NBER WORKING PAPER SERIES

# ESTIMATING THE PRODUCTIVITY SELECTION AND TECHNOLOGY SPILLOVER EFFECTS OF IMPORTS

Ram C. Acharya
Wolfgang Keller

Working Paper 14079
http://www.nber.org/papers/w14079

NATIONAL BUREAU OF ECONOMIC RESEARCH
1050 Massachusetts Avenue
Cambridge, MA 02138
June 2008

We are grateful to Jan DeLoecker, Margaret McMillan, Carol Shiue, Stephen Yeaple, as well as seminar audiences at the University of Colorado and the 2008 NBER International Trade and Investment Spring meeting for comments. Views expressed in the paper are those of the authors and do not necessarily reflect those of Industry Canada, or the National Bureau of Economic Research.

Estimating the Productivity Selection and Technology Spillover Effects of Imports
Ram C. Acharya and Wolfgang Keller
NBER Working Paper No. 14079
June 2008
JEL No. F1,F2,O3,O33

**ABSTRACT**

In the wake of falling trade costs, two central consequences in the importing economy are, first, that stronger competition through increased imports can lead to market share reallocations among domestic firms with different productivity levels (selection). Second, the increase in imports might improve domestic technologies through learning externalities (spillovers). Each of these channels may have a major impact on aggregate productivity. This paper presents comparative evidence from a sample of OECD countries. We find that the average long run effect of an increase in imports on domestic productivity is close to zero. If the scope for technological learning is limited, the selection effect dominates and imports lead to lower productivity. If, however, imports are relatively technology-intensive, imports also generate learning that can on net raise domestic productivity. Moreover, there is somewhat less selection when the typical domestic firm is large. The results support models in which trade triggers both substantial selection and technological learning.

Ram C. Acharya
Industry Canada
10-East, 235 Queen Street
Ottawa, Ontario
Canada  K1A 0H5
Acharya.Ram@ic.gc.ca

Wolfgang Keller
Department of Economics
University of Colorado at Boulder
Boulder, CO 80309-0256
and NBER
Wolfgang.Keller@colorado.edu

# 1 Introduction

The recent growth of international trade has made for a much more integrated world. Many observers hold that trade contributes to the flow of ideas across borders because a major part of imports are new products.[1] These product innovations positively affect productivity if they trigger domestic technological learning. Importing high-technology intermediate goods may also generate productivity spillovers. How important, for example, were the computer-related intermediate imports from the United States to the emerging Irish computer industry for the recent productivity transformation of Ireland?[2]

Moreover, international trade often changes the intensity of competition and leads to productivity selection. An important mechanism is the reallocation of market shares when firms differ in their productivity (Melitz 2003). If trade barriers to a foreign market fall, this improves the relative profitability of high-productivity firms, since low-productivity firms tend to serve only the domestic market. Weak firms exit and market shares are reallocated to high-productivity firms, which raises average productivity. Potential exporters from the liberalizing country in turn find it harder to compete abroad. The reduction in their relative profits leads to the opposite productivity selection: industry productivity in the liberalizing country declines.[3]

While trade is generally a positive-sum game in terms of welfare, it is more likely that

[1] This has been documented recently for the United States by Broda and Weinstein (2006).

[2] Keller (2004) presents an overview of the literature on international technology diffusion.

[3] This prediction assumes that there is free entry, which generally holds in the long run. The seminal work by Melitz (2003) analyzes bilateral liberalization. Unilateral liberalization in a model with variable mark-ups is examined in Melitz and Ottaviano (2008); these authors show in addition that the short-run effects of trade liberalization are pro-competitive. Important extensions of Melitz (2003) include Demidova (2006) and Falvey, Greenaway, and Yu (2006).

trade liberalization yields welfare gains if imports improve domestic production technologies in addition to changing market competition.[4] At the same time, quantitatively very little is known on these effects. This paper fills this gap by examining the relative importance of technology spillovers and productivity selection through imports. We find strong evidence that both are important. The *average* impact of imports on long run domestic productivity is close to zero. However, if the scope for technological learning is limited, the selection effect dominates, and imports lead to lower productivity. At the same time, if imports are relatively technology-intensive, imports raise the productivity of domestic firms. There is also some evidence that imports lead to less selection when the typical domestic firm is large. The results are consistent with models in which trade leads both to important selection processes and technology spillovers.

Recent work has shown that increased openness generates changes in competition and market share reallocations among domestic firms that may amount to substantial aggregate productivity changes. For example, Pavcnik (2002) and others have shown productivity gains from trade liberalization.[5] Technology transfer through international trade has been documented in R&D-productivity studies (Keller 2002). And while the pioneering work using micro data found little evidence for technology externalities (Bernard and Jensen 1999, Clerides, Lach, and Tybout 1998), the evidence is stronger in some more recent papers (van Biesebroeck 2005, De Loecker 2007). The main contribution of this paper is that it

[4] A case where trade liberalization with heterogeneous firms and no technology spillovers leads to lower welfare is discussed in Demidova (2006).

[5] Other studies find that domestic productivity declines with increased openness. For example, Aitken and Harrison (1999) demonstrate that increased foreign direct investment in Venezuela has lowered productivity among domestic plants. A number of factors may account for these different results; we will return to this in section 5.

examines both the competition and learning impact of imports by quantifying the relative importance of technology spillovers and selection for domestic productivity.

We combine the broad coverage and focus on technology investments in industry studies with information on the typical size of firms across industries. The analysis encompasses about 85% of all manufacturing R&D in the world. Moreover, we observe R&D spending by both importers and exporters. This information on technology investments is crucial; without it, learning externalities will likely be missed. Studies of the effects of trade liberalization using micro data rarely employ rich information on technology investments, in part because the information is unavailable: the micro unit is frequently a plant, whereas R&D decisions are made at the firm level.

Having detailed information on technology investments comes at the cost of having no comparable information on firm-level market shares. At the same time, firm-level selection dynamics are traced out by observing changes in the average size of firms. In models of productivity heterogeneity, selection and average firm size move together, because the reason why some firms are small (large) in the first place is that they have low (high) productivity. Therefore, changes in average firm size triggered by imports are a direct albeit imperfect measure of productivity selection.

Related to our work is the paper by Chen, Imbs, and Scott (2006). These authors extend the Melitz and Ottaviano (2008) model to study trade-induced changes in prices and mark-ups with data on European industries. Chen, Imbs, and Schott's work addresses the competition effects of trade, both short-run and long-run, whereas the present paper focuses on long-run predictions in a framework where imports can affect both the degree of competition and technological learning.[6]

In the remainder of the paper, we first introduce the data in section 2 before outlining the estimation approach in section 3. This is followed by the empirical results (section 4). Section 5 provides a concluding discussion.

## 2 Data

Technical discoveries tend to emerge in an uneven way across industries. Therefore we study trade and productivity at the industry-level. For example, during the 1990s most of the technological break-throughs came in the information and communication technology (ICT) industries. While the ICT innovations were important even at the manufacturing or the economy-level, a sufficient degree of industry detail is crucial to the analysis. This paper studies manufacturing disaggregated into twenty-two industries, which are listed in Table 6. The classification allows to isolate key sectors such as computers and communication equipment technologies.

The analysis covers manufacturing activity in seventeen industrialized countries; a list of them is given in Table 3. Throughout the three decades of our sample (the years 1973 to 2002), these countries accounted for a large portion of the world's manufacturing activity, and the countries are located in four different continents. The technology trends we study

[6]Some parallels also exist with work by Combes, Duranton, Gobillon, Puga, and Roux (2007), who analyze firm selection and agglomeration effects on productivity. This paper differs, first, in that our focus is on technology spillovers, not agglomeration economies. Second, firm selection and spillovers have *qualitatively* different productivity implications in our setting, namely negative for unilateral trade liberalization, and positive for technological learning. In contrast, Combes, Duranton, Gobillon, Puga, and Roux examine the effect of larger market size, which raises productivity, albeit differentially, via both selection and agglomeration.

are truly global in the sense that during these three decades the sample encompasses more than 85% of the world's manufacturing R&D investments.

Internationally comparable figures on employment, output, and sectoral prices come from Groningen Growth and Development Centre (GGDC) database (van Ark et al. 2005) for the years 1979-2002. The GGDC project represents an extension of the OECD's STAN database in that output and price measures for sectors that were key drivers of technological change are separately included. We have combined this with information on employment, output and sectoral prices for 1973-78 from the OECD's STAN database (OECD 2008a).[7] Also from the STAN database comes the information on physical capital investment. Figures on R&D spending are from the ANBERD database (OECD 2008b), and information on bilateral trade at the industry level comes from the BTD database (OECD 2008c).

This provides a rich basis for the empirical work in that the sample variation in the country, industry, and time dimension goes beyond what was available in earlier studies. In addition, we have obtained figures on output and the number of establishments in order to study firm size dynamics. This information comes from data collected by the United Nations Industrial Development Organization (UNIDO) and prepared by Nicita and Olarreaga (2006). It yields a measure of average firm size that, as noted above, can shed additional light on market share reallocations analyzed by heterogeneous firm models.[8] The UNIDO data provides average firm size information for the years 1981 to 2002 at the three-digit ISIC

[7] More details on the sources and construction of this data is given in Acharya and Keller (2007).

[8] For the purposes of this paper, we use the terms establishment and firm synonymously. To the best of our knowledge, cross-country, cross-industry data for a broad sample that allows this distinction at the empirical level does not exist. In any case, our definition of average size, industry output divided by the number of establishments, corresponds to the notion of a firm in Melitz (2003) and others. See recent work by Bernard, Redding, and Schott (2006) as well as Nocke and Yeaple (2006) on multi-product firms.

level. For a small number of industries, this is more aggregated than the information on R&D and trade volumes, and in these cases we apply the three-digit average firm size figures to all sectors that belong to this three-digit ISIC industry.[9]

The output measure is the value added produced in an industry. Labor services are measured in terms of the number of workers. Information on physical capital investment has been employed to construct capital stocks, and similarly, we have calculated R&D stocks based on data on R&D spending.

Table 1 presents summary statistics for some key variables. There are typically about 10,000 observations, which reflects the fact that there are only a few missing observations.[10] The exception is information on average firm size, which is available for a somewhat smaller number of years and countries. Both R&D and productivity have grown over these three decades, with R&D growth generally outpacing productivity growth (Table 2). At the same time, the rate of total factor productivity (TFP) growth, of around 3% per year, is itself quite high by historic standards. The average growth of imports from the U.S. is almost twice the growth of U.S. R&D over this period. This is consistent with the trend towards globalization. In terms of our study, the increased product market integration helps to identify any productivity selection and spillovers that imports might initiate.

Tables 3 and 4 provide some initial information on the sample variation across countries. Over these three decades, the United States has been the productivity leader, with the highest average productivity level, and Canada is a close second in the productivity ranking

[9] See Table A1 for details.

[10] With 17 countries, 22 industries, and 30 years, there are 11,220 possible observations.

(Table 3). Productivity growth was highest in Korea, in part because it is still catching-up to the most advanced countries. The country with the second-highest productivity growth rate in our sample is Finland; this may be related to high productivity growth in a number of technology-intensive industries, such as communication equipment.

Looking at the R&D figures in Table 4, the United States is the largest creator of new technology in the world. This is the reason for our focus below on selection and spillovers associated with U.S. R&D and imports. Some key information on the importance of U.S. imports relative to domestic production is presented in Table 5. The U.S.' important role for Canada is well known, with U.S. imports being almost three-fourths of domestic value added on average in the recent half of the sample. But also in Ireland and Australia, U.S. imports are about 15% of the size of the domestic industry, and even in the larger OECD countries such as Germany or the U.K., there are substantial U.S. imports that amount to between 3% and 15% of domestic industry size.

Tables 6 and 7 show the variation across industries. Most technology creation as measured by R&D occurs in the aircraft, motor vehicles industries, and communications equipment industries, but also computers, chemicals, and pharmaceuticals account for a relatively large share of total R&D (Table 6). This is based on R&D in the United States, however, the distribution of R&D across industries in other OECD countries is similar. Table 7 shows that the relative importance of imports from the U.S. is highest for the aircraft and computer industries, followed by instruments and communication equipment. This reflects to some extent U.S. competitiveness in different industries. At the same time, it is important to keep in mind that the extent to which the U.S. sells to foreign markets by exporting, versus through foreign direct investment, varies across industries, and this too is reflected in the figures reported in Table 7.

In the following section we describe the estimation approach.

# 3 Estimation

This paper analyzes productivity dynamics by extending the R&D-and-production function framework pioneered by Griliches (1979) and others to include imports. Earlier work has demonstrated a positive relationship between R&D expenditures and total factor productivity. R&D spending in one firm may raise the productivity of other firms if there are technological externalities, or spillovers. These may also be important at the industry- or country-level.

When firms with different productivity levels compete, market share reallocations are an independent reason for changes in industry productivity. In the context of international trade, an increase in imports is indicative of a relatively less profitable competitive position of domestic firms. With free entry, this lowers average productivity at home. One reason for a surge in imports is often that the domestic market has become more accessible in terms of trade costs (e.g. tariffs, non-tariff barriers, or transport costs have fallen). Another reason for increased imports might be that an increase in R&D spending has made foreign firms relatively more competitive. If so, this reallocates export opportunities away from domestic and towards foreign firms. The reduction of expected profits for domestic firms will shift domestic market shares from high- to low-productivity firms, thereby lowering industry productivity.[11]

Thus, an increase in imports and foreign R&D may lower domestic productivity through selection, and it may raise domestic productivity to the extent that there are significant technology spillovers resulting from imports and foreign R&D. To estimate the relative importance of these effects, consider the following extension of the R&D-productivity framework:

$$tfp_{cit} = \beta_d r^d_{cit} + \sum_{c'} \beta_{c'} r^f_{c'it} + \sum_{c'} \beta_{c'} m_{cc'it} + \varepsilon_{cit}, \tag{1}$$

where $tfp_{cit}$ is a measure of total factor productivity in industry $i$ and year $t$ of country $c$,with $i = 1, ..., 22$, $c = 1, ..., 16$, and $t = 1973, ..., 2002$. Since the assumption of constant returns to scale is not rejected, we impose it and construct TFP as $tfp_{cit} = y_{cit} - \alpha l_{cit} - (1-\alpha)k_{cit}$, where $y_{cit}$ is value added, $l_{cit}$ employment (number of workers), and $k_{cit}$ is the capital stock, all in logs. We choose $\alpha = 0.72$, which is equal to the median labor share in the sample.[12] The variables $r^d_{cit}$ and $r^f_{c'it}$ in equation (1) are domestic and foreign R&D (in logs), and $m_{cc'it}$ is the log imports of country $c$'s industry $i$ from the same industry in country $c'$ in year $t$. The variable $\varepsilon_{cit}$ is an error term that will be defined below.

In principle, we could study the relationships between all OECD countries symmetrically. However, relatively small countries such as Belgium or Denmark are unlikely to have a comparable impact on other OECD countries as have larger countries. The United States,

[11] See Demidova (2006) and Falvey, Greenaway, and Yu (2006) for details.

[12] Acharya and Keller (2007) obtain production function elasticity estimates for these industries, showing that the labor (capital) elasticity is very close to the labor (one minus the labor) share. Below we have also employed alternative TFP measures that incorporate information on industry-specific factor shares; as Table A3 in the Appendix shows, this leads to similar results.

in particular, is relatively large in terms of R&D and exports to all other sample countries, and for the most part we focus on imports- and R&D effects of the U.S. in the 16 other OECD sample countries. Equation (1) is specialized to

$$tfp_{cit} = \beta_0 + \beta_d r^d_{cit} + \beta_U r^f_{Uit} + \beta_m m_{Ucit} + \beta_J r^f_{Jit} + \beta_G r^f_{Git} + \varepsilon_{cit}, \tag{2}$$

where $r^f_{Uit}$, $r^f_{Jit}$ and $r^f_{Git}$ are log R&D stocks in the U.S., Japan, and Germany, and $m_{Ucit}$ is log imports from the United States. Japan and Germany are the second- and third-largest countries in terms of R&D in the sample, and they may have significant effects on productivity independent of U.S. R&D and exports.[13]

In order to better assess the relative importance of selection and technology spillovers, we also add interactions of imports with R&D and imports with average firm size

$$tfp_{cit} = \Psi + \beta_U r^f_{Uit} + \beta_m m_{Ucit} + \beta_e \left[ m_{Ucit} \times r^f_{Uit} \right] + \beta_s \left[ m_{Ucit} \times s_{cit} \right] + \varepsilon_{cit}, \tag{3}$$

where $s_{cit}$ is the average firm size in country $c$'s industry $i$ at time $t$, and $\Psi = \beta_0 + \beta_d r^d_{cit} + \beta_J r^f_{Jit} + \beta_G r^f_{Git}$. The parameters $\beta_e$ and $\beta_s$ give evidence on the extent to which the productivity impact of U.S. imports varies, respectively, with the technology embodied in these imports and with firm size, where this size may also reveal information on the existing degree of productivity selection in the importing industry.

Two complications in obtaining consistent parameters in equation (3) are possible omitted

[13] Adding R&D variables of other major countries (e.g., France, the U.K., Canada, or Italy) does not affect our key results.

variable- and endogeneity problems. To address these, we employ two different estimators: (1) fixed effects ('within') estimation and (2) dynamic instrumental variable (IV) estimation. In the former, the error term is specified as

$$\varepsilon_{cit}^{w} = \mu_{ci} + \eta_t + u_{cit}, \tag{4}$$

where $\mu_{ci}$ are deterministic fixed effects for each country-by-industry combination, $\eta_t$ is a fixed effect for each year, and $u_{cit}$ is a mean-zero but possibly heteroskedastic disturbance. Importantly, the $\mu_{ci}$ fixed effects will control for any heterogeneity across industries that is omitted from (3), as long as it is constant over time.

Results using the IV estimator proposed by Arellano, Blundell, Bond, and others are also presented (Arellano and Bond 1991, Blundell and Bond 2000). In that case, the regression error is given by

$$\begin{gathered} \varepsilon_{cit}^{b} = \lambda_c + \varsigma_i + \eta_t + \nu_{cit} \\ \nu_{cit} = \rho \nu_{cit-1} + u_{cit} \end{gathered} \tag{5}$$

Here, $\lambda_c$, $\varsigma_i$, and $\eta_t$ are deterministic fixed effects for each country, industry, and year, respectively. The random shock $\nu_{cit}$ changes over time following an AR(1). This approach yields moment conditions for combining equations in the variables' levels with equations in the variables' differences for a so-called System GMM approach. In both sets of equations, one essentially uses lagged values to construct instrumental variables for current variables.

An advantage of the Systems GMM estimator is that it deals with endogeneity problems;

for example, the size of industry imports from the U.S. could be in part determined by how sizable the technology spillovers are that this provides. The cost is in the form of additional assumptions and added complexity which can reduce the estimator's performance. Below we find qualitatively similar results using either estimation method.[14]

# 4 Estimation results

This section presents our empirical results. We begin with fixed-effects estimates in Tables 8 and 9 before turning to IV results in Table 10. The first column of Table 8 gives results for the following specification:

$$tfp_{cit} = \mu_{ci} + \eta_t + \beta_U r^f_{Uit} + \beta_d r^d_{cit} + \beta_J r^f_{Jit} + \beta_G r^f_{Git} + u_{cit},$$

where $\mu_{ci}$ and $\eta_t$ are fixed effects that are treated as parameters. The sample consists of the years 1973 to 2002, though the sample is somewhat smaller because all independent variables are lagged by two years in order to reduce endogeneity problems.[15] The domestic R&D elasticity is 0.11, and those for U.S., Japan, and Germany are 0.24, 0.21, and 0.07, respectively; these figures are in line with what earlier studies found (see Griliches 1995).[16] Replacing the U.S. R&D variable with imports from the U.S., the import coefficient is negative (column 2).

[14] We have also considered the Olley and Pakes (1996) estimator, and found that the results are quite similar for this sample; see also van Biesebroeck (2004) who analyzes the robustness of several related estimators.

[15] Since we want to estimate the effects from U.S. imports and R&D, we also eliminate the 22 U.S. industries from the sample; it consists of the remaining 16 OECD countries, times 22 industries.

[16] Note that we do not double-count the Japanese and German R&D in our analysis; for example, for the German industries, we set the value of $r^f_{Git}$ to equal zero.

When both U.S. imports and R&D are included together with their interaction $m_{Ucit} \times r^f_{Uit}$, it is the latter that is estimated to have a positive effect on productivity; the direct U.S. imports and R&D impact actually lower domestic productivity (column 4). This is consistent with substantial productivity selection through the product market impacts of foreign R&D and imports, as predicted by heterogeneous firm models. In addition, the positive coefficient on the imports-R&D interaction indicates that if the imports from the U.S. are highly technology-intensive, this can generate major technological externalities that raise productivity in the importing country.

We also find that the imports-firm size interaction in specification (5) yields a positive coefficient, so that in industries where the typical firm is relatively large, the negative productivity selection effect from imports is muted. This is an interesting result that to our knowledge has not been emphasized in the literature. What could be behind this relationship? It is of course possible that relatively weak industries (i.e., where the typical firm is relatively small) are more vulnerable to import competition than relatively strong industries, but this is not necessarily the case in heterogeneous-firm models.[17] Another possibility is that the selection effect is lower when the typical firm is relatively large because such firms tend to invest more in technology and might thus benefit more from imports-related externalities than smaller firms.[18]

Table 9 presents the same set of results for the period 1984 to 2002. As noted above,

[17] In particular, if no home firm is exporting before the increase in imports, the latter is unlikely to lower expected profits from exporting as those must be already extremely low to begin with.

[18] This so-called absorptive capacity argument has first been made by Cohen and Levinthal (1989). In addition to the firm size-imports interaction, we have also experimented with including the firm size variable by itself. This does not change our main findings. Firm size typically has no significant effect on productivity. When size has an effect, it is positive, and the size-imports interaction has a positive impact as well.

for these years the coverage in terms of countries is more balanced, and the average firm size variable exhibits not only cross-sectional but also time-series variation. We find that while the point estimates change, qualitatively the results are similar. Both U.S. imports and R&D lower while technology-intensive imports raises domestic productivity (column 5). There is also less selection in industries with relatively large firms, although the effect is now quite small.[19]

The IV results are presented in Table 10. The first specification is comparable to column (3) in Table 1, but note that the IV regression has about 1,000 fewer observations due to lags needed to construct instruments. According to both the 'within' and the IV results, U.S. R&D raises domestic productivity while imports from the U.S. tend to lower it. We also report Hansen's J from the test of overidentifying restrictions. The p-value of 0.655 indicates that one cannot reject the null hypothesis that the instruments as a set are valid.[20] Adding the imports-R&D interaction yields the same positive coefficient as before (Table 10, column 2); one difference is that now, the negative US R&D coefficient is less precisely estimated. The IV specification confirms that larger firm size leads to a reduced selection effect from imports, see the results in Table 10 for both the longer (column 3) as well as the shorter sample (column 4).

The robustness of the estimates has been analyzed, and we now summarize some of the findings. First, it is important to see whether the imports and R&D of other major countries such as Japan and Germany also generate a mix of selection and technological externalities,

[19] The impact from domestic R&D is estimated to be smaller for these years, consistent with international sources of productivity change being particularly important during this time.

[20] The set of instruments is given at the bottom of Table 10.

or whether these are specific phenomena for the United States. We find generally similar results for Japan and Germany.[21] Second, the TFP variable employs the same labor- and capital elasticities for all industries. In Table A3 of the Appendix, we report results for an alternative TFP variable with input elasticities varying by industry; overall, the results are quite similar to those in Tables 8 to 10 discussed above.[22]

How large are the selection and spillover effects quantitatively? The elasticity of TFP with respect to U.S. imports and R&D is reported in Tables 8 to 10 at the bottom. The average imports elasticity appears to be close to zero; for the four specifications, the values range from -3.2% to 1.6%. The impact of U.S. imports on domestic productivity varies strongly, however, as the minimum and maximum elasticities indicate. Selection is important; for example, according to the IV specification (3) in Table 10, about 75% of all industries experience lower productivity as a consequence of an increase in U.S. imports. Moreover, firm size has a sizable influence on this magnitude. The estimate of $\hat{\beta}_s = 0.013$ for the imports-size interaction in (5), Table 8, for example, implies that when firm size increases from the 25th to the 75th percentile, the imports elasticity increases by 2.4 percentage points. With an average import elasticity of -3.2%, firm size differences have some but not an overriding impact on the productivity consequences of imports from the United States.[23]

[21] In Table A2, we compare the results for the U.S. with those for Japan and Germany. Table A2's column (1) repeats the earlier results for the U.S. from Table 8, while columns (2) and (3) report analogous results for Japan and Germany, respectively. There are some differences, in particular the linear effect from Japanese R&D is positive, not negative as it is for the United States. At the same time, the similarities dominate: for all three countries, (i) the direct effect of imports is negative, (ii) technology-intensive imports raise productivity, and (iii) large firm size reduces the negative selection effect from imports.

[22] Based on the data on labor's share in total factor payments, most of the variation is in the industry dimension. The alternative TFP indices use $\tilde{\alpha}_i$ as labor's share, which is the median labor share for each industry $i$, together with the assumption of CRS.

[23] Also note that the firm-size impact of the effect from imports is smaller according to estimates of $\beta_s$ in Tables 9 and 10.

In contrast to imports, the average U.S. R&D elasticity is positive, at about 24%. However, the impact of U.S. R&D can vary tremendously, depending on how much the industry exports. From the point of view of the importer, the amount of U.S. R&D determines whether imports from the U.S. lead to higher or lower domestic productivity. For example, a change of U.S. R&D spending from the 25th to the 75th percentile is associated with a 6.3 percentage points increase in the imports elasticity (for (5), Table 8). With an average imports elasticity of -3.2%, it is clear that the extent of U.S. R&D, or, how technology-intensive imports are, is the critical determinant of the productivity consequences in the domestic economy.

Overall, the results are consistent with models in which trade generates both major selection processes and technology spillovers.

# 5 Conclusions

*Does importing affect domestic productivity through selection and technology spillovers?* To answer this question, we analyzed the productivity dynamics in response to U.S. exports in several major countries. It is particularly revealing to look at changes triggered by US exports, both because the U.S. is an important and sometimes even dominant trade partner, and because the United States is the single most important source of technology creation in the world, accounting for about 40% of the world's R&D spending. To examine the impact of imports, we study productivity dynamics at the industry-level. The analysis focuses on the productivity effects of imports through selection and technology spillovers. Admittedly, international product market competition need not take the form of trade, and productivity might be affected by factors other than selection and spillovers. However, these mechanisms are central to recent theoretical and empirical work, and they are much-emphasized in the policy discussion as well. Our empirical results strikingly demonstrate that selection and technology spillovers must figure prominently in any successful model in which international trade affects productivity.

It would have been impossible to arrive at these results without extensive data. To this end, we constructed a unique database on inputs, outputs, and international trade for most of the industrialized world and a relatively long thirty-year sample period. The analysis includes sufficient detail to isolate major technology drivers such as the computer and communication equipment industries. This is combined with information on the typical firm's size to trace out market share reallocations in response to a surge in imports.

Our main conclusions are as follows: (1) On average, an increase in imports has only a small if any impact on domestic productivity. (2) Foreign R&D, in contrast, usually has a positive effect on domestic productivity, with a mean U.S. elasticity of around 24%. (3) The degree to which imports are technology-intensive determines whether imports raise or lower domestic productivity. Imports in high-R&D industries tend to raise productivity while imports in low-R&D industries tend to lower productivity. (4) Selection from imports is somewhat lower when the typical domestic firm is large.

Overall, the results are consistent with a model in which imports lead to both selection and technology spillovers. The net impact of imports hinges on the relative size of the competition, or selection, and the technology transfer effect. If new imports primarily amount to increased product market competition, the selection effect dominates and domestic productivity in the long-run falls. In contrast, if imports are a significant source of new technology, this can outweigh the competition effect, leading to a long-run increase in domestic productivity. It is plausible that our results analogously apply to exports and foreign direct investment as well, although at this point this is a conjecture.

An important question raised by our findings is the following: Why do many studies find that productivity rises with increased foreign competition, while the selection effect here is negative? There could be a number of reasons. First, we know that for a given number of firms across countries –that is, in the short-run–, unilateral trade liberalization raises productivity while in the long-run the shift of firms away from the liberalizing country lowers its productivity (Melitz and Ottaviano 2008). This may explain differences in results, since our study, with three decades of data, arguably estimates long-run relationships whereas other studies with a shorter sample period may have identified short-run effects.

Another possibility is that an increase in openness leads to multiple changes in the domestic market, with increased product market competition being only one of them. Our findings suggest that technological learning might be important, but there are other activities that might affect productivity. For example, there is evidence that firms make technology investments to prepare for more intensive competition, which by itself might lead to higher productivity.[24] Future research will have to analyze the significance of these and possibly other determinants of the impact of increased openness on domestic productivity.

[24] An example is Hallward-Driemeier, Iarossi, and Sokoloff (2002).

# References

[1] Acharya, R., and W. Keller (2007), "The Evolution of the World's Technology Frontier, 1973-2002", Industry Canada Working Paper # 2007-03.

[2] Aitken, B., and A. Harrison (1999), "Do Domestic Firms Benefit from DFI? Evidence from Venezuela", American Economic Review 89: 605-618.

[3] Arellano, M. and S. Bond (1991), "Some Tests of Specification for Panel Data: Monte Carlo Evidence and an Application to Employment Equations", Review of Economic Studies 58: 277-97.

[4] Bernard, A., and B. Jensen (1999), "Exceptional Exporter Performance: Cause, Effect, or Both?", Journal of International Economics 47: 1-25.

[5] Bernard, A., S. Redding, and P. Schott (2006), "Multi-Product Firms and Trade Liberalization", CEP Working Paper 769, London School of Economics.

[6] Blundell, R., and S. Bond (2000), "GMM Estimation with Persistent Panel Data: An Application to Production Functions", Econometric Reviews 19: 321-340.

[7] Broda, C., and D. Weinstein (2006), "Globalization and the Gains from Variety", Quarterly Journal of Economics 121: 541-585.

[8] Chen, N., J. Imbs, and A. Scott (2006), "The dynamics of trade and competition", National Bank of Belgium working paper no. 91.

[9] Clerides, S., S. Lach, and J. Tybout (1998), "Is Learning by Exporting Important? Micro-dynamic Evidence from Colombia, Mexico, and Morocco", Quarterly Journal of Economics 113: 903-947.

[10] Cohen, W., and D. Levinthal (1990), "Absorptive capacity: a new perspective on learning and innovation", Administrative Science Quarterly 35: 128-152.

[11] Combes, P., G. Duranton, L. Gobillon, D. Puga, and S. Roux (2007), "The productivity advantages of large markets: Distinguishing agglomeration from firm selection", October 2007.

[12] De Loecker, J. (2007), "Do Exports Generate Higher Productivity? Evidence from Slovenia", Journal of International Economics 73: 69–98.

[13] Demidova, S. (2006), "Productivity Improvements and Falling Trade Costs: Boon or Bane", Penn State working paper.

[14] Falvey, R., D. Greenaway, and Z. Yu (2006), "Extending the Melitz Model to Asymmetric Countries", University of Nottingham research paper 2006/07.

[15] Griliches, Z. (1995), "R&D and Productivity: Econometric Results and Measurement Issues", Chapter 3 in P. Stoneman (ed.), Handbook of the Economics of Innovation and Technological Change, Basil Blackwell: Oxford.

[16] Griliches, Z. (1979), "Issues in Assessing the Contribution of R&D to Productivity", Bell Journal of Economics 10: 92-116.

[17] Hallward-Driemeier, M., G. Iarossi, and K. Sokoloff (2002), "Exports and Manufacturing Productivity in East Asia: A Comparative Analysis with Firm-level Data", NBER Working Paper # 8894.

[18] Keller, W. (2004), "International Technology Diffusion", Journal of Economic Literature XLII: 752-782.

[19] Keller, W. (2002), "Trade and the Transmission of Technology", Journal of Economic Growth.

[20] Melitz, M. (2003), "The Impact of Trade on Intra-Industry Reallocations and Aggregate Industry Productivity", Econometrica 71: 1695-1725.

[21] Melitz, M., and G. Ottaviano (2008), "Market Size, Trade, and Productivity", Review of Economic Studies 75: 295-316.

[22] Nicita, A., and M. Olarreaga (2006), "Trade, Production, and Protection, 1976-2004", World Bank Economic Review 21(1).

[23] Nocke, V., and S. Yeaple (2006), "Globalization and Endogenous Firm Scope", NBER Working Paper # 12322.

[24] OECD (2008a), Structural Analysis (STAN) Database, OECD, Paris.

[25] OECD (2008b), Analytical Business Expenditure in Research and Development (ANBERD) Database, OECD, Paris.

[26] OECD (2008c), Bilateral Trade Database (BTD), OECD, Paris.

[27] Pavcnik, N. (2002), "Trade Liberalization, Exit, and Productivity Improvements: Evidence from Chilean Plants", Review of Economic Studies 69: 245-276.

[28] van Ark, B., et al. (2005), Groningen Growth & Development Database, Groningen, The Netherlands, http://www.ggdc.net/.

[29] van Biesebroeck, J (2005), "Exporting Raises Productivity in sub-Saharan African Manufacturing Firms", Journal of International Economics 67: 373-391.

[30] van Biesebroeck, J. (2004), "Robustness of Productivity Estimates", NBER Working Paper # 10303.

[31] Windmeijer, F. (2005), "A finite sample correction for the variance of linear efficient two-step GMM estimators", Journal of Econometrics 126: 25-51.

**Table 1: Summary statistics for key variables**

| Variable | Obs | Mean | Stdev |
|---|---|---|---|
| TFP | 9659 | 2.36 | 0.72 |
| US Imports | 10098 | 11.54 | 1.98 |
| US R&D | 10176 | 9.00 | 1.54 |
| US Imports x US R&D | 9738 | 105.33 | 30.23 |
| Domestic R&D | 9525 | 5.38 | 2.28 |
| Japan R&D | 10560 | 7.48 | 2.45 |
| Germany R&D | 10432 | 6.76 | 2.58 |
| Av. firm size | 5433 | 8.77 | 1.44 |
| US Imports x av. firm size | 5147 | 104.59 | 25.96 |
| US Imports x firm size* | 9918 | 103.49 | 25.24 |

All variables in logarithms

* Based on average firm size for a given country x industry combination (no time variation)

**Table 2: Sample dynamics**

| | 1973 - 1987 | | | 1988 - 2002 | | | |
|---|---|---|---|---|---|---|---|
| **Variable** | **Obs** | **Mean** | **Stdev** | **Obs** | **Mean** | **Stdev** | **Growth of Mean** |
| **TFP** | 4916 | 2.11 | 0.74 | 4743 | 2.62 | 0.61 | 0.51 |
| **Domestic R&D** | 4759 | 4.95 | 2.38 | 4766 | 5.81 | 2.09 | 0.86 |
| **US R&D** | 5248 | 8.70 | 1.56 | 4928 | 9.33 | 1.45 | 0.63 |
| **US Imports** | 5280 | 10.99 | 1.91 | 4818 | 12.14 | 1.88 | 1.16 |
| **Japan R&D** | 5632 | 6.91 | 2.30 | 4928 | 8.14 | 2.46 | 1.22 |
| **Germany R&D** | 5632 | 6.28 | 2.62 | 4800 | 7.33 | 2.41 | 1.05 |
| **Av. Firm size** | 2339 | 8.48 | 1.37 | 3094 | 9.00 | 1.44 | 0.52 |

All variables in logarithms

**Table 3: Productivity across countries**

| | 1973 - 1987 | | | 1988 - 2002 | | | |
|---|---|---|---|---|---|---|---|
| | Obs | Mean | Stdev | Obs | Mean | Stdev | Growth of Mean |
| Australia | 296 | 2.25 | 0.47 | 280 | 2.62 | 0.50 | 0.37 |
| Belgium | 328 | 2.17 | 0.59 | 308 | 2.76 | 0.52 | 0.59 |
| Canada | 352 | 2.42 | 0.68 | 308 | 2.87 | 0.50 | 0.45 |
| Denmark | 322 | 2.13 | 0.69 | 294 | 2.43 | 0.53 | 0.30 |
| Finland | 348 | 1.88 | 0.64 | 308 | 2.55 | 0.61 | 0.68 |
| France | 316 | 2.27 | 0.74 | 308 | 2.71 | 0.56 | 0.45 |
| UK | 322 | 1.98 | 0.69 | 308 | 2.64 | 0.57 | 0.66 |
| Germany | 350 | 2.13 | 0.60 | 308 | 2.54 | 0.47 | 0.41 |
| Ireland | | | | 165 | | | |
| Italy | 346 | 2.19 | 0.79 | 308 | 2.59 | 0.42 | 0.40 |
| Japan | 346 | 1.96 | 0.80 | 308 | 2.49 | 0.67 | 0.53 |
| Korea | 352 | 1.53 | 0.94 | 308 | 2.28 | 0.78 | 0.75 |
| Netherlands | 322 | 2.20 | 0.71 | 308 | 2.61 | 0.46 | 0.41 |
| Norway | 346 | 2.16 | 0.75 | 308 | 2.47 | 0.49 | 0.31 |
| Spain | 230 | 2.45 | 0.60 | 308 | 2.69 | 0.62 | 0.25 |
| Sweden | 340 | 2.04 | 0.65 | 308 | 2.56 | 0.63 | 0.52 |
| United States | 322 | 2.54 | 0.69 | 308 | 2.93 | 0.56 | 0.39 |

**Table 4: R&D across countries**

| | Obs | Mean | Stdev | Obs | Mean | Stdev | Growth of Mean |
|---|---|---|---|---|---|---|---|
| Australia | 352 | 4.15 | 1.81 | 308 | 5.29 | 1.14 | 1.14 |
| Belgium | 22 | | | 308 | 5.17 | 1.62 | |
| Canada | 352 | 5.14 | 1.86 | 308 | 5.94 | 1.72 | 0.81 |
| Denmark | 352 | 3.32 | 2.17 | 308 | 4.01 | 2.13 | 0.69 |
| Finland | 352 | 3.41 | 1.65 | 308 | 4.93 | 1.18 | 1.52 |
| France | 352 | 6.51 | 1.72 | 308 | 7.35 | 1.53 | 0.84 |
| UK | 352 | 6.86 | 1.61 | 308 | 7.14 | 1.56 | 0.28 |
| Germany | 352 | 6.70 | 2.12 | 300 | 7.82 | 1.54 | 1.13 |
| Ireland | 198 | | | 308 | 3.17 | 1.86 | |
| Italy | 346 | 5.11 | 2.05 | 308 | 6.31 | 1.62 | 1.19 |
| Japan | 352 | 7.37 | 1.51 | 308 | 8.68 | 1.32 | 1.31 |
| Korea | | | | 154 | | | |
| Netherlands | 352 | 4.86 | 2.07 | 308 | 5.58 | 1.70 | 0.72 |
| Norway | 333 | 3.70 | 1.69 | 308 | 4.48 | 1.24 | 0.77 |
| Spain | 352 | 4.25 | 2.12 | 308 | 5.57 | 1.26 | 1.32 |
| Sweden | 340 | 4.94 | 1.84 | 308 | 5.73 | 1.55 | 0.78 |
| United States | 328 | 8.70 | 1.56 | 308 | 9.33 | 1.45 | 0.63 |

All variables in logs

**Table 5: The significance of imports from the United States by partner country**

| | 1973 - 1987 | | 1988 - 2002 | | |
|---|---|---|---|---|---|
| | Obs | Import Share* | Obs | Import Share* | Change |
| Australia | 352 | 0.11 | 308 | 0.15 | 0.04 |
| Belgium | 352 | 0.08 | 308 | 0.12 | 0.04 |
| Canada | 352 | 0.47 | 308 | 0.73 | 0.26 |
| Denmark | 346 | 0.03 | 308 | 0.04 | 0.01 |
| Finland | 352 | 0.03 | 308 | 0.04 | 0.01 |
| France | 352 | 0.03 | 308 | 0.03 | 0.01 |
| UK | 352 | 0.15 | 308 | 0.08 | -0.07 |
| Germany | 352 | 0.02 | 308 | 0.03 | 0.01 |
| Ireland | 240 | 0.13 | 294 | 0.15 | 0.01 |
| Italy | 352 | 0.05 | 308 | 0.03 | -0.01 |
| Japan | 352 | 0.02 | 308 | 0.04 | 0.02 |
| Korea | | | 198 | 0.09 | |
| Netherlands | 352 | 0.05 | 308 | 0.11 | 0.06 |
| Norway | 352 | 0.06 | 308 | 0.09 | 0.02 |
| Spain | 322 | 0.04 | 308 | 0.04 | -0.01 |
| Sweden | 352 | 0.07 | 306 | 0.05 | -0.02 |

*Median ratio of imports from US to domestic value added across industries

**Table 6: US R&D by industry***

| | 1973 - 1987 | | | 1988 - 2002 | | | |
|---|---|---|---|---|---|---|---|
| | Obs | Mean | Stdev | Obs | Mean | Stdev | Growth of Mean |
| Food products | 256 | 8.68 | 0.19 | 224 | 9.11 | 0.03 | 0.43 |
| Textiles | 256 | 6.73 | 0.22 | 224 | 7.54 | 0.17 | 0.80 |
| Wood products | 256 | 7.94 | 0.23 | 224 | 7.22 | 0.19 | -0.72 |
| Paper products | 256 | 8.54 | 0.23 | 224 | 9.14 | 0.23 | 0.60 |
| Petroleum products | 256 | 9.41 | 0.13 | 224 | 9.44 | 0.13 | 0.03 |
| Chemicals | 256 | 10.16 | 0.27 | 224 | 10.82 | 0.07 | 0.66 |
| Pharmaceuticals | 256 | 9.87 | 0.24 | 224 | 10.79 | 0.25 | 0.92 |
| Rubber & plastics | 256 | 8.23 | 0.13 | 224 | 8.82 | 0.25 | 0.59 |
| Non-metallic mineral prod. | 256 | 8.19 | 0.18 | 224 | 8.43 | 0.09 | 0.24 |
| Iron and steel | 256 | 8.05 | 0.13 | 224 | 7.83 | 0.10 | -0.21 |
| Non-ferrous metals | 256 | 8.05 | 0.04 | 224 | 8.05 | 0.07 | 0.00 |
| Metal products | 256 | 8.39 | 0.15 | 224 | 8.86 | 0.15 | 0.46 |
| Machinery and eq. | 160 | 9.44 | 0.32 | 224 | 10.06 | 0.20 | 0.62 |
| Computers | 256 | 5.29 | 1.64 | 224 | 10.39 | 1.40 | 5.10 |
| Elect. Machinery | 160 | 9.47 | 0.31 | 224 | 9.78 | 0.20 | 0.31 |
| Communication eq. | 160 | 10.24 | 0.08 | 224 | 11.25 | 1.01 | 1.01 |
| Instruments | 256 | 10.06 | 0.25 | 224 | 10.91 | 0.27 | 0.85 |
| Motor vehicles | 256 | 10.87 | 0.12 | 224 | 11.33 | 0.08 | 0.47 |
| Ships | 160 | 8.52 | 0.37 | 224 | 7.42 | 0.23 | -1.10 |
| Aircraft | 256 | 11.94 | 0.08 | 224 | 11.86 | 0.18 | -0.08 |
| Railroad equipment | 256 | 6.85 | 0.65 | 224 | 8.13 | 0.15 | 1.29 |
| Other manufacturing | 256 | 7.45 | 0.58 | 224 | 7.99 | 0.12 | 0.54 |

* log of U.S. R&D stock

**Table 7: The significance of US imports by industry**

| | 1973 - 1987 | | 1988 - 2002 | | |
|---|---|---|---|---|---|
| | Obs | Import Share* | Obs | Import Share* | Change |
| Food products | 239 | 0.04 | 219 | 0.03 | -0.01 |
| Textiles | 239 | 0.03 | 219 | 0.04 | 0.01 |
| Wood products | 239 | 0.05 | 219 | 0.05 | 0.00 |
| Paper products | 239 | 0.03 | 219 | 0.03 | 0.01 |
| Petroleum products | 234 | 0.08 | 219 | 0.07 | -0.01 |
| Chemicals | 234 | 0.14 | 219 | 0.13 | -0.02 |
| Pharmaceuticals | 234 | 0.05 | 219 | 0.09 | 0.04 |
| Rubber & plastics | 234 | 0.03 | 219 | 0.05 | 0.02 |
| Non-metallic mineral prod. | 239 | 0.01 | 219 | 0.02 | 0.00 |
| Iron and steel | 234 | 0.01 | 219 | 0.01 | 0.00 |
| Non-ferrous metals | 234 | 0.10 | 219 | 0.09 | -0.01 |
| Metal products | 234 | 0.04 | 219 | 0.02 | -0.02 |
| Machinery and eq. | 229 | 0.09 | 219 | 0.12 | 0.02 |
| Computers | 229 | 1.03 | 219 | 0.99 | -0.05 |
| Elect. Machinery | 229 | 0.09 | 219 | 0.12 | 0.02 |
| Communication eq. | 229 | 0.17 | 217 | 0.24 | 0.07 |
| Instruments | 234 | 0.36 | 219 | 0.36 | 0.00 |
| Motor vehicles | 234 | 0.05 | 219 | 0.06 | 0.00 |
| Ships | 234 | 0.02 | 219 | 0.03 | 0.01 |
| Aircraft | 213 | 0.88 | 205 | 1.13 | 0.25 |
| Railroad equipment | 229 | 0.02 | 219 | 0.06 | 0.05 |
| Other manufacturing | 239 | 0.02 | 219 | 0.04 | 0.02 |

*Median ratio of imports from US to domestic value added across countries

**Table 8: Technology Transfer and Selection During the Years 1973-2002**

| | (1) | (2) | (3) | (4) | (5) |
|---|---|---|---|---|---|
| **US R&D** | 0.239 | | 0.247 | -0.116 | -0.108 |
| | (0.015) | | (0.015) | (0.035) | (0.036) |
| **US Imports** | | -0.023 | -0.037 | -0.303 | -0.422 |
| | | (0.008) | (0.008) | (0.028) | (0.046) |
| **US Imports x US R&D** | | | | 0.031 | 0.030 |
| | | | | (0.003) | (0.003) |
| **US Imports x Firm Size** | | | | | 0.013 |
| | | | | | (0.004) |
| **Domestic R&D** | 0.110 | 0.190 | 0.113 | 0.101 | 0.103 |
| | (0.011) | (0.013) | (0.011) | (0.010) | (0.010) |
| **JPN R&D** | 0.209 | 0.263 | 0.203 | 0.178 | 0.176 |
| | (0.017) | (0.015) | (0.017) | (0.016) | (0.016) |
| **GER R&D** | 0.067 | 0.140 | 0.065 | 0.097 | 0.102 |
| | (0.011) | (0.013) | (0.011) | (0.011) | (0.011) |
| **# of obs** | 7902 | 8169 | 7902 | 7902 | 7804 |
| **Rsq** | 0.718 | 0.685 | 0.719 | 0.728 | 0.729 |
| **Elasticity US Imports** | | | | | -0.032 |
| **(min, max)** | | | | | (-0.215, 0.123) |
| **Elasticity US R&D** | | | | | 0.245 |
| **(min, max)** | | | | | (-0.035, 0.421) |

Dependent variable: log total factor productivity
All regressions include fixed effects at the country x industry level and for each year
Robust standard errors in parentheses

**Table 9: Technology Transfer and Selection During the Years 1984 - 2002**

| | (1) | (2) | (3) | (4) | (5) |
|---|---|---|---|---|---|
| **US R&D** | 0.230 | | 0.232 | -0.434 | -0.417 |
| | (0.028) | | (0.028) | (0.059) | (0.059) |
| **US Imports** | | 0.003 | -0.010 | -0.484 | -0.497 |
| | | (0.010) | (0.010) | (0.044) | (0.044) |
| **US Imports x US R&D** | | | | 0.054 | 0.053 |
| | | | | (0.005) | (0.005) |
| **US Imports x Firm Size** | | | | | 0.002 |
| | | | | | (0.001) |
| **Domestic R&D** | 0.045 | 0.085 | 0.044 | 0.016 | 0.015 |
| | (0.014) | (0.018) | (0.014) | (0.013) | (0.013) |
| **JPN R&D** | 0.219 | 0.299 | 0.217 | 0.177 | 0.182 |
| | (0.027) | (0.028) | (0.027) | (0.024) | (0.024) |
| **GER R&D** | 0.107 | 0.207 | 0.108 | 0.130 | 0.126 |
| | (0.026) | (0.028) | (0.026) | (0.023) | (0.023) |
| **# of obs** | 4577 | 4577 | 4577 | 4577 | 4577 |
| **Rsq** | 0.637 | 0.619 | 0.637 | 0.663 | 0.664 |
| **Elasticity US Imports** | | | | | 0.007 |
| **(min, max)** | | | | | (-0.168, 0.207) |
| **Elasticity US R&D** | | | | | 0.219 |
| **(min, max)** | | | | | (-0.147, 0.517) |

Dependent variable: log total factor productivity
All regressions include fixed effects at the country x industry level and for each year
Robust standard errors in parentheses

**Table 10: Technology Transfer and Selection - System IV GMM**

| | Years 1973 - 2002 | | | Years 1984 - 2002 |
|---|---|---|---|---|
| | **(1)** | **(2)** | **(3)** | **(4)** |
| **US R&D** | 0.336 | 0.058 | 0.089 | 0.059 |
| | (0.048) | (0.098) | (0.101) | (0.119) |
| **US Imports** | -0.014 | -0.201 | -0.252 | -0.239 |
| | (0.023) | (0.065) | (0.067) | (0.069) |
| **US Imports x US R&D** | | 0.022 | 0.020 | 0.022 |
| | | (0.007) | (0.007) | (0.008) |
| **US Imports x Firm Size** | | | 0.006 | 0.006 |
| | | | (0.002) | (0.002) |
| **Domestic R&D** | 0.061 | 0.056 | 0.045 | 0.048 |
| | (0.020) | (0.019) | (0.020) | (0.022) |
| **JPN R&D** | 0.121 | 0.116 | 0.118 | 0.071 |
| | (0.043) | (0.039) | (0.004) | (0.041) |
| **GER R&D** | 0.070 | 0.078 | 0.082 | 0.123 |
| | (0.023) | (0.022) | (0.022) | (0.029) |
| **# of obs** | 6915 | 6915 | 6821 | 3811 |
| **Hansen OverID J** | 4.16 | 3.56 | 4.46 | 7.55 |
| **[p-value]** | [0.655] | [0.736] | [0.615] | [0.273] |
| **Elasticity US Imports** | | | -0.015 | 0.016 |
| **(min, max)** | | | (-0.120, 0.083) | (-0.073, 0.103) |
| **Elasticity US R&D** | | | 0.238 | 0.263 |
| **(min, max)** | | | (0.099, 0.352) | (0.111, 0.388) |

Dependent variable: log total factor productivity
All regressions include fixed effects for year, country, and industry
Robust Windmeijer (2005)-corrected standard errors in parentheses
Instruments columns (1)-(3): Domestic R&D lags4-6, US imports lags 2-6,
Imports x US R&D lag 2, Imports x Firm Size lag 2, US R&D lag 2; other IVs contemporaneous
Instruments column (4): Domestic R&D lags 2-4, US imports lags 2-6,
Imports x US R&D lag 2, Imports x Firm Size lag 2, US R&D lag 2; other IVs contemporaneous

## Table A1: The matching of industries for the firm size variable

| Classification of this study | | ISIC 3 digit classification employed by UNIDO | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 1 | Food, beverages, and tobacco | 311 | Food products | 313 | Beverages | 314 | Tobacco | | |
| 2 | Textiles, apparel, footwear | 321 | Textiles | 322 | Apparel | 323 | Leather products | 324 | Footwear |
| 3 | Wood products, furniture | 331 | Wood products | 332 | Furniture | | | | |
| 4 | Paper and printing | 341 | Paper | 342 | Printing, publishing | | | | |
| 5 | Petroleum products | 353 | Petroleum refineries | 354 | Petroleum products | | | | |
| 6 | Chemicals | 351 | Industrial chemicals | | | | | | |
| 7 | Pharmaceuticals | 352 | Other chemicals | | | | | | |
| 8 | Rubber & plastics | 355 | Rubber products | 356 | Plastic products | | | | |
| 9 | Non-metallic mineral prod. | 361 | Pottery, china | 362 | Glass | 369 | Other n-met. min. | | |
| 10 | Iron and steel | 371 | Iron and steel | | | | | | |
| 11 | Non-ferrous metals | 372 | Non-ferrous metals | | | | | | |
| 12 | Metal products | 381 | Metal products | | | | | | |
| 13 | Machinery and eq. | 382 | Machinery* | | | | | | |
| 14 | Computers | | | | | | | | |
| 15 | Elect. Machinery | 383 | Electrical machinery** | | | | | | |
| 16 | Communication eq. | | | | | | | | |
| 17 | Instruments | 385 | Instruments | | | | | | |
| 18 | Motor vehicles | 384 | Transportation equipment*** | | | | | | |
| 19 | Ships | | | | | | | | |
| 20 | Aircraft | | | | | | | | |
| 21 | Railroad equipment | | | | | | | | |
| 22 | Other manufacturing | 390 | Other manufacturing | | | | | | |

Notes:
Information on the number of firms is form Nicita/Olarreaga (2006), based on UNIDO data; it is generally available for the years 1981-2002
Major exceptions are France, where 23% of all possible observations are available, as well as Ireland and Germany (about 45%).
* These values are applied to both industries 13 and 14
** These values are applied to both industries 15 and 16
*** These values are applied to industries 18, 19, 20, and 21

**Table A2: Productivity and Imports from the United States, Japan, and Germany**

| | **Imports from the US** (Foreign = US) | **Imports from Japan** (Foreign = JPN) | **Imports from Germany** (Foreign = GER) |
|---|---|---|---|
| | **(1)** | **(2)** | **(3)** |
| **Foreign R&D** | -0.108 | 0.169 | -0.027 |
| | (0.036) | (0.028) | (0.027) |
| **Imports** | -0.422 | -0.211 | -0.232 |
| | (0.046) | (0.029) | (0.040) |
| **Imports x Foreign R&D** | 0.030 | 0.015 | 0.012 |
| | (0.003) | (0.002) | (0.003) |
| **Imports x Firm Size** | 0.013 | 0.007 | 0.014 |
| | (0.004) | (0.002) | (0.004) |
| **Domestic R&D** | 0.103 | 0.074 | 0.133 |
| | (0.010) | (0.010) | (0.012) |
| **US R&D** | | 0.162 | 0.176 |
| | | (0.015) | (0.018) |
| **JPN R&D** | 0.176 | | 0.216 |
| | (0.016) | | (0.018) |
| **GER R&D** | 0.102 | 0.053 | |
| | (0.011) | (0.011) | |
| **# of obs** | 7804 | 7793 | 7800 |
| **Rsq** | 0.729 | 0.738 | 0.711 |

Dependent variable: log total factor productivity
All regressions include fixed effects at the country x industry level and for each year
Robust standard errors in parentheses

**Table A3: TFP Based on Industry-Specific Factor Shares**

| | Fixed-Effects ('Within') | | System IV GMM | |
|---|---|---|---|---|
| | **(1)** | **(2)** | **(3)** | **(4)** |
| **US R&D** | -0.118 | -0.111 | 0.058 | 0.075 |
| | (0.034) | (0.034) | (0.098) | (0.100) |
| **US Imports** | -0.255 | -0.378 | -0.164 | -0.200 |
| | (0.027) | (0.043) | (0.065) | (0.067) |
| **US Imports x US R&D** | 0.027 | 0.027 | 0.018 | 0.017 |
| | (0.003) | (0.003) | (0.007) | (0.007) |
| **US Imports x Firm Size** | | 0.014 | | 0.004 |
| | | (0.004) | | (0.003) |
| **Domestic R&D** | 0.075 | 0.077 | 0.037 | 0.030 |
| | (0.010) | (0.010) | (0.021) | (0.022) |
| **JPN R&D** | 0.170 | 0.168 | 0.123 | 0.123 |
| | (0.015) | (0.015) | (0.038) | (0.038) |
| **GER R&D** | 0.098 | 0.104 | 0.067 | 0.069 |
| | (0.011) | (0.011) | (0.022) | (0.022) |
| **# of obs** | 7902 | 7804 | 6915 | 6821 |
| **Hansen OverID J** | | | 9.38 | 10.44 |
| **[p-value]** | | | [0.153] | [0.107] |

Dependent variable: log total factor productivity with industry-varying factor shares
Columns (1) and (2) include fixed effects for year and country-by-industry
Columns (3) and (4) fixed effects for country, year, and industry
Robust standard errors in parentheses; Windmeijer-corrected in columns (3) and (4)
In columns (1) and (2), all right hand side variables are lagged by two years
Instruments columns (3)-(4): Domestic R&D lags4-6, US imports lags 2-6,
Imports x US R&D lag 2, Imports x Firm Size lag 2, US R&D lag 2; other IVs contemporaneous