

[6] See, for example, Griliches (1995). In addition, in studying patents citation across countries, Jaffe and Trajtenberg (1998) found that the probability of citation to existing patents rises rapidly in the first few years after the cited patent, then peaks and declines slowly over time, suggesting a gradual diffusion of knowledge.

knowledge stocks as the measure of knowledge in their regressions. Thus, they implicitly assume that new R&D has its biggest effect immediately after it is performed.

(3) New model

In this paper, we address both the issue of interdependence among economies and the measurement of knowledge flows. We begin with the same basic model as CH's:

$$LogTFP_{i,t} = b_{0i} + b_{1i} LogS^{d}_{i,t-1} + b_{2i} LogS^{f}_{i,t-1} + e_{it} \qquad (2)$$

The format of equation (2) is very similar to that of equation (1) in CH paper, with S^d and S^f representing domestic R&D capital stock and foreign R&D capital stock respectively. However, rather than using a fixed effect model approach to estimation, we use seemingly unrelated regression (SUR). SUR allows us to find unique coefficients for each nation. We are thus able to formally test the hypothesis whether the coefficients of both domestic and foreign R&D are constant for all countries. Also, since the covariance matrix of the error is not block diagonal, SUR assumes an error structure that incorporates interdependence among economies, thus improving the efficiency of our estimates.

Second, we address the issue of time lags on R&D by assuming there is a universal one-year lag of domestic and foreign R&D efforts behind their impacts on productivity growth. In practice, the time lag structure could be very complex, because different types of R&D activities have different time lag structures, which also could be affected by some institutional and policy environment.

In addition, to capture flows of knowledge that might not be picked up via international trade, we use a stock of foreign patents, rather than R&D, as the measure of foreign R&D spillovers[7]. The use of patent data offers several advantages. First, by using patents granted to foreigners in each nation, we have a more direct measure of knowledge flowing into a nation than trade-weighted R&D, as the patent can be seen as a signal that the inventor felt the product would be of use to the domestic market. In addition, because it takes, on average, two years for a patent to be granted, the use of patent data allows for an additional time lag before the absorption of foreign knowledge. However, since domestic knowledge presumably diffuses more quickly, we follow CH and use domestic R&D expenditure data for the domestic knowledge stock.

However, it is important to note that there are disadvantages to the use of patent data. The existing literature on the benefits and drawbacks of using patent data is quite large.[8] An important concern is that the quality of individual patents varies widely. Some inventions are extremely valuable, whereas others are of almost no commercial value. This is partly a result of the random nature of the inventive process. In addition, variations in the patent systems in each country mean that a patent in country *A* might not be equivalent to a patent in country *B*.[9] Since these laws tend to remain constant within countries across time, we argue that the coefficients on the foreign knowledge stock offer

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[7] Proceeding in a similar fashion to CH, we construct the foreign patent stock based on the perpetual inventory model, and the initial benchmark is calculated using the same procedure as CH. In addition, we use a depreciation rate of 0.05 just as they did.

[8] Griliches (1990) provides a useful survey.

[9] For example, until 1976, patents in Japan were limited to a single claim, whereas patents in most other nations often have multiple claims. Even today, Japanese patents traditionally have fewer claims per patent than other nations. As a result, each individual Japanese patent embodies less knowledge than an equivalent patent in other nations.

reliable estimates of the effect of changes in knowledge for each country. However, the magnitudes of the effect are not directly comparable across countries.

3. Data

There are two key differences between our model and CH's. The first is that we consider interdependence among national economies by means of SUR. The other is that we use a different specification of the knowledge stock, both by introducing a one-year lag and by using foreign patents, rather than trade weighted foreign R&D expenditures, to measure foreign knowledge spillovers. In order to differentiate the effects from modeling and measurement of foreign R&D, we estimate our model using both new measure of foreign knowledge spillovers and the same measure and data from CH paper. Table 1 presents a detailed description of the variables used.

CH use data from 21 OECD countries and Israel. Due to availability of data, we choose 19 of the 22 countries: the United States, Japan, Germany, France, the United Kingdom, Canada, Australia, Belgium, Denmark, Finland, Ireland, Israel, Netherlands, Norway, Austria, Portugal, Spain, Sweden and Switzerland.[10] To keep our work comparable to CH's, we use their data for domestic business R&D expenditure stock and TFP in each of

[10] We do not have complete patent data for Italy and New Zealand. In addition, we also drop out Greece because it is the least investor in R&D activities. We excluded Greece in the analysis since estimation with these data results in a singular variance-covariance matrix. This same condition occurs where using the original CH data on the 21 OECD nations and Israel. Since there are no structural causes for the singularity, we conclude it was simply due to highly correlated measurement data.

Table 1: Description of models and variable

	CH model	The first estimation of new model	The second estimation of new model
Number of countries	22	19	19
Domestic R&D measurement	Domestic business R&D expenditure stock	Domestic business R&D expenditure stock	Domestic business R&D expenditure stock
Foreign R&D measurement	Trade weighted foreign R&D expenditure stock	Trade weighted foreign R&D expenditure stock	Patents stock for nonresidents
Interaction	Trade	SUR	SUR

the two estimations. Foreign patent data in the second estimation comes from WIPO Industry Property Statistics[11].

4. Results and discussions

Table 2 presents the results of our estimation. Both estimations use SUR and lagged knowledge stocks. The first estimation uses the trade weighted R&D stocks from CH, and the second one uses patent data as a measure of foreign knowledge. In both cases, our estimates of the coefficient of domestic R&D are consistent with most other studies, and show a positive effect on TFP growth. Interestingly, using patents as a measure of foreign knowledge appears to offer a slight improvement to the results on domestic R&D, as the estimate for Canada is negative when using CH's data. As we expected, the signs of estimates of coefficients for foreign R&D are context sensitive, rather than universally positive as in works of CH and many other scholars. It is noteworthy that we get negative estimates for US, UK, Ireland, Israel, and Spain with high significance in both

[11] In the first estimation, the data of TFP, domestic business R&D expenditure stock, and foreign business R&D expenditure stock we borrowed from CH are indexed. In the second estimation, only the TFP data from CH's paper are indexed. The data of domestic business R&D expenditure stock (also from CH) and patent stock for nonresidents are not indexed.

Table 2: Estimates for coefficients of domestic R&D and foreign spillover measures

Country	The first estimation				The second estimation			
	b_1 (Domestic R&D)		b_2 (Foreign R&D)		b_1 (Domestic R&D)		b_2 (Foreign R&D)	
US	0.253	(19.05)	-0.077	(-9.25)	0.148	(-3.92)	-0.077	(-2.25)
Japan	0.328	(27.79)	0.002	(0.12)	0.325	(43.81)	-0.847	(-8.08)
Germany	0.229	(18.39)	-0.127	(-12.37)	0.145	(12.29)	0.094	(7.45)
France	0.629	(39.50)	-0.109	(-8.82)	0.526	(58.02)	0.134	(19.82)
UK	1.586	(22.83)	-0.143	(-9.41)	1.022	(14.99)	-0.294	(-3.71)
Canada	-0.035	(-3.35)	0.190	(8.16)	0.157	(10.91)	0.303	(6.22)
Australia	0.076	(5.71)	0.014	(0.58)	0.089	(11.58)	-0.049	(-1.76)
Belgium	0.367	(23.95)	-0.107	(-8.96)	0.468	(16.56)	0.353	(6.44)
Denmark	0.234	(11.73)	-0.028	(-1.74)	0.303	(7.37)	0.190	(2.39)
Finland	0.299	(20.00)	-0.109	(-8.53)	0.084	(6.59)	0.750	(21.18)
Ireland	0.356	(15.49)	-0.268	(-9.88)	0.344	(16.12)	-0.618	(-9.88)
Israel	0.139	(16.78)	-0.114	(-6.00)	0.166	(19.67)	-0.639	(-9.69)
Netherlands	0.292	(15.10)	0.101	(10.96)	1.021	(42.80)	-0.173	(-40.29)
Norway	0.210	(21.76)	0.137	(11.47)	0.169	(15.01)	0.259	(18.15)
Austria	0.149	(9.46)	-0.091	(-4.66)	0.199	(20.18)	0.670	(16.11)
Portugal	0.269	(8.17)	-0.001	(-0.06)	0.267	(8.13)	0.578	(20.57)
Spain	0.097	(18.45)	-0.183	(-19.85)	0.123	(19.59)	-0.326	(-23.05)
Sweden	0.123	(7.11)	-0.051	(-2.34)	0.098	(8.29)	0.050	(1.79)
Switzerland	0.703	(14.09)	-0.130	(-8.57)	0.420	(11.49)	0.205	(14.16)
N	20 observations/country				20 observations/country			
System weighted R^2	0.9983				0.9998			

Note: t-values in parenthesis.

Table 3: Test of uniqueness of coefficients

	The first estimation	The second estimation
F-value	2030 (0.0001)	6735 (0.0001)

Note: Significance levels in parenthesis.

estimations. CH R&D data yield 14 negative estimates (12 significant), whereas our patent data yields 8 negative estimates, all of which are significant at the 10 percent level.

Our empirical output seems very different from what most scholars estimate as the impact of foreign R&D spillovers. This difference is not due to different measurements of foreign R&D spillover effects, as it also occurs when we use the same trade-weighted foreign R&D data as CH. Rather, the results suggest that the hypothesis of constant coefficients across countries, as would hold in fixed effects estimation, is incorrect. To formally test this hypothesis, we use an F-test on the null hypothesis that the coefficients for both domestic and foreign R&D are constant for each country. As shown in Table 3, the F-test easily rejects the null hypothesis in both cases.

In order to consider the question of interdependence between these economies, table 4a and 4b present the estimated cross correlation matrices associated with the first and second SUR estimations respectively. We note that many of the individual correlations are large (shown as underlined). One way to understand the implications of these results is to note that a large correlation suggests that the two associated countries respond in either similar (positive) or contrary (negative) ways to random global events (not included in the model) consistently over time. The existences of these strong correlations verify the interdependencies we suspected, and result in greater estimation efficiency in the individual parameter estimates. It is important to note that this interpretation assumes that the model is correctly specified and does not suffer from missing variable bias.

Our results suggest that something is missing in the basic model proposed by Coe and Helpman. One possibility is that CH's model ignores the competitive effect that foreign R&D might have on an economy. While most economists have focused on the positive externalities generated by foreign knowledge spillovers, our results suggest that negative externalities due to competition need also be considered. For example, the search model of invention, introduced by Evenson and Kislev (1976), hypothesized that technological improvements become increasingly difficult as the threshold for new discoveries rises. Analogously, it is possible that an increase of foreign innovations reduces the opportunities for domestic inventive activities, except for periods of fundamental technological breakthrough.

Such findings are not new at the firm level. As Jaffe (1986) pointed out, both technological spillovers and competitive effects of others' R&D affect the economic returns to a firm's research. His work showed that the direct effect of the spillover pool is to lower profits and market value of the firm, although the net impact of technology spillovers are positive because they can significantly increase the return to the firm's own R&D efforts. Many of the negative signs on foreign R&D are for countries that are technological leaders, such as the United States, who likely have less to learn from foreign knowledge spillovers. Thus, our results raise the possibility that such competitive effects can occur at the national level as well, and should be included in the model.

5. Conclusion

In the past decade, most scholars and policy makers concluded that foreign knowledge spillovers, just as domestic innovative activities, have positive impacts on national economy. Our work reveals that this notion is not universal, but rather context-sensitive.

We find that, in a group of interdependent economies, some countries enjoy more benefit than others, and some economies may suffer negative effects from international knowledge spillovers.

Although our work provides evidence to shed doubts on the generally accepted belief that each country can benefit from both internal and external sources of innovation, more research is needed to provide a comprehensive explanation. In a group of interdependent economies, knowledge spillovers act as a “double-edged sword.” Knowledge spillovers can increase the productivity of domestic research by enlarging the knowledge pool available for further R&D, and can be used in the production process. Meanwhile, knowledge spillovers also signify the foreign competition that has to be confronted.

The key question, therefore, is whether the positive effects of knowledge spillovers dominate or are dominated by the competitive effects of foreign R&D. Separate identification of each effect is not only of interest to economists, but also has important policy implications. Technology spillover and competitiveness at national level are likely influenced by purposive institutional arrangements and strategic policy initiatives. Differences in policy are thus one possible source for differences in the coefficient of foreign R&D across nations. Not only might inclusion of the appropriate policy variables into CH’s basic model help to identify the magnitudes of negative and positive spillovers, but it may also serve as a useful guide to policymakers desiring to make better use of such spillovers. Thus, rather than viewing our results as a definitive conclusion as to the effect of knowledge spillovers on economic growth, we prefer to see the results as demonstrating the need for additional work to investigate the factors that aid countries in absorbing knowledge spillovers.

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