

Transfer of Technology

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February 2007

Forthcoming, *New Palgrave Dictionary of Economics*, 2nd edition

This entry discusses the transfer of technological knowledge. The primary focus is on technology transfer between firms in different countries. Asymmetric information often makes arms-length transactions of technology infeasible. Instead, international technology transfer tends to occur through non-market channels. For example, technology externalities provided by the US to other countries are an order of magnitude larger than US technology licensing receipts.¹ These externalities are called technology spillovers.

A good starting point is the model of international technology transfer by Howitt (2000). There are many intermediate good sectors each characterized by its own level of technology. Different countries and sectors employ different technologies based on domestic innovation and technology transfer from abroad. At any given time t , the technology frontier, A_t^{\max} , denotes the highest technology level across all countries and sectors. The technology frontier is growing because innovations worldwide push it out over time. An innovation in a particular sector brings this sector's productivity up to the technology frontier. This means that the model includes international and inter-sectoral technology spillovers, since if there had been many innovations in other countries or sectors, the jump to the technology frontier for sector i will be larger than if there had been few innovations elsewhere.

With productivity in successfully innovating sectors jumping to the frontier level, a country's average productivity across sectors (denoted A_t) rises. In Howitt's model, average productivity changes according to

$$(1) \quad \dot{A}_t = \lambda r_t (A_t^{\max} - A_t),$$

where r_t is a measure of domestic R&D investment, and $\lambda > 0$ is a parameter. In (1), the change in A_t is positively related to domestic R&D, and it is positively related to the average technology gap, $(A_t^{\max} - A_t)$. Equation (1) leads to a common long-run growth rate shared by all countries; however, those investing more in R&D will enjoy relatively high productivity levels, all else equal.

The literature emphasizes that technology transfer is facilitated by firms' international activity, though to date this has not been comprehensively articulated at the theoretical level. International trade and foreign direct investment have long been

¹ See US balance of payments data on trade in services, and McNeil and Fraumeni (2005) on spillovers.

mentioned as some of the most important channels, and the econometric evidence is discussed in the following (see also Keller 2004).

First of all, imports may lead to technology transfer. Coe and Helpman (1995) test the prediction of the trade and growth models of Grossman and Helpman (1991) and Rivera-Batiz and Romer (1991), in which foreign R&D creates new intermediate inputs and perhaps generates spillovers for the home country through importing activity. Output is produced with labor and differentiated capital goods that enter in a CES function. The intermediate product range in each country is expanded through R&D, and countries can benefit from other countries' R&D by importing foreign-developed intermediate goods. Under certain assumptions, a country's productivity f is given by

$$(2) \quad \ln f = \ln B + \alpha \ln n^e,$$

where n^e is the range of intermediate goods employed in the country, and $B > 0$ is a parameter. According to (2), productivity is positively related to the intermediate products range employed in this country.

A country's demand for intermediates will depend on bilateral trade barriers and transport costs. Coe and Helpman (1995) distinguish between foreign and domestic products, since trade costs are often very different between these:

$$(3) \quad \ln f_c = \alpha_c + \beta^d \ln n_c + \beta^f \ln n_c^f + \varepsilon_c,$$

where n_c^f is defined as the bilateral import-share weighted R&D of country c 's trade partners: $n_c^f = \sum_{c' \neq c} m_{cc'} r_{c'}$. This captures the prediction that if a country imports primarily from high-R&D countries, it is likely to benefit more from foreign technology than if it imports primarily from low-R&D countries.

While Coe and Helpman (1995) estimate a positive and quantitatively large effect from import-weighted foreign R&D, subsequent work by Keller (1998) shows that this *per se* cannot be taken as evidence for imports-related international technology transfer. Instead of using data on actual bilateral imports, Keller (1998) conducts robustness checks with two alternative foreign variables, one based on randomly created shares and another with no shares at all: $\tilde{n}_c^f = \sum_{c' \neq c} \mu_{cc'} r_{c'}$ and $\tilde{\tilde{n}}_c^f = \sum_{c' \neq c} r_{c'}$. Since these alternative variables yield similar or even stronger results as in Coe and Helpman (1995), the observed import patterns cannot explain the estimated effects.

By making progress on a number of fronts, further work has produced robust evidence for imports-related technology transfer. First, Xu and Wang (1999) and Keller (2000) note that as a matter of theory, foreign technology spillovers are the result of capital goods trade, and not aggregate trade, which Coe and Helpman (1995) use to construct their import shares. Xu and Wang (1999) show that if the foreign variable n_c^f is based on bilateral capital goods trade shares, it performs better than both Coe and Helpman's (1995) original and Keller's (1998) alternative variables. Moreover, since

most R&D is conducted in a relatively small part of manufacturing, imports-related technology transfer effects are relatively difficult to estimate with country-level data, as in Coe and Helpman; in a study among OECD countries at the two- and three-digit industry level, Keller (2002) finds robust evidence that imports are a channel for international technology transfer.

Second, the major question regarding exports is whether firms learn about foreign technology through exporting experience. There is abundant evidence that in a given cross-section, exporters are on average more productive than non-exporters (Bernard and Jensen 1999). That does not address the question whether exporting firms become more productive because of learning associated with exporting, or whether firms that are more productive to begin with export more. According to much anecdotal evidence, firms do benefit from interacting with foreign customers, for instance because the latter impose higher product quality standards than the domestic customer, while at the same time providing information on how to meet the higher standards. The econometric evidence is more mixed however.

While learning-by-exporting has been emphasized primarily for low- and middle-income countries' firms, there is in principle no reason why it is limited to these countries. Bernard and Jensen (1999) analyze learning-by-exporting using data on U.S. firms. In studying the performance of four different sets of firms—exporters, non-exporters, starters, and quitters—separately, Bernard and Jensen (1999) do not model export market participation explicitly. They find that labor productivity growth is about 0.8% higher among exporters than non-exporters. This estimate is fairly small, and it becomes even smaller (and insignificant) for longer time horizons. At the same time, this is conditional on plant survival. Bernard and Jensen also show that exporters are 10% more likely to survive than non-exporters. This difference is indicative of higher productivity growth for exporters than non-exporters, because low productivity growth is the primary reason of why plants fail. Thus, there may be learning-from-exporting effects that amount to more than 0.8%, although it is not clear whether they are substantial.

The paper by Clerides, Lach, and Tybout (1998) provides evidence on learning externalities from exporting using micro data from Columbia, Morocco, and Mexico. By estimating simultaneously a dynamic discrete choice equation that determines export market participation, these authors take into account that it is on average the already-productive firms that self-select into the export market. The export market participation decision is given by

$$y_{it} = \begin{cases} 1 & \text{if } 0 \leq \beta^x X_{it} + \beta^e e_{it} + \sum_{j=1}^J \beta_j^c \ln(AVC_{it-j}) \\ & + \sum_{j=1}^J (F^0 - F^j) y_{it-j} + \eta_{it} \\ 0 & \text{otherwise,} \end{cases} \quad (4)$$

and any learning from exporting effects are uncovered by simultaneously estimating an autoregressive cost function

$$\begin{aligned}
\ln(AVC_{it}) &= \gamma_0 + \sum_{j=1}^J \gamma_j^k \ln(K_{it-j}) + \gamma^e \ln(e_t) \\
&+ \sum_{j=1}^J \gamma_j^c \ln(AVC_{it-j}) + \sum_{j=1}^J \gamma_j^y y_{it-j} + v_{it}
\end{aligned}
\tag{5}$$

In equation (4), y_{it} is the export indicator of plant i in period t , X_{it} is a vector of exogenous plant characteristics, e_t is the exchange rate, AVC_{it} are average costs, K_{it} is capital, and F^0 and F^j are sunk costs of export market participation.

Equation (4) states that one only sees a plant exporting if the profits from doing so are greater than from not exporting (the latent threshold is expressed in terms of observables). Equation (5) asks whether past exporting experience reduces current cost (captured by the parameters γ_j^y), conditional on past costs and size (proxied by capital). Clerides, Lach, and Tybout (1998) show results for the three countries separately, and also by major industry, using MLE and GMM methods. These estimations show no significant positive effects from past exporting experience on current cost. Clerides et al's descriptive plots of average cost before and after export market entry support this conclusion. Thus, exporting does not facilitate technology transfer. According to Clerides, Lach, and Tybout's (1998) analysis, exporters are more productive, but that is because they self-select themselves into the export market.

Using similar methods, van Biesebroeck (2005) has revisited the issue by studying productivity dynamics of firms in nine African countries. In contrast to Clerides et al., he estimates that firms starting to export boost productivity by about 25% on average in his sample. Van Biesebroeck (2005) also estimates that the higher productivity growth of exporters versus non-exporters is sustained. By employing instrumental-variable and semi-parametric techniques as alternative ways to deal with the selection issue, van Biesebroeck's analysis is more comprehensive than most. His analysis generally supports the notion that exporting leads to the transfer of technological knowledge. In trying to reconcile his findings with some of the earlier results, van Biesebroeck shows that part of the difference in productivity growth between exporters and non-exporters appears to be due to unexploited scale economies for the latter. This suggests that at least in part his results are due to constraints imposed by demand, and not due to technology transfer in the sense of an outward shift of the production possibility frontier at all levels of production. We need richer data to make further progress on distinguishing these hypotheses.

Third, foreign direct investment (FDI) has long been considered as an important channel for technology transfer. Among the possible mechanisms are knowledge spillovers, labor turnover, linkages, and advanced specialized inputs. Also multinational companies are well-known to be more productive and do more R&D than purely domestic firms, so they are likely sources for such productivity benefits. Moreover, governments all over the world spend large amounts of resources to attract affiliates of multinationals to their jurisdiction. If this is rational economic policy, there ought to be large technology transfers associated with FDI.

Numerous studies have estimated FDI spillovers over the last four decades. Recently, authors focus on panel data analysis with micro data, since this reduces problems resulting from unobserved heterogeneity across firms and sectors. Typically, a general relationship between productivity growth of domestically-owned firms (Δf) and a measure of the change in inward FDI (ΔFI) is specified in order to uncover evidence for FDI spillovers:

$$(6) \quad \Delta f_{ist} = \beta X' + \gamma \Delta FI_{ist} + u_{ist},$$

Here, X is a vector of control variables, u is a regression error, and i , s , and t are firm, industry, and time subscripts, respectively. The spillover parameter γ is estimated positive if productivity growth of firms in industries that have experienced large increases in FDI exceeds that of firms in industries where FDI has grown little.

Until very recently, many authors concluded, by and large, that there is no evidence for FDI spillovers. This is also reflected in a number of surveys (Lipsev and Sjöholm 2005, Görg and Greenaway 2004, Hanson 2001). The paper by Aitken and Harrison (1999) even estimates a *negative* relationship between FDI and productivity for a sample of Venezuelan plants. Since technology learning spillovers can hardly be negative, most likely the analysis picks up something else. One possibility, first suggested by Aitken and Harrison (1999), is that the negative coefficient is due to increased competition for local plants through foreign entry. Alternatively, it could be due to endogeneity, if FDI flows to sectors in which firms are relatively weak.

The paucity of evidence has led some to look elsewhere: if there are no spillovers to domestic firms in the same industry, perhaps they exist for domestic suppliers of multinational firms? Contractual relations between foreign-owned affiliates and their domestic suppliers suggest that the technology transfer could, in principle, be specified and paid for—in which case these are not externalities. However, there could be learning effects on top of this. The paper by Smarzynska Javorcik (2004) finds evidence consistent with vertical spillovers between firms in different industries in Lithuania, but no within-industry spillovers.

Haskel, Pereira, and Slaughter (2002) and Keller and Yeaple (2003) have returned to the original question of spillovers from FDI in a given industry. Haskel et al. estimate an equation like (6) for FDI into the United Kingdom, and Keller and Yeaple for FDI into the United States. Haskel et al (2002) estimate positive spillovers, which, however, are relatively small, as the authors note. More importantly, Haskel et al., as is the case for Smarzynska Javorcik (2004), do not fully address the possibility that FDI inflows may be endogenous.

The first paper to show that multinational affiliates can cause economically large productivity benefits to domestically-owned firms is Keller and Yeaple (2003). These authors deal with endogeneity concerns using instrumental variable techniques, and they employ the by now well-known Olley-Pakes (1996) method of computing firm productivity. The resulting estimates imply an influence of FDI on productivity growth

that is much larger than in existing studies. Using data on about 1,300 US manufacturing firms for the years 1987-1996, they estimate that FDI spillovers explain about 11% of productivity growth during this time.

Keller and Yeaple (2003) also reconcile their results with earlier studies that have found no evidence for FDI spillovers. For one, FDI spillovers are heterogeneous, with much stronger effects in the relatively high-technology industries. Secondly, large FDI spillovers are estimated only with the high-quality data on FDI by industry they employ. If instead Keller and Yeaple (2003) use FDI data similar to that more commonly available in other studies, they too estimate only a small or zero effect.

Thus, in contrast to the earlier literature, the most recent micro productivity studies tend to estimate positive, and in some cases also economically large spillovers associated with FDI. As one would expect, the effects are heterogeneous across industries, with stronger effects in relatively high-tech industries. It is not clear yet whether strong FDI spillovers occur only in relatively rich but not in relatively poor countries. Another of Keller and Yeaple's findings, that relatively weak firms benefit more from FDI than stronger firms, suggests that FDI spillovers are not limited to rich countries, where firm productivity tends to be relatively high.

To conclude, recent experience with research on the channels of technology transfer in all three areas, imports, exports, and FDI, clearly shows that it is crucial to have access to detailed information or at least proxy variables on the technology being transferred. Given that much of technology transfer is associated with externalities, this may be the single most important issue that future work needs to address.

References

- Aitken, B., and A. Harrison (1999), "Do domestic firms benefit from FDI? Evidence from Venezuela", *American Economic Review* 89: 605-618.
- Bernard, A., and B. Jensen (1999), "Exceptional exporter performance: cause, effect, or both?", *Journal of International Economics* 47: 1-26.
- Clerides, S., S. Lach, and J. Tybout (1998), "Is learning by exporting important? Microdynamic evidence from Columbia, Mexico, and Morocco", *Quarterly Journal of Economics* 113: 903-947.
- Coe, D., and E. Helpman (1995), "International R&D Spillovers", *European Economic Review* 39: 859-887.
- Görg, H., and D. Greenaway (2004), "Much ado about nothing? Do domestic firms really benefit from FDI?", *World Bank Research Observer* 19: 171-197
- Grossman, G., and E. Helpman (1991), *Innovation and Growth in the Global Economy*, MIT Press.

- Hanson, G. (2001), "Should countries promote FDI?", G-24 Discussion Paper Series, United Nations, New York and Geneva.
- Haskel, J., S. Pereira, and M. Slaughter (2002), "Does inward FDI boost the productivity of domestic firms?", NBER Working Paper # 8724.
- Howitt, P. (2000), "Endogenous growth and cross-country income differences", *American Economic Review* 90: 829-44.
- Keller, W. (2004), "International Technology Diffusion", *Journal of Economic Literature* 42: 752-782.
- Keller, W. (2002), "Trade and the Transmission of Technology", *Journal of Economic Growth* 7: 5-24.
- Keller, W. (2000), "Do trade patterns and technology flows affect productivity growth?", *World Bank Economic Review* 14: 17-47.
- Keller, W. (1998), "Are international R&D spillovers trade-related? Analyzing spillovers among randomly matched trade partners", *European Economic Review* 42: 1469-1481.
- Keller, W., and S. Yeaple (2003), "Multinational enterprises, international trade, and productivity growth: firm-level evidence from the United States", NBER Working Paper # 9504.
- Lipsey, R., and F. Sjöholm (2005), "The Impact of Inward FDI on Host Countries: Why so Different Answers?", in *Does Foreign Direct Investment Promote Development?*, Moran, Graham, and Blomström (eds.), Institute for International Economics, Washington, D.C., chapter 2.
- McNeil, L., and B. Fraumeni (2005), "International trade and economic growth: A possible methodology for estimating cross-border R&D spillovers", BEA Working Paper 2005-03, Washington, D.C.
- Olley, S., and A. Pakes (1996), "The dynamics of productivity in the telecommunications equipment industry", *Econometrica* 64: 1263-1297.
- Rivera-Batiz, L., and P. Romer (1991), "Economic Integration and Endogenous Growth", *Quarterly Journal of Economics* 106: 531-555.
- Smarzynska Javorcik, B. (2004), "Does FDI increase the productivity of domestic firms? In search of spillovers through backward linkages", *American Economic Review* 94: 605-627.

Van Biesebroeck, J. (2005), “Exporting raises productivity in sub-Saharan African manufacturing firms”, *Journal of International Economics* 67: 373-391.

Xu, B., and J. Wang (1999), “Capital goods trade and R&D spillovers in the OECD”, *Canadian Journal of Economics* 32: 1258-74.