International Trade and Economic Growth:
A Possible Methodology for Estimating Cross-Border R&D Spillovers

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I. Introduction

The Bureau of Economic Analysis (BEA) has initiated a National Science Foundation (NSF) funded project to produce an official BEA/NSF R&D Satellite Account (R&DSA).[1] The R&DSA differs from the National Income and Product Accounts (NIPA) in that R&D is capitalized and allows for the estimation of R&D's contribution to economic growth. The research BEA R&DSA (Fraumeni and Okubo, 2004 and forthcoming), which is the starting point for the BEA/NSF project, does not contain an international discussion regarding cross-border trade in R&D services or cross-border R&D spillovers.[2] Cross-border trade in R&D services was not included in the research R&DSA satellite account as estimates are not available for many of the years covered in the study (1961-2002).[3] Cross-border R&D spillovers were not included because further research was needed to estimate the size of these spillovers. Towards that end, this paper is an initial step in developing a possible trade-based methodology for estimating cross-border spillovers. Reaction to and analysis of our proposed methodology will be important factors in the overall decision of whether cross-border R&D spillovers are incorporated into the official BEA/NSF R&DSA. Given an affirmative decision, further consideration will be given regarding how spillover estimates are formally integrated into the base case or an alternative scenario. Subsequent papers will review other possible approaches to estimating cross-border R&D spillovers.

Literature demonstrating the critical linkages between economic growth, domestic R&D capital, and foreign R&D capital has abundantly grown over the past 25 years, largely as a result of improved modeling techniques and the availability of micro-level data sources. The globalization of national economies and nascent technological connectivity of international businesses has resulted in a world in which a country's economic growth is dependent upon its own, as well as foreign, R&D investment. We

[1] Satellite accounts provide a framework linked to the central account which enables attention to be focused on a certain field or aspect of economic and social life in the context of national accounts; examples are satellite accounts for travel and tourism and household production.
[2] Spillovers are the impact on non-performers of R&D.
[3] BEA is the source of data for trade in R&D services. For a description of the data available from BEA, see Borga and Mann (2003).

have classified the channels of transmission of international R&D spillovers into one of three categories—international trade, multinational corporations (MNCs) and foreign direct investment (FDI), and international knowledge and ideas.

Much of the literature regarding international trade as a transmission channel highlight very specific areas of trade and productivity relationships, such as measuring the volume of trade, capital vs. non-capital goods trade, the importance of intermediate vs. final goods trade, and relative country sizes. The literature exploring the dynamics of MNCs and FDI as transmission channels emphasize the existence of three transmission sub-channels provided by MNCs and FDI: domestic firms learning efficiency-enhancing productivity techniques from MNCs ('demonstration effect'), competition from MNCs resulting in improved productivity from affected domestic firms ('competition effect'), and the highly skilled staff movements from MNCs to domestic firms (Gorg and Strobl, 2001). Finally, the literature discussing international knowledge flows considers nations' geographic distance relative to one another and how distance affects the prominence of spillovers among nations, whether through trade, FDI, or individual contact (Keller, 2002). Many authors also view patent citations or patent licensing as determinants for capturing the externalities associated with knowledge flows (Al-Azzawi, 2004).

The objective of this paper is to present a possible methodology for estimating cross-border R&D spillovers by considering the literature on country-level effects.[4] In Section Two, the paper discusses the evolution of a methodology for quantifying international R&D spillovers with respect to the international trade channel of transmission. In Section Three, the quantitative estimates will be presented, which could then be considered for possible incorporation into the R&DSA. To accomplish this task, an in-depth assessment of the underlying econometric models that capture R&D spillovers through international trade will be provided. Thus, it is necessary to be mindful of the following considerations:

- The key elements which underlie international trade as a channel of transmission and, specifically, how such elements interact.

[4] The impact of cross-border R&D spillovers at the firm level could be to hasten exit by less productive firms or to raise the productivity of all firms. This paper focuses on country-level effects because of the potential difficulty of generalizing from firm-level analysis to country-level effects. Firm level analyses are of interest however, if they might lead to significant different conclusions from the studies reviewed in this paper.

- The portion of economic growth, typically measured by total factor productivity, explained by the econometric estimates of foreign R&D spillovers.
- The lack of consensus throughout the literature from the empirical findings and techniques for the presence of spillovers through trade.[5] Given the large body of literature, this paper will review those trade-based models commonly accepted as highly effective for capturing spillovers.

While there are several methods for estimating the relationship between economic growth and international R&D spillovers (all of which depend on the empirical technique and model assumptions), the majority of models compare total factor productivity (TFP) elasticities with domestic and foreign R&D. These models enable us to effectively determine the relative degree of foreign and domestic sources of technology (Keller, 2004). Section Four concludes by discussing future research plans.

II. Modeling International Trade Spillovers

While much of the pre-1990s literature focused on the benefits to economic growth derived from domestic R&D, later findings suggests that nations' growth is directly linked to both its domestic R&D investment as well as to the R&D capital stocks of its trade partners. In an extensive survey paper, Nadiri (1993) documented substantial increases in international technology trade among the OECD countries and the subsequently rapid diffusion of new technology. This paper undertakes a review of the trade spillovers model based on Grossman and Helpman's (1991) work on innovation and growth, in which they incorporate R&D-based endogenous technological change.[6] Coe and Helpman (1995, hereafter CH) derived a simplified version of the model to test for international R&D spillovers among OECD countries and were succeeded by numerous economists who, in time, modified the model. Finally, it is important to note that the following model was drawn from developed country samples. This is so because domestic R&D data in many relatively poorer or developing nations is difficult to obtain.

For their study of 21 OECD countries plus Israel from 1971-1990, CH used a relatively simple single equation regression model based on the work of Grossman and

[5] Keller concludes that the empirical results are disparate and should be agglomerated and quantified (Keller, 2004). Additionally, he suggests that there is still a large knowledge gap with regard to how strong diffusion is through embodied technology in intermediate goods versus other imports.

[6] The selection of this model follows a comparative study conducted of existing spillover models.

Helpman. They related total factor productivity to both foreign and domestic R&D and estimated a quantitatively large and positive effect from their import-weighted foreign R&D variable. Their simplest specification took the form:

$$\log F_{it} = \alpha_i + \alpha^d \log S_{it}^d + \alpha^f \log S_{it}^{f-CH} + \varepsilon_{it} \,, \tag{1}$$

where F_{it} is TFP, i = 1,…., 22 is a country index, $t = 1,\ldots, 20$ is a time index (1971-1990), S_{it}^d is domestic R&D capital (the aggregation of domestic R&D expenditures), and α_i is a country-specific constant. S_{it}^{f-CH} is the import-weighted foreign R&D stock, which constrains the impact of foreign R&D to be identical for all countries, denoted as

$$S_{it}^{f-CH} = \sum_{j \neq i} \frac{m_{ijt}}{m_{it}} S_{jt}^d \,, \tag{2}$$

where m_{ijt} is the import flow of goods and services of country i from j, m_{it} is total imports of country i from its 21 trade partners, S_{jt}^d is the domestic R&D stock of trade partners.[7] This equation indicates that the more country i imports from countries with a relatively high R&D expenditure, the more R&D spillovers country i will receive, ceteris paribus.

Their second specification allows the impact of domestic R&D to differ between the G-7 and non G-7 (or remaining) economies. CH interact the domestic R&D stock with a dummy variable valued at 1 for the G-7:

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[7] The R&D stock data, which is used by other authors, including Xu and Wang, may be misestimated. The R&D deprecation rate is set by Coe and Helpman at 5 percent; the R&D depreciation rate used in Fraumeni and Okubo varies from 11 to 20 percent. In addition, Coe and Helpman do not assume that there is either a gestation or application lag, e.g., they assume that all R&D is completed in the year it is initiated and that benefits begin to accrue to performers and non-performers in that same year. Fraumeni and Okubo employed a one-year lag to capture both effects and are examining as part of the BEA/NSF project whether this is the appropriate lag structure and whether the benefit stream from R&D might be lumpy. Spillovers should be assumed to occur with lags if there is a gestation or an application lag. The lag and benefit stream might differ for cross-border spillovers from that for domestic spillovers or for performers of R&D.

$$\log F_{it} = \alpha_i + \alpha^d \log S_{it}^d + \alpha^{G7} G7 \log S_{it}^d + \alpha^f \log S_{it}^{f-CH} + \varepsilon_{it} \quad . \tag{3}$$

Their final specification drops the constraint in (1) and (3) with respect to S_{it}^{f-CH} and interacts an import share effect with the foreign R&D capital stock. CH note that this technique allows for country-specific, time-varying elasticities on foreign R&D. The specification is noted as

$$\log F_{it} = \alpha_i + \alpha^d \log S_{it}^d + \alpha^{G7} G7 \log S_{it}^d + \alpha^f \left(\frac{m_{it}}{y_{it}} \right) \log S_{it}^{f-CH} + \varepsilon_{it} \quad , \tag{4}$$

where $\frac{m_{it}}{y_{it}}$ is a country's ratio of total imports to gross domestic product (GDP).

CH established that foreign R&D has a potentially larger effect on domestic productivity, as a measurement of total factor productivity, the greater the domestic economy is open to international trade and that domestic R&D has a significantly higher impact on TFP the larger the country's GDP (for example, the G-7 countries have much larger estimated elasticities of TFP regarding their domestic R&D). Letting $m = \frac{m_{it}}{y_{it}}$, CH estimated $\alpha^f m$ as 0.294—the elasticity with respect to the share of imports in GDP in equation (4), which indicate quantitatively large R&D spillovers, and an R^2 of 0.651.[8]

Significant modifications of the CH framework were made by other economists, with particular regard to the S_{it}^f specification. Keller (1998) argued that import shares are not paramount in the construction of the S_{it}^f variable. In his estimation, he utilized

[8] Since the computed t-value indicate the error correction terms are significantly different than zero and stationary, the equations are considered to be cointegrated. Edmonds (2001) enumerated concerns beyond the scope of this paper regarding CH's, Keller's, and LP's results being sensitive to the estimation methodology. Given the relevance of heterogeneous slope coefficient specification, Edmonds suggested that some attention be given to alternative group mean estimation results. Edmond's conclusion was that models derived from the CH approach are subject to misspecification, unable to reject a spurious regression null, or yield coefficient signs which are sensitive to whether one utilizes pooled or group mean estimations. Keller's models passed Edmond's panel cointegration tests and his group mean estimation approaches appeared relatively robust. However, Edmond's suggested CH and LP reevaluate their panel cointegration approaches and consider utilizing the more robust pooled FM or panel ARDL methods. These methods would serve to decrease the bias in estimating their long-run parameters.

randomly created shares instead of S_{it}^{f} and the estimation yielded similarly high coefficients as in the CH study. Keller utilized a methodology he denotes as 'counterfactual estimation', in which his models consist of Monte-Carlo experiments where the CH regressions are repeated with foreign knowledge stock variables. These variables were then computed based on counterfactual (simulated) trade patterns.[9] In comparison to CH's estimation results, Keller established that his simulated foreign knowledge stock variable better explained part of the variation in TFP levels. Specifically, Keller's $\alpha^{f} m$ is 0.329 and R^2 is 0.747 for equation (4), compared to CH's $\alpha^{f} m$ of 0.294 and R^2 of 0.651, indicating CH's import shares are not essential to ascertain their results.[10] Keller's estimates also performed better in equations (1) and (3).

Additionally, Keller computed international R&D spillovers given that S_{it}^{f-CH} was simply the unweighted sum of foreign countries' R&D stocks, denoted

$$S_{it}^{f-CH} \Rightarrow \overline{S}_{it}^{f} = \sum_{h \neq i} S_{ht}^{d} \,. \qquad (5)$$

Obviously, with the absence of share-weighted domestic R&D stocks, trade patterns do not affect the S_{it}^{f} variable. Keller found that the R&D stocks yield significantly higher R&D spillover estimations—α^{f} is 0.335 compared to CH's 0.294 in equation (4). Also, utilizing S_{it}^{f} as an unweighted variable resulted in higher $R^2 s$ than those from all three of CH's equations. His conclusion confirms that international trade plays a role in embodied technological diffusion, but measuring the magnitude of R&D spillover's relation to international trade patterns should take place in a model where trade-unrelated technology diffusion can occur simultaneously.[11]

[9] The complete methodology is explained in Keller (1998) on page 1476.

[10] Coe and Hoffmaister (1999) dispute these findings, claiming that Keller's random weights are effectively simple averages with a random error.

[11] Here, Keller alludes to the importance of the distinction between embodied vs. disembodied knowledge flows. While the two terms connote varying meanings throughout the literature, in this paper embodied technological diffusion represents how new technology physically diffuses through the purchases of goods and services by country A from country B. Disembodied technological diffusion represents country A's generation of new ideas from country B without country A purchasing country B's goods or services.

Other economists have made further strides regarding the impact to productivity from R&D spillovers. Lichtenberg and van P. Potterie (1998, hereafter LP) advanced the literature by finding that the CH weighting scheme is subject to an aggregation and indexation bias. They contend that, given CH's S_{it}^{f-CH} specification, if nations merge, there would always be an increase in the stock of foreign R&D (see equation (2)). Their alternative measurement is

$$S_{it}^{f-LP} = \sum_{j \neq i} \frac{m_{ijt}}{y_{jt}} S_j^d \quad , \tag{6}$$

where y_{jt} is country *j's* GDP. This measurement considers the percentage of imports from country *j* to country *i* with respect to the GDP of country *j* (the scale factor). LP finds this measure particularly useful because it eliminates the aggregation bias while reflecting the direction and intensity of R&D spillovers.

Additionally, LP attempted to improve CH's statistical methodology. LP noted that due to the presence of fixed country effects, CH's S_{it}^{f-CH} variable would be imprecise because CH measure S_{it}^{f-CH} as index numbers (1985=1, or $S_{i,1985}^{f}$ =1) and multiply them by the import share $\frac{m_{it}}{y_{it}}$.[12] LP contend that this term cannot be added into the country-specific constants because it is not time invariant.[13] By taking equation (4) and expressing the explanatory variables as levels instead of indices, the estimated coefficient of the foreign R&D stock becomes 0.004 (S.E. 0.004) as opposed to CH's estimate of 0.294 (S.E. 0.041). This result indicates an indexation bias in CH's model, in which the impact of the foreign R&D capital stock on TFP, as measured by CH, is misspecified.

To correct for this misspecification, LP created a reformulated version of equation (4) denoted as

[12] Fixed country effects are time-invariant parameters representing the unique characteristics of countries that affect TFP independently of R&D stocks.
[13] LP elaborate on this issue on pages 1486-1487.

$$\log F_{it} = \alpha_i + \alpha^d \log S_{it}^d + \alpha^{G7} G7 \log S_{it}^d + \alpha^f \left(\frac{m_{it}}{y_{it}}\right) \log S_{it}^{f-LP} + \alpha^m \left(\frac{m_{it}}{y_{it}}\right) + \varepsilon_{it} \qquad (7)$$

in which the import share $\frac{m_{it}}{y_{it}}$ is added as an additional regressor which avoids establishing restrictions on the productivity elasticities. In LP's estimation of equation (7), utilizing equation (6) as the scale factor, they found a relatively higher (than CH's) foreign R&D elasticity α^f of 0.310 and an R^2 of 0.700. However, the import share elasticity α^m of –2.768 indicated that import share has a negative relationship with TFP, which is offset by the foreign R&D variable. The conclusion here is that both the CH and LP specifications demonstrate the more open an economy is to trade, the more it will benefit from foreign R&D. However, LP further show that the intensity of imports, as measured by $\frac{m_{it}}{y_{it}}$, matters less than the distribution of the originating countries and that foreign R&D's impact on TFP will increase with increased exports from R&D intensive countries. LP developed significant improvements, in correcting for the model's aggregation and indexation biases, still, future economists would find additional techniques to advance the model.

Xu and Wang (1999, hereafter XW) found that CH estimated the impact of spillovers embodied in trade flows and did not control for disembodied trade flows. As a result, their study focused on the importance of trade in capital goods and international R&D spillovers for 21 OECD countries over the 1983-1990 period.[14] Sveikauskus (2004) considers XW's contribution particularly insightful because of the range of potential channels they assess as well as the specific information regarding rates of return.[15]

XW's model includes a measure of the domestic R&D capital stock, the R&D transmitted through capital goods, and the disembodied flow of information. Based on equation (4), they undertook a comprehensive quantitative assessment of CH's and LP's

[14] The sample countries are the same as those utilized by CH and LP, however, the period is different because bilateral capital goods data are available after 1983.
[15] See Section III: Estimating Cross-Border Spillovers.

approaches separately, while specifying capital goods imports, instead of total imports, as the weight variable for both approaches. XW contend there are two reasons to separate capital from non-capital goods in these models. First, capital goods contain higher elements of technology and, therefore, are the primary goods which convey R&D spillovers within trade flows. Second, XW demonstrate that the portion of capital goods among total imports is highly volatile.

They conclude that trade in capital goods is a significant source of R&D spillovers in OECD countries. Using a levels approach similar to LP, XW's capital goods-weighted foreign R&D variable S_{it}^{f-CH} increases the goodness of fit of the CH model. Again, the R^2 in CH's model was 0.651, while the R^2 in the XW approach was 0.771 (although CH's elasticity coefficient $\alpha^f m$ was 0.294 compared to XW's 0.245). Additionally, XW's variable performed better than Keller's R^2 of 0.747. When XW weighted their foreign R&D variable by non-capital goods imports, domestic R&D spillovers were not different from zero.

These results must be mitigated by the reality that international linkages are established outside the channels of trade, as Keller suggests. Therefore, XW controlled for non-trade spillover channels, specifically by adding unweighted, distance-weighted, human capital regressors into equation (3).[16] They also added the import intensity variable $\frac{m_{it}}{y_{it}}$ as a regressor to control for the presence of any trade-related disembodied knowledge spillovers which were not captured by their unweighted variable. When XW implemented LP's weighting scheme and levels approach in equation (3), while separately controlling for these variables, they found in all cases that the elasticity of productivity α^f is highly reduced, yet remains statistically significant. The goodness of fit, however, remains generally the same for all the tests.

The coefficient α^f declined the most—to 0.068—when controlling for the unweighted, human capital, and import intensity variables in the following equation:

[16] The unweighted variable equals the sum of R&D capital stocks of all other OECD countries in the sample, similar to the approach taken by Keller in equation (5). The human capital variable equals average years of school attainment measured by Barro and Lee (1996). The distance-weighted variable is a measurement of foreign R&D spillovers weighted by the inverse of geographic distance. XW further specify the calculations for the distance variable on page 1266.

$$\log F_{it} = \alpha_i + \alpha^d \log S^d_{it} + \alpha^{G7} G7 \log S^d_{it} + \alpha^f \log S^{f-LP}_{it}(KM) + \alpha^{uw} \log S^f_{it}(UW) + \alpha^h \log H_{it} + \alpha^m \left(\frac{m_{it}}{y_{it}}\right) + \varepsilon_{it}, \quad (8)$$

where $\log S^f_{it}(UW)$ is the unweighted variable and $\log H_{it}$ is the human capital variable. The coefficients on the unweighted, human capital, and import intensity variables in equation (8) all were insignificant.[17]

It can be concluded that XW offer a more insightful look into the factors impacting productivity with respect to foreign R&D spillovers than their predecessors because, as equation (8) shows, they control for the disembodied variables specifically through the testing of capital goods trade against non-trade spillover channels. Based on these tests, XW's layered analysis points to the fact that the significance of foreign R&D spillovers embodied in trade can be overestimated if one does not control for disembodied spillovers.

III. Estimating Cross-Border Spillovers

Our approach is a very generalized treatment of cross-border R&D spillovers. Based on the premise that R&D "produces" spillovers, the goal is to include calculated outward and inward spillovers in GDP, similar to the way exports and imports of goods and services are included in GDP. Accordingly, spillovers from the US to other countries (outward spillovers) should be added and spillovers from other countries to the US (inward spillovers) should be subtracted from GDP. A possible methodology for constructing "net outward spillovers" utilizes XW's elasticity figures.

XW calculated the estimated elasticities of TFP in the 21 sample countries with respect to the stock in the G7 countries.[18] The following formula represents α_{ij}, the elasticity of country *i's* TFP with respect to the domestic R&D capital stock of country *j* (the elasticities are presented in tables 1 and 2):[19]

[17] The import intensity variable may be picking up the impact of other unspecified variables, such as distance, language, similarity in tastes, and costs of trade.
[18] The results are found in table 5 on page 1269.

$$\alpha_{ij} = \frac{\partial \log F_i}{\partial \log S_j^d} \quad \Rightarrow \quad \left[\frac{\alpha_{km}^f \partial \log S_i^f (KM)}{\partial \log S_j^d}\right] + \left[\frac{\alpha_{uw}^f \partial \log S_i^f (UW)}{\partial \log S_j^d}\right]$$

$$\Rightarrow \quad \alpha_{km}^f \left[\left(\frac{M_{ij}}{Y_j}\right)\left(\frac{S_j^d}{S_i^f (KM)}\right)\right] + \left[\frac{\alpha_{uw}^f S_j^d}{S_i^f (UW)}\right] \tag{9}$$

In order to estimate cross-border spillovers, we algebraically reorganized XW's rate of return equation to:

$$r_{ij} = \frac{\partial Y_i}{\partial S_j^d} = \alpha_{ij} \frac{Y_i}{S_j^d} \quad \Rightarrow \quad r_{ij} S_j^d = \alpha_{ij} Y_i \tag{10}$$

where r_{ij} equals the rate of return in country *i* on R&D investment in country *j* and Y_i is GDP in country *i*.[20] Given this formulation, $r_{ij} S_j^d$ represents the nominal dollar value of cross-border spillovers to country *i* from country *j*.

Outward Spillovers

Table 1
OECD Country Elasticities of TFP with respect to R&D Capital Stocks in the U.S., 1990

Japan	0.0844	Austria	0.0399	New Zealand	0.0632
Germany	0.0515	Belgium	0.0407	Norway	0.0538
France	0.0536	Denmark	0.0471	Portugal	0.0367
Italy	0.0416	Finland	0.0470	Spain	0.0468
U.K.	0.0539	Greece	0.0383	Sweden	0.0517
Canada	0.0927	Iceland	0.0584	Switzerland	0.0430
Australia	0.0678	Netherlands	0.0461		

Source: Xu and Wang (1999). Based on equation (8) and (9).

[19] These elasticities are overall elasticities computed using equation (9), including both the imported capital goods channel effect and the unweighted trade R&D stocks effect. The average over all countries elasticity corresponding to Table 1 is the sum of the imported capital goods channel effect estimate of .0260 and the unweighted trade intensity channel effect .0353. A split between these two effects is not available in XW on a country-by-country basis.

[20] This rate of return formula was also used in Coe and Helpman. In this equation, the elasticity of country *i* productivity with respect to country *j* R&D capital stock is multiplied by the GDP of country *i* (Y_i) to convert the results from a percent to a level change in GDP. A percent change in productivity transmits one-to-one to a percent change in GDP.

Outward spillovers are an item for which there may be no remuneration, for example, those benefiting from spillovers may receive them at zero cost.[21] Inclusion in GDP of cross-border flows for which there is no remuneration already occurs in NIPA.[22] These are monetary sums which are received by entities abroad without payment. The proposed treatment of outward spillovers is therefore applying a methodology already present in the accounts. Outward spillovers, just as exports, would be an addition to GDP in the same fashion that returns to nonprofit and general government performers are an addition to GDP in the R&DSA.

With the use of table 1, calculating cross-border outward spillovers was a three-step process. First, we multiplied each country's 1990 elasticity by its 1990 GDP to ascertain the cross-border spillovers it received from the U.S. For example, by multiplying Japan's TFP elasticity (0.0844) by its GDP (1990=$3,039.7 billion), we calculated $256.5 billion as Japan's cross-border spillovers.[23] Second, we summed all the cross-border outward spillovers, which totaled $686 billion and effectively represent the total nominal dollar value of spillovers to other countries from the US. Third, we calculated that total as a percentage of U.S. GDP, which was 11.83%.

Inward Spillovers

Table 2
U.S. Elasticities of TFP with respect to R&D Capital Stocks in OECD Countries, 1990

	Japan	Germany	France	Italy	U.K.	Canada
U.S.	0.0493	0.022	0.0106	0.0039	0.0167	0.0134

Source: Xu and Wang (1999). Based on equation (8) and (9).

If we apply the Fraumeni-Okubo assumption that all spillovers accrue to business, inward spillovers are already part of GDP. Product and process innovations resulting from inward spillovers are reflected in profits from production using these innovations.

[21] Beneficiaries of spillovers may be paying for them through higher prices for imported goods or through payments for patents and royalty licenses. To the extent that the value of U.S. exports and imports already include these payments, care must be taken not to double-count when estimating the value of cross-border spillovers.
[22] For example, current government transfer payments to the rest of the world are included in GDP.
[23] GDP figures were obtained from the OECD.

Spillovers in the form of product and process innovations are embedded in goods and services produced in the United States. Inward spillovers, just as imports, would be subtracted from GDP.

With the use of table 2, calculating cross-border inward spillovers was also a three-step process. First, we summed all of the U.S. elasticities, which amounted to 0.1159. Second, we multiplied that figure by U.S. GDP (1990=$5,757.2 billion) to get $667.3 billion, which represents the total nominal dollar value of spillovers to the U.S. from other countries. Third, we calculated that total as a percentage of U.S. GDP, which was 11.50%. Therefore, given the 11.83% of U.S. GDP which comprises outward spillovers, the net outward spillover figure is 0.33%, which is well under the 1 percent addition to GDP from treating R&D performed by business as investment rather than intermediate input and the 1 percent addition to GDP from estimating private returns to R&D performed by nonprofits and general government. However, with further estimation of additional years of net outward spillovers, we expect to ascertain numerically significant figures which have important implications for how we treat international R&D spillovers going forward, particularly as part of the BEA/NSF R&DSA project.

IV. Conclusion

Our study evaluated four important methodologies used to estimate the impact of international R&D spillovers on economic growth. By comparative analysis, we selected XW as the most appropriate for undertaking the task of calculating net outward spillovers. Given their emphasis on examining embodied as well as disembodied channels of R&D transmission, XW presented the most cogent and convincing methodology for determining TFP elasticities.

As this research is in its initial stages, there are some limitations of our work. In future analysis, we expect to extend our scope in three important ways. First, and most essential, we will include other channels for capturing R&D transmissions, such as through MNCs, FDI, and international knowledge flows. Second, we will undertake a review of the estimation methodologies employed by the different authors. Finally, we will include the international R&D investment impact on factor intensities. XW stated from the outset that a limitation of their study was its lack of accounting for the response of factor intensities to R&D spillovers. Bernstein and Mamuneas (2000) address this issue with their examination of the overall elements that contribute to productivity growth. Their model estimations of TFP might serve as the framework from which our future analysis draws. Finally, although we are now approaching this research on a channel-by-channel basis, we also will investigate to see if some literature will allow us to examine several channels at once within a unified framework.[24]

[24] See for example Keller (2001).

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