International Technology Adoption, R&D, and Productivity Growth*

Seung Mo Choi Daniel Toro González Peter Gray

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Abstract

International knowledge diffusion is considered an important source of productivity growth. However, direct observations on such diffusion have not been available at the macro level. We analyze novel data on international technology trade. Our empirical analyses indicate a positive association between payments for international technology adoption and the growth of labor productivity. Those payments appear to be a stronger contributor than research and development (R&D) investments for a large group of economies. For economies with high productivity, technology adoption payments tend to be complementary to R&D investments.

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I. INTRODUCTION

In growth accounting, cross-country differences in measured inputs, such as human capital and physical capital, account for only a small part of the differences in output (see Barro and Sala-i-Martin (2004), Chap. 10). The unexplained residual in growth accounting is likely to include the accumulation of knowledge useful for production. Numerous studies document that international knowledge diffusion could explain how some economies achieved faster economic growth. See, for example, Parente and Prescott (1994), Parente (1995), Eaton and Kortum (1996, 1999, 2001), Comin and Hobijn (2004, 2010), Klenow and Rodríguez-Clare (2005), and Foster and Rosenzweig (2010). However, the unavailability of direct observations on international knowledge diffusion often makes the studies difficult.

Economists adopt two alternative approaches. First, they make assumptions about certain properties of diffusion in theoretical models. For example, Klenow and Rodríguez-Clare (2005) assume that benefits from diffusion depend on the economy's productivity relative to that of the frontier economy. Second, economists study data that are imperfectly correlated with diffusion. For instance, Comin and Hobijn (2010) study per-capita indices consisting of the length of railway line, the number of mobile phones, etc., as proxies for diffusion. Caselli and Wilson (2004) study the data on equipment trade. Peri (2005) and Eaton and Kortum (1999) analyze international patent data.

This paper analyzes a novel dataset on technology trade, so it falls into the second approach. However, our dataset has several advantages. Compared to Comin and Hobijn's (2010) indices, our technology trade is a relatively direct and comprehensive measure of an economy's effort to adopt foreign knowledge. While Caselli and Wilson's (2004) equipment trade is only an indirect measure of international knowledge diffusion, our technology trade is a direct measure.

Compared to Peri's (2005) and Eaton and Kortum's (1999) patents, our technology trade includes not only the purchase or sale of patents but also transactions regarding other forms of knowledge not patented.

Technology trade data are maintained by OECD (2011). In OECD (1990) definitions, technology trade consists of two variables: technology adoption (TA) payments and technology export (TE) receipts. TA payments are the economy's expenditure for the acquisition of foreign technologies. Just as investments for research and development (R&D) measure the dollar amount invested in domestic research to raise productivity, TA payments measure the amount that an economy pays to foreigners for the same purpose. TE receipts are their counterpart, i.e., the dollar revenues the economy receives from the sale of knowledge. Specifically, technology trade includes the sale, purchase, or licensing of;

(i) patents,

(ii) invention and know-how (i.e., "ideas" not patented),

(iii) trademarks, including franchising,

(iv) patterns and designs, of industrial character only, excluding, for example, those of purely artistic nature,

(v) services with technical content, (e.g., staff training, reassignment of technicians, consultancy services, assistance for quality control and trouble-shooting, technical studies, or engineering work required for design and preparation of industrial projects), and

(vi) finance of industrial R&D outside the economy (e.g., financial flows between unrelated firms for joint R&D, or from multinationals to subsidiaries to finance R&D).

Only monetarily compensated transactions are included. For example, technology transfers through foreign direct investments that do not involve a flow of receipts or expenditures are excluded.

This paper characterizes international knowledge diffusion by analyzing technology trade data. While some studies address the roles of TA payments in productivity growth, most of them are at a micro level. For example, Basant and Fikkert (1996) analyze a database of Indian firms, finding that private returns to technology purchases were higher than returns to firms' own R&D investments. Other micro-level studies include Hines (1995), Katrak (1997), Aggarwal (2000), Hagspiel, Huisman and Nunes (2010), Ray (2010), Akcigit and Kerr (2010), and Huang, Arundel and Hollanders (2010). However, these studies do not provide clear macro-level implications. An exception is Hahn (1995), whose analysis provides macro-level implications. However, Hahn's (1995) observations are limited to two economies, Japan and Korea. This paper's scope of analysis is wider, providing estimation results not only on the impacts of TA payments and R&D investments, but also on their roles as substitutionary or complementary inputs.

Our empirical analyses indicate a positive association between TA payments and the growth of labor productivity. TA payments appear to be a stronger contributor than R&D investments for a large group of economies. For the economies with higher productivity, TA payments tend to be complementary to R&D investments. Hence, adoption of foreign technologies could be subsidized to increase the returns from R&D. For lower-productivity economies, TA payments and R&D investments are relatively substitutionary. Hence, governments can consider lowering barriers to importing knowledge to facilitate productivity growth, provided if TA payments are less costly than R&D investments.

The structure of this paper is as follows. Section II presents descriptive analyses for technology trade data. Section III presents the empirical analyses to explore the effects of TA payments and R&D investments on productivity growth. Policy implications are also discussed. Section IV presents the conclusion.

II. DESCRIPTIVE STATISTICS

We consider 28 economies with observations for TA payments and R&D investments for the period 1981-2008. The data for R&D investments and TA payments are obtained from the OECD (2011). Throughout the paper, the data for all other variables are from World Development Indicators unless otherwise noted. In the data, the resources devoted to technological advances have grown substantially. In 1981, R&D investments, on average, were 1.5% of the gross domestic product (GDP). The ratio increased to 2.0% by 2008. For TA payments, the increase is even greater: from 0.2% to 1.2%.

A. Technology Trade and Relative Productivity

The ratio of TA payments to R&D investments can be interpreted as an indicator of an economy's relative dependence on foreign technologies in raising productivity. We expect the economies that are not at the productivity frontier to be relatively more interested in purchasing foreign technologies than in domestic R&D investments.

To see this, we consider labor productivity, obtained by dividing the GDP by total employment. An advantage of this measure over total factor productivity is that labor productivity is more readily available in the data and it is easier to calculate without assumptions about the capital income share. According to Klenow and Rodríguez-Clare (1997), the correlation between the logs of labor productivity and of total factor productivity across economies is 0.93. Assuming that the United States (U.S.) is at the frontier of these technologies, we obtain relative labor productivity for economy i, A_i/A_F, where A_i is economy i's labor productivity and A_F is the U.S. counterpart.

In Figure 1, we observe a negative relationship between the ratio of TA payments to R&D investments and relative labor productivity, on average during 1981-2008. This relationship suggests that to increase labor productivity, economies further from the productivity frontier tend to spend less on R&D investments than on TA payments in proportional terms.

In Figure 2, the ratio between TA payments and TE receipts is on the vertical axis, and productivity relative to the frontier is on the horizontal axis. A lower level on the vertical axis reflects a higher technology balance of payments. The negative slope observed in the figure implies that higher-productivity economies are likely to have lower technology import to export ratios.

B. Technology Trade and R&D Investments

Part (A) of Figure 3 plots the relationship between R&D investments and TA payments as shares of GDP. There is only a weak relationship between them. This is because as in Figure 1, the relationship between them appears to be determined by the level of technologies relative to the frontier. In the figure, a 45-degree line represents the situation in which an economy spends the same amount of resources on purchasing foreign technologies and on developing its own. Economies below the 45-degree line represent those economies that spend more resources on R&D than on TA payments. Most economies fall into this category. An exception is Singapore, which is a small economy, depending more on TA compared to other economies at similar levels of R&D investments as a ratio of GDP.

Part (B) of Figure 3 plots R&D investments and TE receipts. A positive association implies that the economies performing R&D activities more intensively tend to be net exporters of technologies.

C. Technology Trade and Commodity Trade

Figure 4 plots commodity trade (the sum of imports and exports of goods and services) and technology trade (the sum of TA payments and TE receipts), as shares of GDP. The economies that have more commodity trade relative to GDP also have more technology trade relative to GDP. One interpretation is that producers in more open economies tend to use technology trade more intensively as a strategy to raise productivity to compete in global commodity markets. An alternative (but not exclusive) interpretation is that with more commodity trade, economies interact internationally, gaining a better understanding of technologies available in foreign economies.

D. Technology Trade and Educational Attainment

Educational attainment can be a determinant of the pattern of technology trade. Figure 5 plots the numbers of years of schooling for the population of persons more than 25 years old, obtained from Barro and Lee (2010), versus the ratio of TA payments to TE receipts. A negative association implies that the economies with higher stocks of human capital are likely to have higher net export ratios for technology.[1]

E. Technology Trade and Other Measures of International Knowledge Diffusion

Technology trade can be related to other measures of diffusion, such as international patent applications, foreign direct investment (FDI) flows, and trade in capital goods, as discussed in Eaton and Kortum (1996, 2001) and Comin and Hobijn (2004, 2010).

Figure 6 plots the relationship between international patent applications and technology trade. Part (A) plots the log of the number of patent applications of nonresidents against the log of TA payments in millions of U.S. dollars. These two measures of technology inflows are positively correlated. Part (B) plots the log of the number of triadic patent families to the log of TE receipts in millions of U.S. dollars. Here, triadic patents are a series of corresponding patents filed at the European Patent Office, the United States Patent and Trademark Office, and the Japan Patent Office, for the same invention, by the same applicant or inventor. These two measures of technology outflows are also positively, and relatively strongly, correlated.

Figure 7 plots FDI flows and technology trade. Part (A) plots the log of FDI inflows and the log of TA payments, both in millions of U.S. dollars. Part (B) plots the log of FDI outflows and the log of TE receipts. Both plots show positive associations, suggesting that FDI flows are associated with the flows of technologies.

[1] While we do not provide a further statistical analysis, it is also possible that subsidies to education (and other forms of human capital production such as on-the-job training and in-home training) can multiply the effects of R&D and TA, accelerating productivity growth. See Choi (2011) and James and Choi (2012) for a related discussion.

Finally, Figure 8 plots trade in capital goods versus technology trade. Part A plots imports of machinery and transport equipment and TA payments, both as shares of GDP. Part B plots their export counterparts. Positive relationships in both plots suggest that trade in capital goods is associated with technology trade. It appears likely that capital goods and improved technology are complementary, so if one is imported, the other should be as well, to maximize productivity growth per dollar spent.

F. Technology Investments and Labor Productivity Growth

Industry-level data are available for three economies: Germany, Italy, and Japan. The data for real labor productivity in 16 industries was obtained from the OECD Structural Analysis Database for the years 2000 to 2008. Figure 9 connects each of the three measures of technology investments as shares of GDP – R&D investments, TA payments, and their sum – to the real annual growth rate of labor productivity. This figure illustrates that each measure of technology investments and labor productivity growth are positively associated. It suggests that both R&D investments and TA payments can be inputs for labor productivity growth.

III. REGRESSION ANALYSES

This section provides regression analyses on how R&D investments and TA payments contribute to the growth of labor productivity, and whether they are substitutionary or complementary inputs to labor productivity growth. We also discuss policy implications.

A. Associations of R&D Investments and TA Payments with Productivity Growth

R&D investments may not reflect all activities that enhance productivity growth. For example, Griffith, Redding and Van Reenen (2004) suggest that "in addition to the conventional role of stimulating innovation, R&D enhances technology transfer." This subsection extends Griffith, Redding and Van Reenen (2004) by allowing economies to increase productivity directly with TA payments. For each economy i at the period t, we consider the following statistical model:

$$(1) \qquad \ln\left(\frac{A_{it+1}}{A_{it}} - 1 + \psi\right) = \alpha + \rho_1 \ln((R/Y)_{it}) + \rho_2 \ln((T/Y)_{it}) + \delta_1 \ln(A_{Ft}/A_{it})$$

$$+\delta_2 \ln\left(\frac{A_{Ft+1}}{A_{Ft}} - 1 + \psi\right) + \delta_3 X_{3it} + \delta_4 X_{4it} + \delta_5 X_{5it} + u_{it+1},$$

where:

A_{it}: labor productivity of economy i at period t, (that is, $A_{it} = Y_{it}/L_{it}$, where Y_{it} is real GDP and L_{it} is employment),

A_{Ft}: labor productivity of the economy at the frontier, assumed to be the United States,

$(R/Y)_{it}$: R&D investments, as a share of GDP,

$(T/Y)_{it}$: TA payments, as a share of GDP,

X_{3it}: years of schooling,

X_{4it}: openness to commodity trade,

X_{5it}: size of the economy; real GDP in trillions of U.S. dollars..

Here, ψ is a productivity depreciation rate. The value is assumed to be 0.4, taken from Benkard (2000). Later, we use ψ =0.15 (as in Guellec and van Pottelsberghe de la Potterie, 2001) as a robustness check. In addition, u_{it+1} is an error term, independent and identically distributed, following a normal distribution with mean zero, for all i and t.

In (1), the direct effects of R&D investments and TA payments (as shares of GDP) on productivity growth are measured by ρ_1 and ρ_2, respectively. Productivity growth before depreciation ($A_{it+1}/A_{it} - 1 + \psi$), as well as R&D investments and TA payments as shares of GDP ($(R/Y)_{it}$ and $(T/Y)_{it}$), are logged. Numerous studies use a Cobb-Douglas production function to describe the production of goods, productivity, etc. Equation (1) can be similarly understood as

$$\frac{A_{it+1}}{A_{it}} - 1 + \psi = ((R/Y)_{it})^{\rho_1}((T/Y)_{it})^{\rho_2} X_{it},$$

where X_{it} reflects all control variables and the error term, implying that productivity growth is "produced" with R&D and TA inputs with a Cobb-Douglas form. Later, we also estimate a variation of (1) with a linear form (i.e., without logarithms) to further implications.

The distance from the productivity frontier, captured by δ_1, reflects an observation that an economy with a different productivity distance against the frontier may grow at a different rate. For example, one may argue that an economy more distant from the frontier has a larger scope of imitating foreign technologies, and hence, will grow its productivity faster. The effects of the logarithm of the frontier's productivity growth (captured by δ_2), of years of schooling (captured by δ_3), of openness to commodity trade (captured by δ_4), and of the size of the economy (captured by δ_5) are also estimated in (1). Selecting these control variables is based on Section II's discussion on their correlations with TA payments, as well as the discussions provided by Griffith, Redding and Van Reenen (2004) and Ulku (2004).

Data sources are the same as in Section II. All estimations include time and country dummy variables. For example, country dummy variables help to alleviate concerns about country-specific characteristics driving both TA payments and productivity growth. Limited data availability in control variables limits the years to 1996 through 2007. To increase the number of observations, we include all economies even with missing observations for some years. There are 89 economies in the data.

Table 1 reports the results based on ordinary least squares. The first column lists parameters. The second column reports the results of estimation (1), but the control variables, other than productivities, i.e., years of schooling, openness to commodity trade, and the size of the economy, are excluded as a starting point. The third column reports the result of estimation of (1) without any variations. The fourth and fifth columns report the same estimations except that either R&D investments or TA payments are excluded from explanatory variables. This helps to understand the separate roles of R&D investments and TA payments in productivity growth. The sixth column reports the estimation of (1) except that (total) R&D investments are replaced by non-public R&D investments as a robustness check. This is motivated by Guellec and van Pottelsberghe de la Potterie's (2001) finding that business R&D is more important in productivity growth, compared to public R&D. The seventh and eighth columns report the estimation results of (1), separately for the "frontier group" and for "less productive economies." Here, the "frontier group" consists of the economies in the highest quintile of labor productivity in 1996-07. Table 1 provides a note with a list of the "frontier group" and "less productive economies."

Results show that for all specifications, TA payments as a ratio of GDP has a positive slope, which is significant at least at the 5% level. This suggests that TA payments contribute substantially to the growth of productivity. Interestingly, R&D investments as a ratio of GDP are not always significant, and they are even estimated to have a negative slope in some specifications. One possibility is that R&D investments are positively correlated with TA payments, and hence the association between R&D investments and productivity growth is captured by the association between TA payments and productivity growth. However, Figure 3, which we discussed in Section II.B, does not clearly show such a positive association. Furthermore, in the fifth column, explanatory variables, and R&D investments are still insignificant. Another, more plausible possibility, is that R&D activities are concentrated in the economies with high productivity. With 89 economies including emerging and developing economies, TA payments are a more significant contributor than R&D investments. Although in the seventh column, that reports the results for high-income economies only, R&D investments are still insignificant, an estimation result with an alternative regression equation, discussed later and reported in Table 3, implies that R&D investments are positive and significant for high-income economies.

Table 1 also suggests that openness to commodity trade has a negative slope. Section II illustrated that openness to commodity trade is positively correlated with TA payments as a ratio of GDP. Hence, it is possible that economies that are more open are likely to raise their productivity with TA spending. The size of the economy has mixed results. In a group of "less productive economies," larger economies tend to raise their productivity faster, possibly because there can be fixed costs (e.g., building up desired institutions) in productivity growth. Overall, for other specifications, such an observation is not valid. This may reflect the fact that as an economy's GDP grows over time, it is more likely to already have advanced technologies, so it becomes more difficult to increase productivity. Finally, productivity growth at the productivity frontier is negatively associated with economy i's productivity growth for some specifications. This result is counterintuitive because followers should have a wider scope for catch-up when the frontier productivity grows faster. However, the dataset spans only 12 years. For example, it is possible that in years when the U.S. (i.e., frontier) productivity growth was particularly low, for example, right after the collapse of the "IT bubble" in the early 2000s, emerging economies may have enjoyed faster growth through export-driven strategies.

Table 2 provides the results when ψ=0.4 is replaced by ψ=0.15, following Guellec and van Pottelsberghe de la Potterie (2001). The results are similar to those of Table 1.

While Tables 1 and 2 implicitly assume a Cobb-Douglas production function, we now consider a linear production function where R&D investments and TA payments are completely substitutionary. Our second statistical model is

$$(2) \qquad \frac{A_{it+1}}{A_{it}} - 1 + \psi = \alpha + \rho_1 (R/Y)_{it} + \rho_2 (T/Y)_{it} + \delta_1 (A_{Ft}/A_{it}) + \delta_2 \left(\frac{A_{Ft+1}}{A_{Ft}} - 1 + \psi \right)$$

$$+ \delta_3 X_{3it} + \delta_4 X_{4it} + \delta_5 X_{5it} + u_{it+1}.$$

Tables 3 reports the estimation results of (2), with ψ=0.4. Using ψ=0.15 provides identical results since this alternative value will be fully captured by a constant term, α. TA payments as a share of GDP are still positively associated with productivity growth, which is significant at least at a 10% level. An exception is for "less productive economies," but TA payments are only marginally rejected at a 10% level, with a p-value of 0.13. The fact that TA payments are significant in estimation of (1) but not in estimation of (2) for "less productive economies" may imply that decreasing returns to scale (with an estimate of the Cobb-Douglas parameter, ρ_2, between 0 and 1) is more appropriate for describing the contribution of TA payments to productivity growth.

For the "frontier group," Table 3 reports that both R&D investments and TA payments have positive slopes, significant at 10%. The fact that only TA payments are significant in Tables 1 and 2, while R&D investments and TA payments are both significant in Table 3, implies a possibility that the logs of these two variables are more closely correlated. Another possibility is that they are complementary rather than substitutionary in production of productivity growth, but our estimation of the constant-elasticity-of-substitution production function in the next subsection suggests that they are likely to be complementary.

Overall, our findings highlight the importance of TA payments as a share of GDP in productivity growth. In most specifications, the association between TA payments and productivity growth appears stronger. For "less productive economies," R&D investments are not significant, implying that they depend on other factors of productivity growth, including TA payments and education.

B. R&D Investments and TA Payments as Substitutes or Complements

In order to understand whether R&D investments and TA payments are substitutionary or complementary inputs in producing productivity growth, we adopt a constant-elasticity-of-substitution (CES) production function. That is, we consider:

$$\frac{A_{it+1}-A_{it}}{A_{it}} + \psi = C[\delta((R/Y)_{it})^{-\rho} + (1-\delta)((T/Y)_{it})^{-\rho}]^{-1/\rho} + u_{it+1}. \quad (3)$$

Here, ρ is a parameter determining the elasticity of substitution between the two inputs. If $\rho = -1$, the two inputs are perfect substitutes. A higher value of ρ implies stronger complementarity between the two inputs. The value $\rho = 0$ yields a special case of the Cobb-Douglas production function. As ρ goes to infinity, R&D investments and TA payments become perfect complements.

We assume $\psi = 0.4$, but using $\psi = 0.15$ does not substantially change the estimation results. Again, u_{it+1} is independent and identically distributed, following a normal distribution with mean zero, for all i and t. The coefficients of (3) are estimated using the nonlinear-least-squares method with country and year dummy variables. The dataset is the same as in Subsection III.A.

Table 4 summarizes the results. For the "frontier group," the estimate for ρ is 0.48, which is statistically significant at the 10% level. This suggests a complementarity between R&D investments and TA payments. That is, new technologies are produced with R&D investments, which become more productive if accompanied by TA payments. On the other hand, for "less productive economies," the estimate for ρ is -0.14. This implies that R&D investments and TA payments are more substitutionary in these nations than in the "frontier group." That is, the productivity growth that can be achieved by R&D investments can be alternatively achieved by TA payments.

C. Policy Discussion

A positive association between TA payments and productivity growth, as estimated in Subsection III.A, implies that restrictions on TA payments (such as those on technology licensing agreements) may reduce productivity growth. Better understanding of the relationship between R&D investments and TA payments will provide further insights into whether those restrictions should be removed. That is, if the two inputs are substitutionary (which is the case for "less productive economies" in Subsection III.B), then a tax or a restriction on TA payments may indirectly encourage R&D investments. This may negatively affect productivity growth if TA payments are more effective than R&D investments. On the other hand, if the two inputs are complementary (which is the case for the "frontier group" in Subsection III.B), then a tax or a restriction on TA payments may reduce the effectiveness of R&D investments as well.

This implies that a tax reduction or a subsidy on TA payments is likely to accelerate productivity growth in both groups. Our view is consistent with Basant and Fikkert's (1996) argument in a country-specific study of India, that taxing technology purchases is inefficient and likely to increase social costs. See Hines (1995) and Aggarwal (2000) for related policy discussions based on micro-level data.

A policy implication for international trade is that establishing and improving an international market for technology can accelerate productivity growth.

IV. CONCLUDING REMARKS

The patterns of technology trade are closely related to relative productivity, R&D investments, openness to commodity trade, educational attainment, patents, FDI flows, and the trade in capital goods. Our results suggest that TA payments contribute to the growth of labor productivity. They also suggest that R&D investments and TA payments become more complementary as productivity grows.

For economies that are not in the frontier group, TA payments appear to contribute more to productivity growth than R&D investments do. On the other hand, lower-productivity economies still perform some R&D activities. This result can be understood as increasing “absorption capacity” for imported technologies. On one hand, for less productive economies in the estimation of a CES production function, R&D investments appear to be substitutionary, not complementary, to TA payments. This does not support this “absorption capacity” argument. On the other hand, Figure 1 still illustrates an interesting relationship between R&D investments and TA payments according to the level of labor productivity. That is, an interpretation of Figure 1 is that for a lower-productivity economy, the amount of R&D investments required to absorb imported technologies is smaller. Thus, the simple CES production function that we estimated may be insufficient to capture a richer relationship between R&D investments and TA payments.

It will be interesting to study, in greater detail, how R&D investments are related to TA payments. See, for example, Griffith, Redding and Van Reenen (2004) for a related discussion.

Providing a better theoretical form of the productivity production function will also be useful. For example, one may separately obtain the social returns on R&D investments and on TA payments, comparing them to private returns to determine whether the government needs to correct the difference. The framework of Jones and Williams (1998) to estimate social returns on R&D investments can be a starting point.

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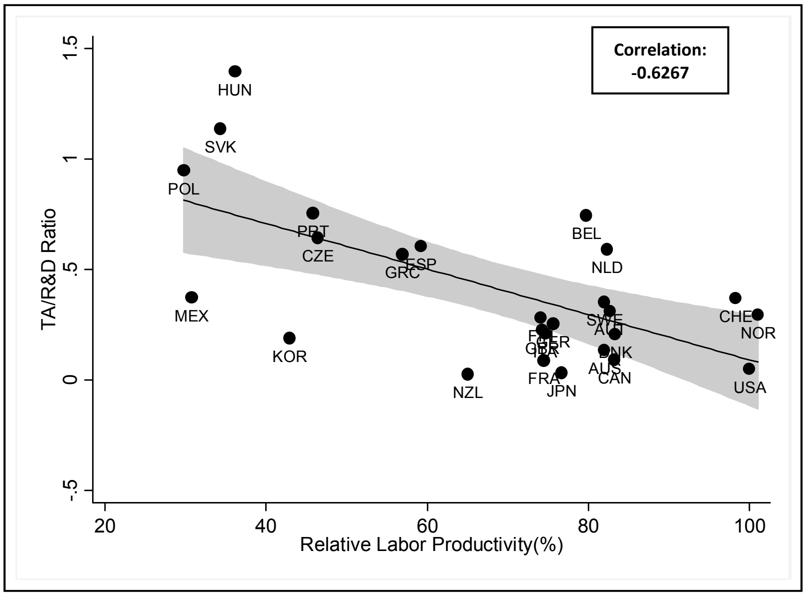
TABLES AND FIGURES

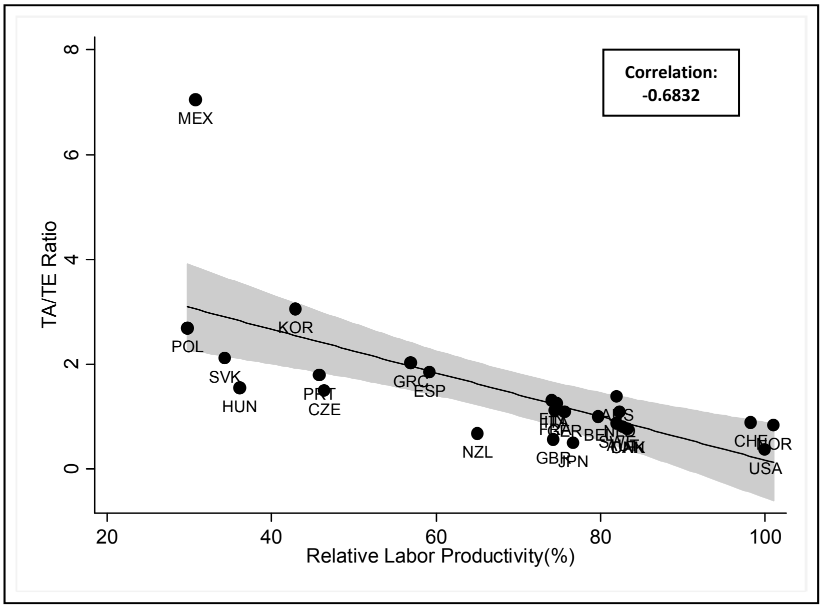
Figure 1
Labor Productivity Relative to the Frontier and TA/R&D Ratio
(Country Average, 1981-2008)



Note: The solid line is the adjusted linear regression line with a 95% confidence interval.

Source**:** SourceOECD and World Development Indicators.

Figure 2
Labor Productivity Relative to the Frontier and TA/TE Ratio
(Country Average, 1981-2008)

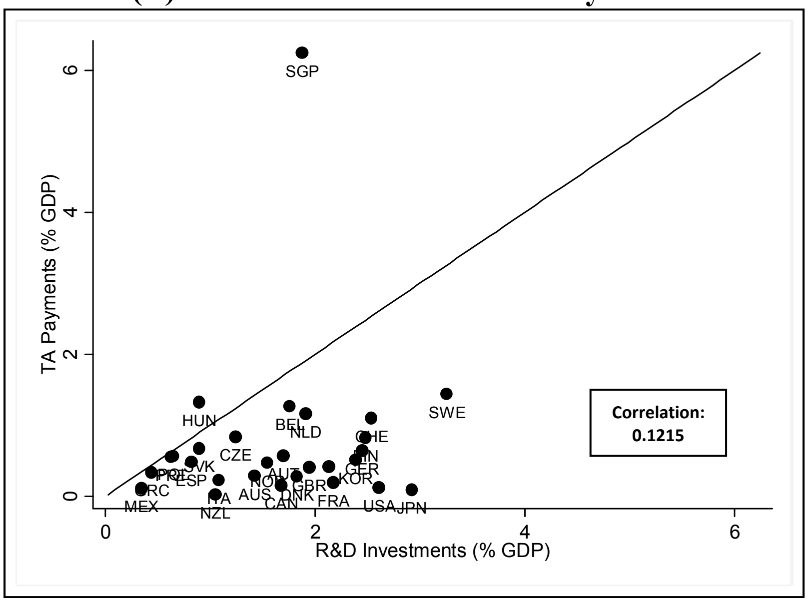


Note: The solid line is the adjusted linear regression line with a 95% confidence interval.

Source**:** SourceOECD and World Development Indicators.

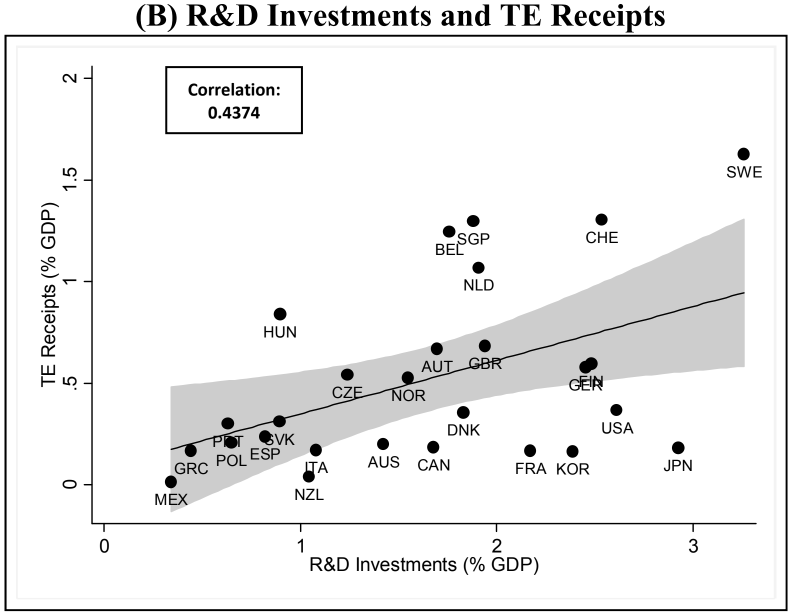
Figure 3
R&D Investments and Technology Trade
(Country Average, 1981-2008)

(A) R&D Investments and TA Payments



Note: Solid line represents a 45-degree angle.

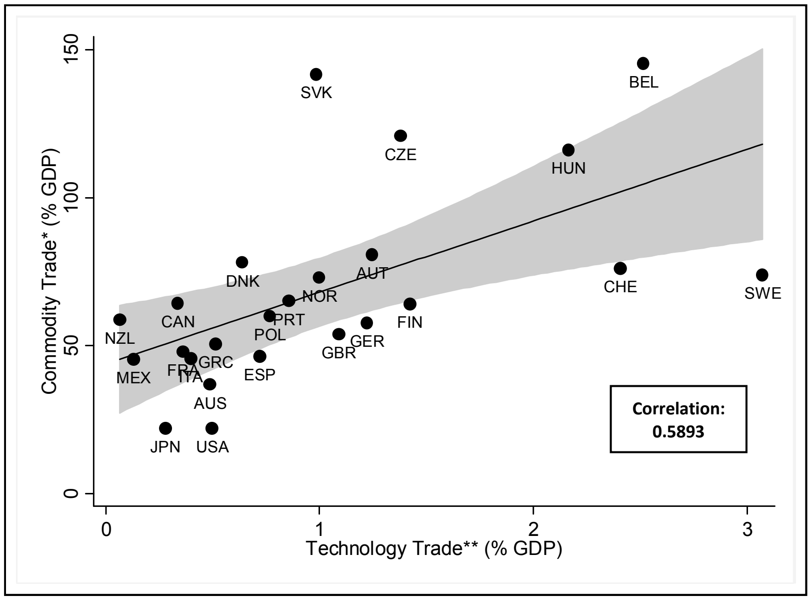
(B) R&D Investments and TE Receipts



Note: The solid line is the adjusted linear regression line with a 95% confidence interval.

Source**:** SourceOECD and World Development Indicators.

Figure 4
Technology Trade and Commodity Trade
(Country Average, 1981-2008)



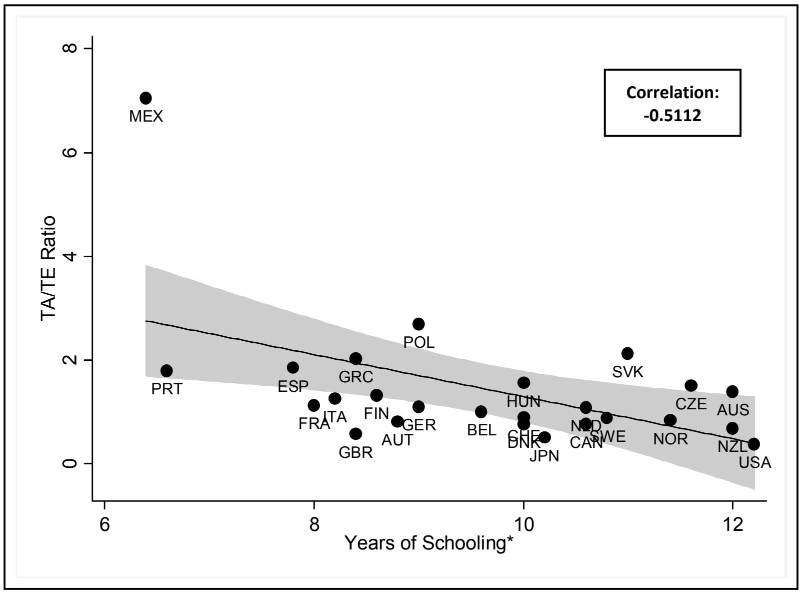
Note: The solid line is the adjusted linear regression line with a 95% confidence interval.

*Commodity Trade is the sum imports and exports of goods and services.

**Technology Trade is the sum of TA payments and TE receipts.

Source**:** SourceOECD and World Development Indicators.

Figure 5
Years of Schooling and TA/TE Ratio
(Country Average, 1981-2008)



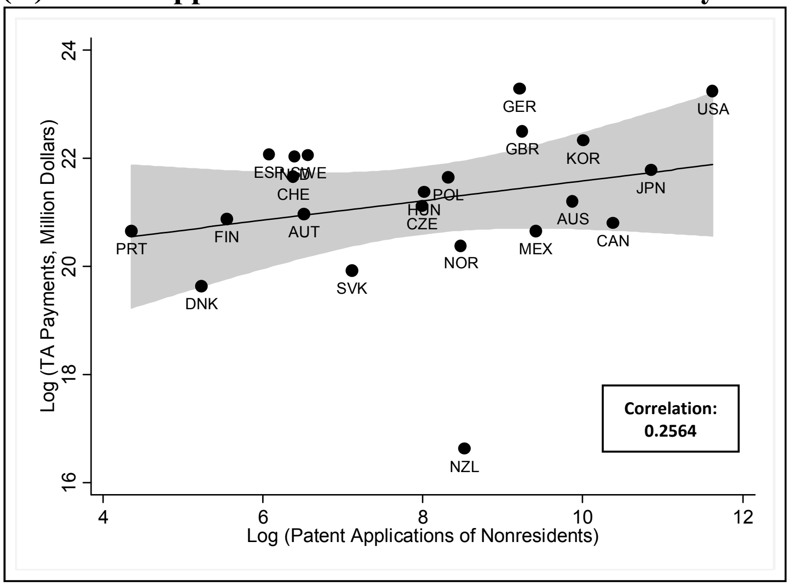
Note: The solid line is the adjusted linear regression line with a 95% confidence interval.

* Years of schooling for population more than 25 years old.

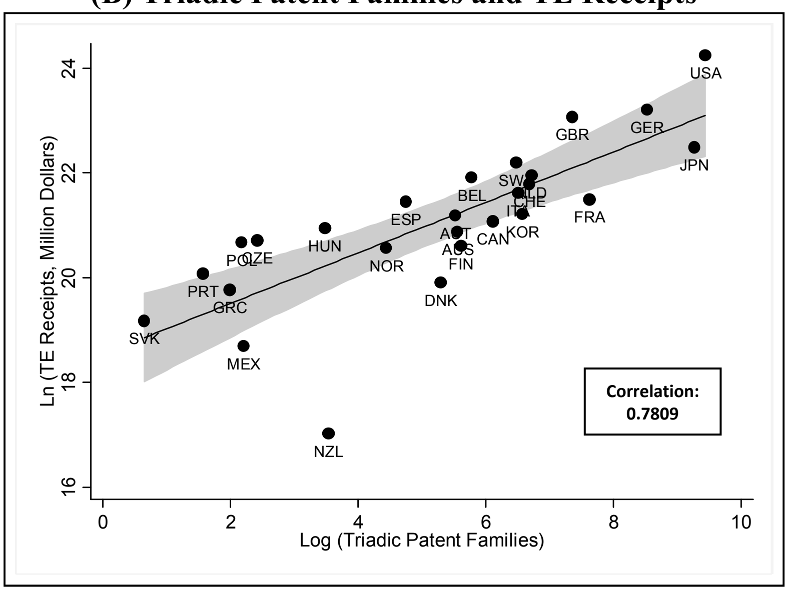
Source**:** SourceOECD, World Development Indicators, and Barro and Lee (2010).

Figure 6
Patents and Technology Trade
(Country Average, 1981-2008)

(A) Patent Applications of Nonresidents and TA Payments



(B) Triadic Patent Families and TE Receipts

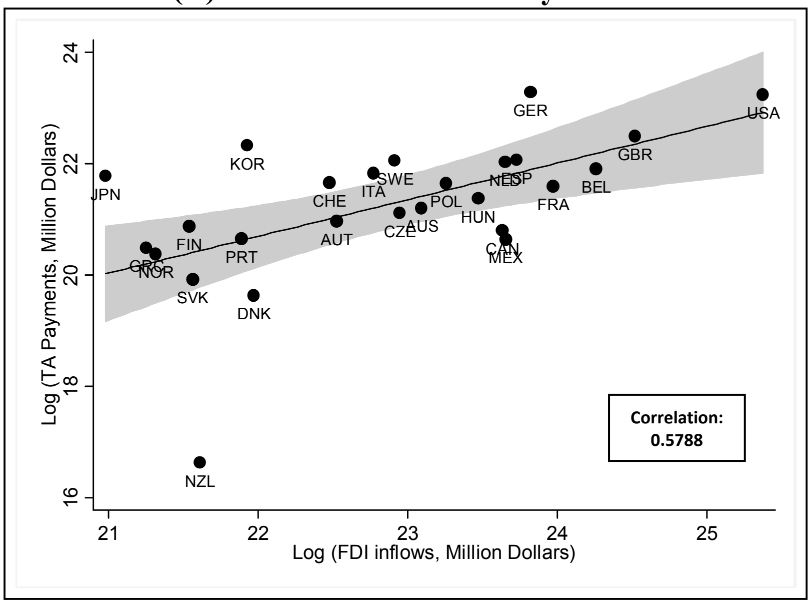


Note: The solid line is the adjusted linear regression line with a 95% confidence interval.

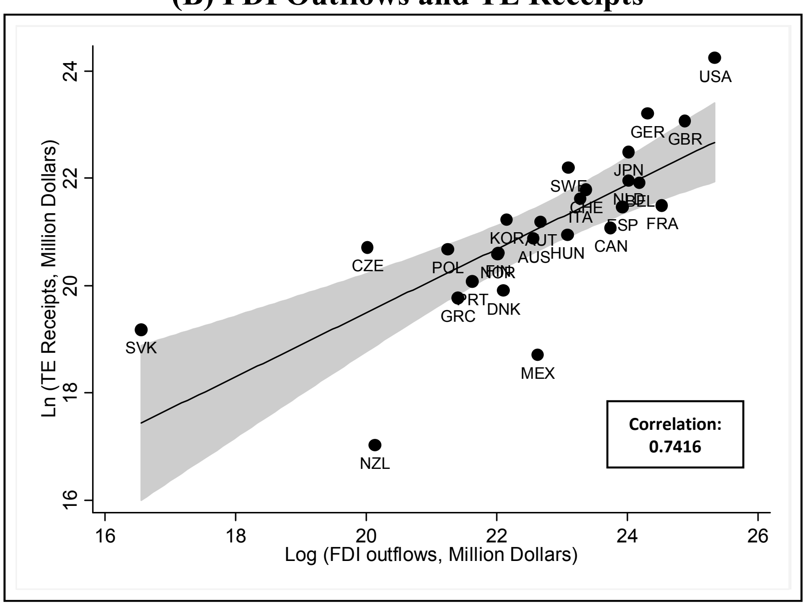
Source**:** SourceOECD and World Development Indicators.

Figure 7
FDI Flows and Technology Trade
(Country Average, 1981-2008)

(A) FDI inflows and TA Payments



(B) FDI Outflows and TE Receipts

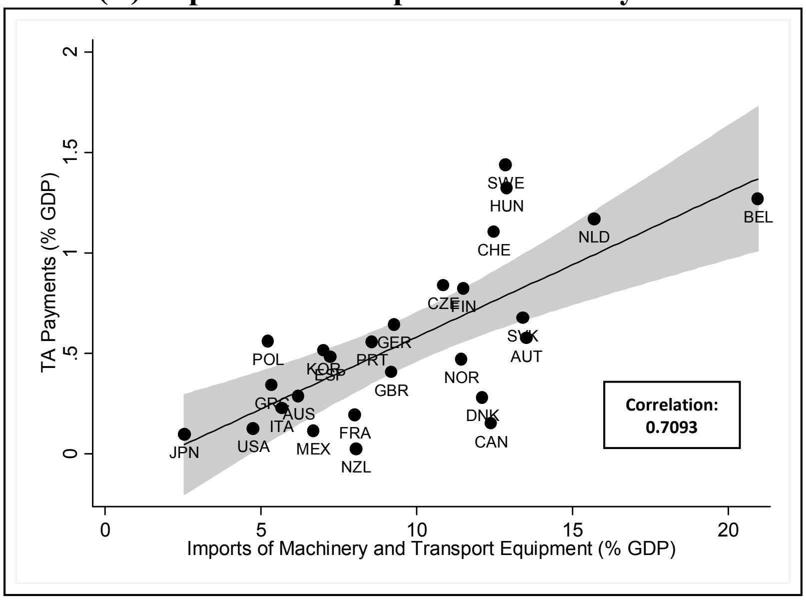


Note: The solid line is the adjusted linear regression line with a 95% confidence interval.

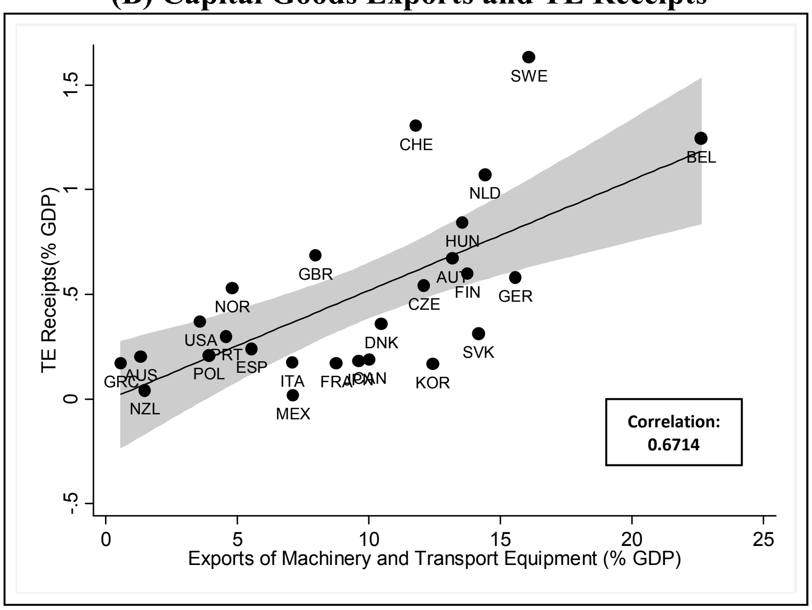
Source**:** SourceOECD and World Development Indicators.

Figure 8
Capital Goods Trade and Technology Trade
(Country Average, 1996-2007)

(A) Capital Goods Imports and TA Payments



(B) Capital Goods Exports and TE Receipts

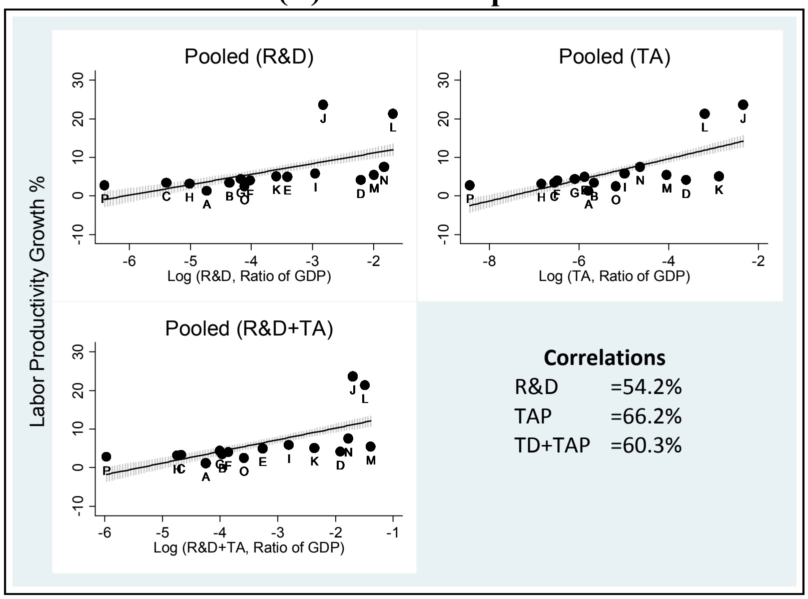


Note: The solid line is the adjusted linear regression line with a 95% confidence interval.

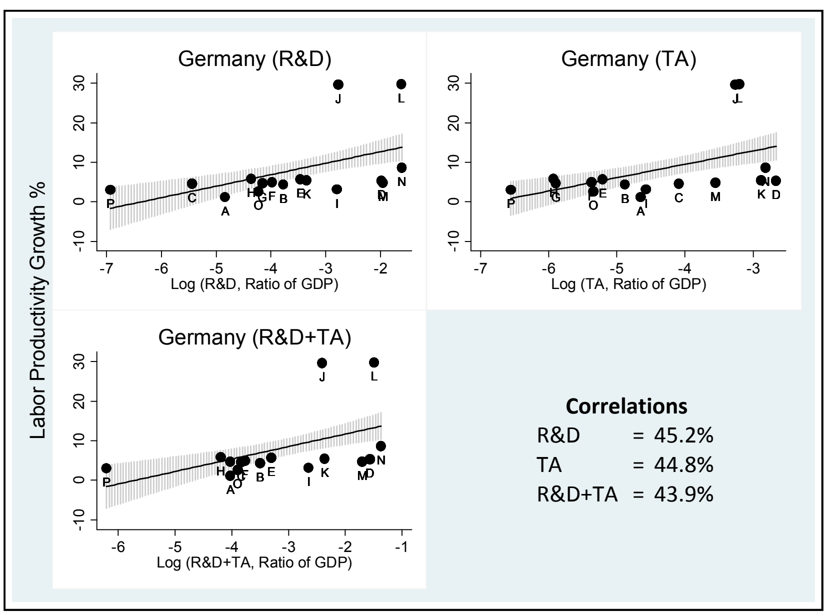
Source**:** SourceOECD and World Development Indicators.

Figure 9
Technological Investments and Labor Productivity Growth by Industry
(Industry Average, 1981-2008)

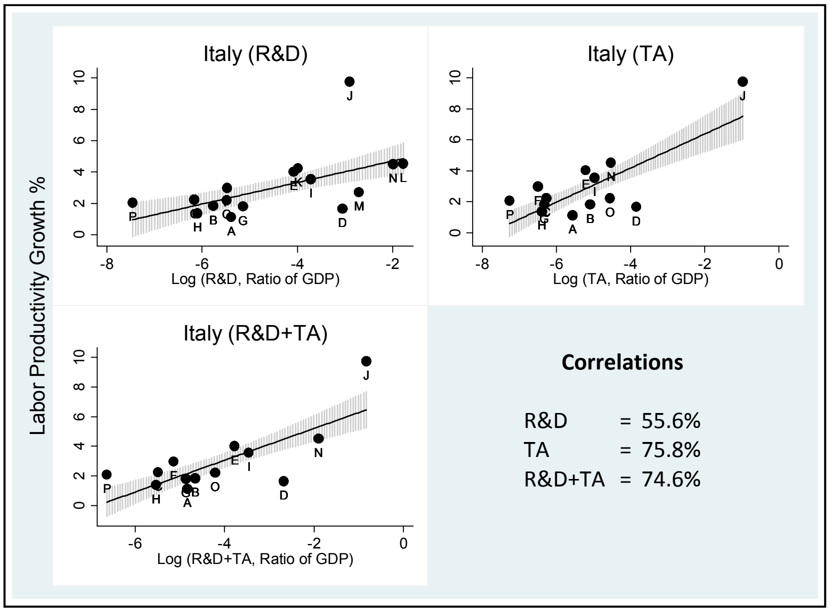
(A) Pooled Sample



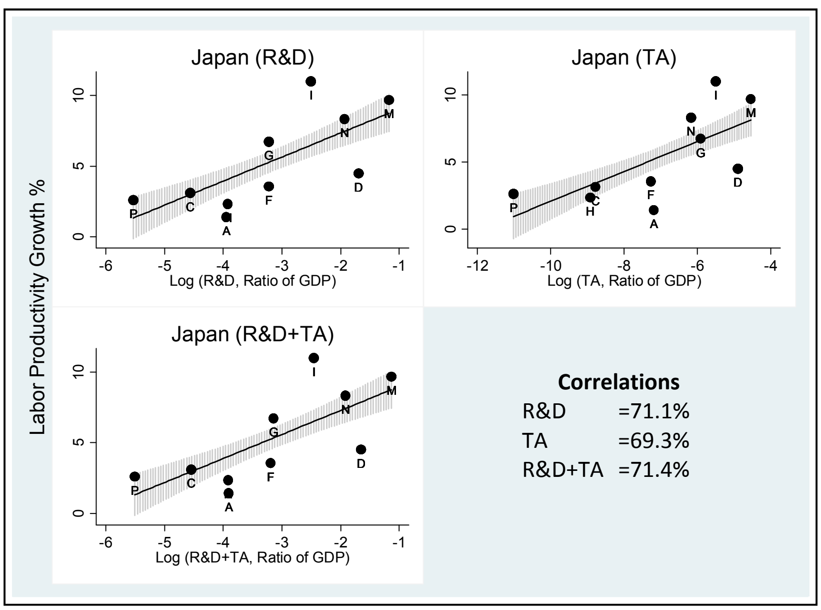
(B) Germany



(C) Italy



(D) Japan



Note: The solid line is the adjusted linear regression line with a 95% confidence interval. List of industries:

A. Food, Beverages, Tobacco (ISIC-3: 15-16)
B. Textiles, Apparel, Fur, Leather (17-19)
C. Wood, Paper, Printing, Publishing (20-22)
D. Chemical Products (26)
E. Rubber, Plastics (25)
F. Non-Metallic Mineral Products (26)
G. Basic Metals (27)
H. Fabricated Metal Products (28)
I. Non-Electrical Machinery (29)
J. Office and Computing Machinery (30)
K. Electronic Machinery (31)
L. Radio, TV, and Comm. Equ. (32)

M. Scientific and Precision Instruments (33)	N. Transport Equipment (34-35)
O. Furniture and Other Manufacturing (36-37)	P. Construction, Electricity, Gas/Water (40-45)

Source**:** SourceOECD and World Development Indicators.

Table 1
Impacts of R&D Investments and TA Payments on Productivity Growth: OLS Estimation of Equation (1)

(Dependent Variable: Log Productivity Growth)

Parameter	Without Control Variables		Original Model of (1)		Without Log R&D/GDP		Without Log TA/GDP		Using Non-public R&D		Frontier Group Only		Less Productive Economies	
ρ_1: Log R&D/GDP	-0.006	*	-0.010				-0.003		-0.010		0.011		-0.076	***
	0.078		0.480				0.823		0.429		0.592		0.007	
ρ_2: Log TA/GDP	0.020	***	0.070	***	0.068	***			0.078	***	0.047	**	0.118	***
	0.000		0.006		0.007				0.005		0.031		0.003	
δ_1: Log Relative Productivity	0.020	***	0.004		0.011		0.018		-0.001		-0.041		-0.063	**
	0.000		0.801		0.501		0.337		0.951		0.341		0.041	
δ_2: Log Frontier Productivity Growth	0.053	***	-0.043	**	-0.043	**	-0.058	***	-0.045	**	-0.047	**	-0.027	
	0.000		0.019		0.016		0.004		0.022		0.010		0.239	
δ_3: Years of Schooling			0.052		0.048		0.040		0.060		-0.002		0.129	***
			0.148		0.178		0.313		0.125		0.971		0.001	
δ_4: Openness			-0.074	**	-0.070	**	0.008		-0.083	**	-0.059	*	-0.071	*
			0.016		0.020		0.456		0.012		0.051		0.080	
δ_5 GDP			-0.009	*	-0.008	*	0.000		-0.010	*	-0.012	**	0.013	*
			0.072		0.083		0.953		0.052		0.048		0.061	
R2 (Adjusted)	0.16		0.51		0.51		0.34		0.53		0.78		0.72	
Years	1996-07		1996-07		1996-07		1996-07		1996-07		1996-07		1996-07	
Countries	89		89		89		89		89		16		73	
Number of Observations	728		728		728		728		728		126		602	

* All models include time and country dummy variables for control. Estimates in the first line, and p-values are in the second line. ***: Significant at 1% level. **: At 5%. *: At 10%. The “frontier group” (top 20% in labor productivity) includes Austria, Belgium, Bermuda, Canada, Denmark, Finland, France, Germany, Iceland, Japan, Luxembourg, Netherlands, Norway, Sweden, Switzerland, and the United States. “Less productive economies” include Algeria, Argentina, Armenia, Australia, Azerbaijan, Belarus, Bolivia, Bosnia and Herzegovin, Botswana, Brazil, Bulgaria, Burkina Faso, Cambodia, Chile, Colombia, Costa Rica, Croatia, Cyprus, Czech Republic, Ecuador, Egypt, El Salvador, Estonia, Ethiopia, Georgia, Greece, Guatemala, Honduras, Hungary, India, Indonesia, Ireland, Israel, Italy, Jamaica, Jordan, Kazakhstan, Kuwait, Latvia, Lesotho, Lithuania, Malaysia, Malta, Mauritius, Mexico, Moldova, Mongolia, Morocco, Mozambique, New Zealand, Pakistan, Panama, Paraguay, Peru, Poland, Portugal, Romania, Saudi Arabia, Senegal, Slovak Republic, Slovenia, South Africa, Spain, Sri Lanka, Sudan, Thailand, Tunisia, Turkey, Uganda, Ukraine, United Kingdom, Uruguay, and Zambia.

Data**:** SourceOECD and World Development Indicators.

Table 2
Robustness Check of Table 1: ψ=0.15 instead of ψ=0.40

(Dependent Variable: Log Productivity Growth)

Parameter	Without Control Variables		Original Model of (1)		Without Log R&D/GDP		Without Log TA/GDP		Using Non-public R&D		Frontier Group Only		Less Productive Economies	
ρ_1: Log R&D/GDP	-0.012 0.122		-0.024 0.476				-0.008 0.829		-0.022 0.427		0.027 0.581		-0.177 0.007	***
ρ_2: Log TA/GDP	0.056 0.000	***	0.168 0.006	***	0.163 0.007	***			0.186 0.005	***	0.112 0.030	**	0.280 0.003	***
δ_1: Log Relative Productivity	0.045 0.000	***	0.008 0.837		0.024 0.532		0.040 0.355		-0.004 0.927		-0.104 0.307		-0.146 0.041	**
δ_2: Log Frontier Productivity Growth	0.124 0.000	***	-0.102 0.018	**	-0.103 0.016	**	-0.138 0.004	***	-0.106 0.022	**	-0.111 0.010	***	-0.065 0.221	
δ_3: Years of Schooling			0.123 0.145		0.114 0.173		0.095 0.309		0.144 0.121		-0.008 0.951		0.309 0.002	***
δ_4: Openness			-0.178 0.015	**	-0.169 0.019	**	0.018 0.494		-0.199 0.011	**	-0.141 0.050		-0.175 0.071	*
δ_5 GDP			-0.021 0.069	*	-0.020 0.078	*	-0.001 0.923		-0.025 0.049	**	-0.029 0.046	**	0.029 0.073	*
R2 (Adjusted)	0.14		0.52		0.51		0.33		0.53		0.78		0.72	
Years	1996-07		1996-07		1996-07		1996-07		1996-07		1996-07		1996-07	
Countries	89		89		89		89		89		16		73	
Number of Observations	728		728		728		728		728		126		602	

* All models include time and country dummy variables for control. Estimates in the first line, and p-values are in the second line. ***: Significant at 1% level. **: At 5%. *: At 10%.

Data**:** SourceOECD and World Development Indicators.

Table 3
OLS Estimation of Equation (2): Results without Logarithms in Equation (1)

(Dependent Variable: Productivity Growth)

Parameter	Without Control Variables		Original Model of (1)		Without Log R&D/GDP		Without Log TA/GDP		Using Non-public R&D		Frontier Group Only		Less Productive Economies	
ρ_1: Log R&D/GDP	-0.770 0.000	***	0.205 0.514				0.218 0.477		0.214 0.542		0.699 0.039	**	-1.607 0.251	
ρ_2: Log TA/GDP	0.023 0.030	**	0.074 0.095	*	0.075 0.088	*			0.084 0.087	*	0.060 0.075	*	0.103 0.129	
δ_1: Log Relative Productivity	0.043 0.000	***	0.229 0.246		0.204 0.280		0.282 0.196		0.199 0.332		-2.437 0.011	**	-0.032 0.911	
δ_2: Log Frontier Productivity Growth	0.000 0.000	***	0.000 0.006	***	0.000 0.005	***	0.000 0.003	***	0.000 0.008	***	0.000 0.042	**	0.000 0.161	
δ_3: Years of Schooling			0.194 0.173		0.204 0.151		0.156 0.319		0.227 0.156		-0.253 0.210		0.480 0.029	**
δ_4: Openness			-0.017 0.327		-0.018 0.286		0.006 0.355		-0.020 0.274		-0.015 0.128		-0.022 0.436	
δ_5 GDP			0.000 0.585		-0.048 0.558		0.006 0.932		0.000 0.506		0.000 0.166		0.000 0.333	
R2 (Adjusted)	0.16		0.46		0.45		0.35		0.47		0.73		0.47	
Years	1996-07		1996-07		1996-07		1996-07		1996-07		1996-07		1996-07	
Countries	89		89		89		89		89		16		73	
Number of Observations	728		728		728		728		728		126		602	

* All models include time and country dummy variables for control. Estimates in the first line, and p-values are in the second line. ***: Significant at 1% level. **: At 5%. *: At 10%.

Data**:** SourceOECD and World Development Indicators.

Table 4
Nonlinear-Least-Squares Estimation of Equation (3)

(Dependent Variable: Productivity Growth)

Sample	ρ
High-income Economies	0.48
Less Productive Economies	–0.14

Note: If $\rho = -1$, then two inputs, R&D investments and TA payments, are perfect substitutes. If $\rho = 0$, the production function is Cobb-Douglas. If ρ goes to infinity, the two inputs are perfect complements.