# Can trade really hurt? An empirical follow-up on Samuelson's controversial paper

Jürgen Bitzer* Holger Görg† Philipp J.H. Schröder‡

March 2010

**Abstract**

This paper investigates Samuelson's (JEP, 2004) argument that technical progress of the trade partner may hurt the home country. We illustrate this prospect in a simple Ricardian model for situations with outward knowledge spillovers. Within this framework Samuelson's Act II effects may occur. Based on industry level panel data for seventeen OECD countries for the period 1973 to 2000 we show econometrically that the outflow of domestic knowledge via exports or FDI to the rest of the world may have a negative impact on industry output in the home country. This is particularly so when exporting to technologically less advanced countries and, more specifically, China.

*Keywords:* international R&D spillovers, outward foreign direct investment, export driven spillovers
*JEL:* F10, F11, F14, O30.

*Corresponding author: Carl von Ossietzky University Oldenburg, Germany, jbitzer@uni-oldenburg.de

†Kiel institute for the World Economy and Christian-Albrechts-University of Kiel, Germany, and CEPR, holger.goerg@ifw-kiel.de

‡Aarhus School of Business, University of Aarhus, DK-8000 Aarhus C, Denmark, psc@asb.dk

*Acknowledgements:* We are grateful to the late Paul A. Samuelson, Udo Kreickemeier, Doug Nelson, Pascalis Raimondos-Møller, Roy Ruffin, Jonathan Temple, participants of the Annual Conference of the European Trade Study Group in Vienna, the Annual Conference of the Royal Economic Society in Warwick, the Zeuthen Workshop at the University of Copenhagen, the European Economics Association Annual Conference in Budapest and a workshop at Nottingham University for helpful comments. Holger Görg is also affiliated with GlobID at Aarhus School of Business. Philipp J.H. Schröder gratefully acknowledges financial support from the Danish Social Sciences Research Council (grant no. 275-06-0025).

# 1 Introduction

In what has become quite a controversial paper, Samuelson (2004) has renewed the discussion that trade does not always and automatically bestow overall gains on each trade partner. Specifically, he discusses in a Ricardian setting that technological progress in the trade partner country (induced, for example, through imitation of goods exported from the home country) may hurt welfare in the home country. This is what is referred to as Act II in his paper. Taken up by media and enriched with some anecdotal evidence on theft of intellectual property by trade partners, politicians, business people and ordinary citizens concluded that the negative impact of outward knowledge diffusion via trade might countervail the benefits from trade.

The heated public discussion on the Samuelson (2004) paper leaves a mark that the phenomenon was discovered only recently. However, Samuelson's (2004) contribution links to an important branch of the international economics literature that deals with the interaction of trade and technological competition as early as in the 1970s (Samuelson, 1977; Johnson and Stafford, 1993; Gomory and Baumol, 1997, 2000; Jones and Ruffin, 2008 and Ruffin and Jones, 2007). What all these papers have in common is that in one way or another, technological progress in the backward country may hurt welfare (usually measured as relative or real wages) in the technologically advanced home country. These are Samuelson's (2004) Act II type effects.[1]

[1] In fact many of these papers rather show when this type of effect does not occur. A recent example is the Technology Transfer Paradox discussed by Ruffin and Jones (2007) for the two goods case and Jones and Ruffin (2008) for the many goods case. The Paradox is that even when home loses its most advanced comparative advantage sector to foreign, due to a technology shift to foreign, home may actually be better off due to the improvement in the terms of trade. However, depending on parameter ranges – in particular when there is partial specialization – Samuelson's Act II effect may occur, see Ruffin and Jones (2007,

While these papers generally pay little attention to the actual drivers of technological progress in the foreign country, a substantial literature on international knowledge diffusion has evolved in parallel, as summarised recently by Keller (2004). On the theoretical side, papers such as Helpman (1993) and Eaton and Kortum (2001, 2006) provide models which discuss the implications of international technology diffusion on the incentives to innovate, and the relationship with trade.[2] Along with the theoretical literature empirical studies generally acknowledge that trade is an important channel for the diffusion of foreign knowledge (e.g., Coe and Helpman 1995, Bitzer and Geishecker 2006).[3] A related literature stresses the importance of foreign direct investment (FDI) as relevant channels of technology transfer (e.g. van Pottelsberghe and Lichtenberg, 2001, Bitzer and Kerekes 2008). Multinationals' headquarters possess certain firm specific assets (technology) which are, at least partly, transferred to the affiliate abroad (e.g., Markusen, 2002).[4] Evidence shows that local competitors may subsequently learn the technology through either imitation, movements of workers, or input-output linkages with multinationals (e.g., Görg and Greenaway, 2004).

However, thus far the focus of the empirical studies on international

p.212). For an illustrative account of an Act II type effect and under what conditions the effect vanishes see also Krugman (1996, chapter 4).

[2]This branch of literature, however, does not focus on Act II type effects. On the contrary, for example Eaton and Kortum (2006) identify that the high research country may benefit from faster diffusion.

[3]In line with existing literature, we interpret the notion that imports contain knowledge in the broadest possible sense, ranging from actual backwards engineering of products to the wider information contained in the fact that import activities can establish the existence of domestic demand for a certain product, etc.

[4]For example, empirical evidence shows that multinationals have higher productivity than comparable domestic firms, which is in line with this assumption (e.g., Girma and Görg, 2007; Criscuolo and Martin, 2010).

knowledge diffusion has been on the effects in the country *receiving* the knowledge spillover. It is generally examined what impact knowledge from foreign countries has on output or productivity of the receiving (host) country. Obviously, this method can only partly help to answer the questions that emerged with Samuelson's (2004) paper: First, does trade in itself transfer domestic knowledge to trade partners? Here, the answer from existing empirical studies is most likely to be yes. The second, and perhaps more important question is, however, whether this outward-diffusion of knowledge may hurt the home country. While there is anecdotal evidence that knowledge might diffuse to trade partners (e.g., Maskus, 2000) there is, to the best of our knowledge, no formal empirical evidence to answer this question.[5]

This is the starting point of our paper. First, we examine in a simple Ricardian model situations in which, for example, export activity does not only mean the exchange of goods but also constitutes a partial export of the technology used to produce these goods. In the presence of such knowledge spillovers Samuelson's Act II effect can occur.

The present paper differs from previous accounts of such effects (e.g., Johnson and Stafford, 1993, Gomory and Baumol, 1997, Ruffin and Jones, 2007) by tying foreign's technological progress explicitly to knowledge spillovers. The externality of emitting knowledge only occurs while the technologically superior nation features the given industry. The home country, when losing a comparative advantage sector and ceasing production, stops to emit further knowledge within this sector. This way of modelling international knowledge diffusion and the dynamics of changing comparative ad-

[5]This question, however, has important policy implications: if trade indeed has the potential to hurt the home economy through technology diffusion then the commonly used policy to support export activity (e.g., Bernard and Jensen, 2004, Görg, Henry and Strobl, 2008) may need to be rethought.

vantages captures the empirically relevant situation where foreign may take over some of home's previous comparative advantage sectors, while still having a relatively low productivity in the sector in question (e.g. auto-motive, consumer electronics).[6]

We illustrate the effects of this situation on home welfare and output. In particular, within our framework we show that reductions in home welfare caused by spillover-driven foreign technological progress is always associated with output reductions in home's knowledge emitting sector. This provides a motivating framework for our empirical analysis, where we examine econometrically whether R&D embodied in exports and outward FDI are significant channels for outward-diffusion of domestic knowledge and which impact these knowledge spillovers have on production in the home country.

Based on a newly built industry level panel data set for seventeen OECD countries for the period 1973 to 2000 our estimations show that such an outflow of domestic knowledge has indeed a negative impact on industry output in the home country on average. The data and methods applied here are fully embedded in the theoretical and empirical foundations of the international knowledge diffusion literature, and hence the observed effect is distinct from other popular globalisation notions, such as, for example, outsourcing.

Taking the analysis a step further we distinguish trade for OECD countries into exports to technologically advanced and less advanced countries. In the latter category we pay particular attention to China, whose entry into the world economy has received much comment recently. We show that

[6] In contrast previous works, for example, Ruffin and Jones (2007) and Jones and Ruffin (2008), examine situations where home's entire technology for a sector is transferred, allowing foreign to produce after the technology transfer at the same productivity that previously prevailed at home.

the negative impact of export driven knowledge spillovers stems – as theory would suggest – from exports to technologically less advanced countries, and here in particular to China.[7]

Furthermore, taking up a concern repeatedly voiced in the public debate in the US, we investigate whether the US economy – as a technology leader – suffers particularly strongly from exports to technological less advanced countries in Asia. We do not find any evidence for such an argument.

The rest of the paper is structured as follows. The next section presents a simple model to formalize Samuelson's Act II effect and examines the effect on home welfare and output in situations when export activity also constitutes knowledge diffusion. Section 3 describes our empirical approach and data used. Section 4 discusses the estimation results while Section 5 concludes.

## 2 A simple model

This section provides a simple formalization of Samuelson's Act II effect, based on Johnson and Stafford (1993), and illustrates how such an effect may occur in the presence of knowledge spillovers.[8]

Consider a simple Ricardian two country world, where home and foreign

[7] In contrast exports to Central and Eastern Europe, for example, do not show such effects. This difference between various knowledge-receiving regions underlines the fact that our estimations do not simply capture the increased integration of the world economy and the associated relocation of production, but do in fact measure spillovers in the sense of the international knowledge diffusion literature.

[8] Thus, the economic integration captured here is that of knowledge diffusion and not the customary trade or tariff cost reduction. Furthermore, since we are in a Ricardian world the welfare effects derived differ from the effects of economic integration found in imperfect competition trade models, see e.g. Krugman (1980), Gros (1987), Jørgensen and Schröder (2005) and Schröder (2007) for examples.

(denoted by an asterisk) each have the potential ability to produce in three sectors $j = A, B, C$. Goods within each sector are homogeneous. Each sectors' output $(Q_j, Q_j^*)$ is a function of the amount of labor $(L_j, L_j^*)$ used – assuming labor market clearing $(\sum L_j = L, \sum L_j^* = L^*)$ – and a sectorial productivity parameter $(\lambda_j, \lambda_j^*)$, e.g. $Q_j = \lambda_j L_j, j \in \{A, B, C\}$ and similarly for the foreign country. For the sake of clarity we assume that home has an absolute advantage in all sectors throughout, namely $\lambda_j > \lambda_j^*, j \in \{A, B, C\}$, and thus technology transfer – or rather knowledge spillovers – can only occur from home to foreign.[9]

Both countries display identical Cobb-Douglas utility functions

$$U(D_A, D_B, D_C) = D_A^{\alpha} D_B^{\beta} D_C^{\gamma} \quad , \quad U^*(D_A^*, D_B^*, D_C^*) = D_A^{*\alpha} D_B^{*\beta} D_C^{*\gamma} \ , \tag{1}$$

where $D_j$ and $D_j^*$ represent consumption of goods from sector $j$ in home and foreign respectively, and where $\gamma = 1 - \alpha - \beta$.

We consider two time periods $(0, 1)$ where in the initial period, trade patterns feature full specialization and home has a comparative advantage in two sectors, namely $\frac{\lambda_{j,0}}{\lambda_{C,0}} > \frac{\lambda_{j,0}^*}{\lambda_{C,0}^*}, j \in \{A, B\}$, and accordingly foreign has a comparative advantage in sector $C$. In period 1, in contrast, some knowledge diffusion in sector $B$ has occurred and hence a situation of partial specialization may arise in the sense that both home and foreign produce goods in sector $B$.

If partial specialization in period 1 occurs, it will be driven by an increase in $\lambda_{B,1}^*$ compared to $\lambda_{B,0}^*$. We depart from previous literature (e.g.,

[9]Hence, we assume that there is a technology gap between home and foreign, where home is the technological leader. This seems appropriate, given that our empirical analysis focuses on exports and investments from industrialized OECD countries to the rest of the world. Aghion et al. (2007) is a recent paper that provides empirical evidence on the existence of technology gaps between countries.

Johnson and Stafford, 1993, Gomory and Baumol, 1997, Samuelson, 2004, Jones and Ruffin, 2008) and focus explicitly on international knowledge spillovers as the source of foreign technological progress. In particular, $\lambda^*_{B,1} = max\{\theta\lambda_{B,0}, \lambda^*_{B,0}\}$, where $\theta$ measures the extent to which technology spills over – for example via exports by the home country in period 0. Accordingly, $0 \leq \theta \leq min\{1, \bar{\theta}\}$, where $\bar{\theta}$ is the level of spillovers at which the home country ceases production in the $B$ sector. Thus spillovers – and with it spillover-driven foreign technological progress – stop once home has lost its $B$ sector, i.e. is unable to emit any further knowledge. [10] The exact value of $\bar{\theta}$ is derived below. Time subscripts are omitted where unnecessary.

Under the assumption of perfect competition and constant returns to scale, world market prices $P_j$ are equal to marginal (and average) costs, such that in period 0, we have $P_A = \frac{w}{\lambda_A}$, $P_B = \frac{w}{\lambda_B}$ and $P_C = \frac{w^*}{\lambda^*_C}$, where $w$ and $w^*$ are the domestic and foreign wage rates respectively.

Full employment and clearing of income and expenditures implies for the foreign country $w^*L^* = P_C Q_C = \gamma E$, and for the home country $wL = P_A Q_A + P_B Q_B = (\alpha + \beta)E$, where $E$ is the total world expenditure. Accordingly, relative wages in the initial period are

$$\frac{w_0}{w^*_0} = \frac{1-\gamma}{\gamma}\frac{L^*}{L} \ . \tag{2}$$

A Samuelson Act II type effect is observed in terms of real – not relative – wages. In order to calculate real wages we compose the common world price index which, given the above assumptions, is the geometric mean of commodity prices, $P = P_A^{\alpha}, P_B^{\beta}, P_C^{\gamma} = \frac{w^{1-\gamma}w^{*\gamma}}{\lambda_A^{\alpha}\lambda_B^{\beta}\lambda_C^{*\gamma}}$. Now domestic real wages $r = \frac{w}{P}$, which are our measure of welfare for the home country, can be

[10] The possibility for a technology transfer paradox as in Jones and Ruffin (2008) arises for $\theta = 1 > \bar{\theta}$

expressed, using (2), as

$$r_0 = \left(\frac{1-\gamma}{\gamma}\frac{L^*}{L}\right)^{\gamma} \lambda_A^{\alpha}\lambda_B^{\beta}\lambda_C^{*\gamma} , \tag{3}$$

and for the foreign country – based on the same world price index – one finds

$$r_0^* = \left(\frac{\gamma}{1-\gamma}\frac{L}{L^*}\right)^{1-\gamma} \lambda_A^{\alpha}\lambda_B^{\beta}\lambda_C^{*\gamma} . \tag{4}$$

Next consider period 1. With little technology spillover (small $\theta$, such that $\lambda_{B,0}^* > \theta\lambda_{B,0}$) we have $\lambda_{B,1}^* = \lambda_{B,0}^*$, and accordingly full specialization continuing along the same patterns established in period 0. However, for a sufficient degree of knowledge diffusion the increase in $\lambda_{B,1}^*$ could ensure that the foreign country finds it worthwhile to start production in sector $B$. Partial specialization occurs once the ratio of foreign productivity in sector $B$ – i.e. the sector in which potentially both countries are active – to its comparative advantage sector exceed the price ratio of the comparative advantage sector to the partial specialization sector. Formally, partial specialization arises once $\frac{\lambda_{B,1}^*}{\lambda_C^*} > \frac{P_C}{P_B}$. Similarly, once $\frac{\lambda_B}{\lambda_A} < \frac{P_A}{P_B^*}$, home will shut down its $B$ industry and we return to a situation of full specialization, albeit now foreign supplies all goods from sectors $B$ and $C$, and no further spillovers from home to foreign occur in the $B$ sector. Setting prices and the relative wage expression in the above condition yields the following result. Partial specialization in period 1 occurs if

$$\frac{1-\alpha}{\alpha}\frac{L}{L^*} = \bar{\theta} > \theta > \underline{\theta} = \frac{\gamma}{1-\gamma}\frac{L}{L^*} . \tag{5}$$

In the case when $\theta < \underline{\theta}$ we still have full specialization replicating period 0, and in the case where $\theta = \bar{\theta}$ full specialization with reversed roles for home and foreign is obtained. It is easily verified that $\bar{\theta} > \underline{\theta}$ for $\beta > 0$, thus a zone of partial specialization does exist. Furthermore, notice that the lower threshold $\underline{\theta}$ decreases, and thus partial specialization becomes more likely, the larger is the foreign country and the smaller the global preferences for the foreign comparative advantage sector (lower $\gamma$). Similarly, the upper threshold $\bar{\theta}$ increases, thus full reversal of roles becomes less likely, if the home country is larger and if the global preferences for home's comparative advantage sector is smaller (smaller $\alpha$). Put differently, the more important the $B$ sector is in global demand, the larger the zone of partial specialization, where neither country wants to give up production of the goods in question.

The effect on the real wage rates of both countries, should (5) be fulfilled, can be determined as follows: Intra-country inter-sectoral labor mobility ensures wage equalization within each country, and accordingly $w_1 = \lambda_A P_A = \lambda_B P_B$ and similarly $w_1^* = \lambda_C^* P_C = \lambda_{B,1}^* P_B *$. International price equalization results then in the new wage ratio

$$\frac{w_1}{w_1^*} = \frac{\lambda_B}{\lambda_{B,1}^*} = \frac{1}{\theta} \,, \tag{6}$$

which only depends on relative productivity and thus the extent to which technology spills over. Based on (6) the real wages under partial specialization become:

$$r_1 = \theta^{-\gamma} \lambda_A^{\alpha} \lambda_B^{\beta} \lambda_C^{*\gamma} \,, \tag{7}$$

$$r_1^* = \theta^{1-\gamma} \lambda_A^{\alpha} \lambda_B^{\beta} \lambda_C^{*\gamma} \,. \tag{8}$$

Comparison of the home country's real wage from (3) with that derived in (7), yields that $r_1 < r_0$ as long as $\theta > \frac{\gamma}{1-\gamma} \frac{L}{L^*}$, which is exactly the condition for partial specialization ($\theta > \underline{\theta}$) laid out in (5).

The following results (replicating Samuelson's Act II) have thus been derived. First, with sufficient technological spillover from the home to foreign country, home welfare is reduced both absolutely and relatively in the case where partial specialization occurs. This effect occurs, even though the foreign technology is strictly less than the home technology also after the spillover of knowledge ($\theta < 1$). Second, inspection of (7) and (8), discloses, that $\frac{\partial r_1}{\partial \theta} < 0$ and $\frac{\partial r_1^*}{\partial \theta} > 0$; thus, any further spillovers of technology from home to foreign (higher $\theta$) has opposing effects on home and foreign. Improvements in the foreign technology in the $B$ sector – further spillovers – increase the foreign real wage but decrease the home real wage, and thus benefits foreign but hurts home. In contrast, notice that in the real wage expressions of period 0, technology advances in either country benefitted both countries. In particular $\frac{\partial r_0}{\partial \lambda_B} > 0$ and $\frac{\partial r_0^*}{\partial \lambda_B} > 0$, which will of course also be the case once roles are reversed, and foreign is – after a sufficient increase in $\lambda_B^*$ – the sole producer of $B$ goods.[11]

In terms of an empirical investigation into the above effect, items like welfare and/or real wage are either not directly observable or the result of complex and potentially distorted wage formation processes. Yet, the above model has clear and testable implications for the effects of trade and knowledge diffusion on sector output. In particular, consider the home output in the $B$ industry. Under full specialization we have

$$Q_{B,0} = L\lambda_B \left(1 - \frac{\alpha}{\alpha + \beta}\right) \tag{9}$$

in period zero. While in period 1 – assuming that partial specialization has occurred – we have:

$$Q_{B,1} = L\lambda_B \left(1 - \alpha \left(1 + \theta \frac{L^*}{L}\right)\right) \ . \tag{10}$$

Finally, should knowledge diffusion lead to complete role reversal, home's sector $B$ output becomes zero.

[11] Notice however, that after the point for complete role reversal, $\bar{\theta}$, further technological progress in foreign must be due to own ingenuity, as home no longer sponsors a $B$ sector and accordingly there can be no further knowledge spillovers.

Within this framework there are 5 distinct scenarios of trade and knowledge diffusion. The simplest situation is one where the combination of trade and knowledge diffusion in sector $B$ is such that the foreign country does not launch a production of its own within the observed time period. Namely, we start and end in full specialization. Accordingly, from (9) any observed output reductions at home stem either from a deterioration of home's technology (which is empirically not-relevant) or from changes in the taste parameters $\alpha$ and $\beta$.

The next scenario is the key situation illustrated in the above model, namely a move from full specialization to partial specialization. Thus in terms of home's sector $B$ output we move form $Q_{B,1}$ to $Q_{B,0}$. It is easy to verify that $Q_{B,1} < Q_{B,0}$. Thus the reduction in welfare established above is associated with a reduction in home's sector $B$ output.

A third scenario depicts situations where both start and end point feature partial specialization, i.e. the foreign country features over the entire observed time period an active $B$ sector. Accordingly, home output is given by (10) throughout. We have seen in (7) that welfare reductions from trade and knowledge diffusion, will stem from any additional spillovers, i.e. increases in $\theta$. From (10) it follows that such welfare reductions are again associated with output reductions in home's $B$ sector.

The fourth scenario is a situation of complete role reversal. In this situation the home country starts as the sole producer of sector $B$ goods but loses the entire sector. Home's sector $B$ output goes to zero and the home real wages becomes $r_1^{'} = \left(\frac{\alpha}{1-\alpha}\frac{L^*}{L}\right)^{1-\alpha} \lambda_A^{\alpha}(\lambda_B\bar{\theta})^{\beta}\lambda_C^{*\gamma}$. It is is easy to show that such role reversal is a reduction in welfare, i.e. $r_1^{'} < r_0$ for all $\beta > 0$. Thus a reduction in welfare is associated with a reduction in output.[12]

[12]However, for sufficiently large increase in foreign technology - i.e. if foreign obtains

The fifth scenario is a situation where the diffusion of technology from home to foreign moves the two countries from an initial situation of partial specialization to full specialization, where foreign is the sole producer of sector $B$ goods. Again such a situation is associated with an output reduction (zero output) in the $B$ sector of the home country. In terms of welfare it can be shown that $r_1 \geq r_1^{'}$.

Obviously from an empirical perspective the last two scenarios are special, in the sense that the home country ceases all production in the $B$ sector. Given the aggregation level of our data we do not observe such examples.[13] Furthermore, for the unlikely case that all sub sectors are in full specialisation no spillover effect would occur.[14]

technology beyond the level of $\bar{\theta}$ the opposite may be the case, and the elimination of home's $B$ sector can be associated with an increase in home welfare. This is exactly the Technology transfer Paradox of Jones and Ruffin (2008).

[13]See also Redding (2002) for an investigation of levels and dynamics of specialization among OECD countries. He finds, using more disaggregated data than we have, that production values are positive in all country-sector combinations, further substantiating our assumption that full specialization is unlikely in our OECD home countries.

[14]Consider, as an example, the complete specialization case where home produces in a given sub-sector and foreign does not. Under full specialization foreign has no production and will therefore not be able to receive a spillover effect within the sector in question. Thus, outgoing knowledge cannot cause an effect on home's output in the sub-sector, i.e. the estimated coefficient will not be different from zero. In the reverse full specialization case, in which foreign is the sole producer in a given sub-sector, home has no output and hence no R&D in that sector to transmit. Thus, the home sub-sector would not show up in the data. Therefore in the case of full specialization in all sub-sectors no outgoing spillover effect will be observed at the aggregate sector level, i.e. no coefficient different from zero would be obtained. Furthermore, should spillovers occur across the sub-sector boundaries (say due to technical similarities or substitutability of products), it would be appropriate to bundle the sub-sectors into an aggregated sector, hence depicting a situation of partial specialization envisaged in the model.

In order to make the link to our empirical analysis that follows, what is important in all the above examples (including the empirically relevant cases where both home and foreign have a $B$ sector) is that the harmful welfare effects of knowledge diffusion and trade are associated directly with a reduction in sector output in the technology sending country. Put differently, within this framework a knowledge spillover driven Samuelson Act II type effect – expressed in real wage terms – goes hand in hand with a reduction in home output of the sector in question. This is the starting point for our empirical analysis.

Finally, return once more to our key condition. When (5) is fulfilled a spillover driven Act II effect occurs. Thus under this condition the combination of trade and knowledge spillovers is harmful for the sending country. Inspection of (5) shows that a larger size of the home country reduces the risks of harmful trade in the presence of knowledge diffusion, while a larger size of the foreign country, a larger spillover of technology (larger $\theta$) and a smaller world preference for the comparative advantage sector of the foreign country (lower $\gamma$) all exacerbate the problem. In particular, the last force is worth pointing out, since it implies that once foreign is stuck with a relatively unattractive sector, its willingness to start producing in the $B$ industry and thus generating partial specialization is larger. In this case foreign will launch a production of $B$ goods and therewith trigger partial specialization and the associated output and welfare costs for the home country, even though its absolute technology level $\lambda^*_{B,1}$ may be substantially lower than that of home. Maybe even more problematic, if foreign is large and stuck with a relatively unattractive sector, it will choke home's $B$ sector already at relatively lower levels of spillovers and therewith eliminate the opportunity for further spillovers and technological progress.

# 3 Empirical methodology and data

The theoretical model shows that the diffusion of technology from more to less advanced countries, which may improve the latter's sectoral productivity parameters, may lead to reductions in welfare and output in the advanced country. Two important channels for such knowledge diffusion have been identified in the literature, namely trade and FDI. These bring new technology to the less advanced countries which can then be imitated.[15] In this empirical part of the paper we now investigate econometrically the existence and effects of such outward knowledge diffusion associated with exports and outward FDI on home country's output, motivated by the theoretical discussion in the previous section.

Thus far, knowledge spillovers have mainly been studied as an input factor on the side of the spillover receiving industries or countries (e.g., Keller, 2004). Our paper takes another approach and investigates empirically the hypothesis that outward diffusion of domestic knowledge might be harmful to the sending country, as such knowledge diffusion might result in a Samuelson Act II effect and thus lead to output reductions.

To analyse this idea empirically we estimate the following transformed Cobb-Douglas production function

[15] Of course, such technological progress in the trade partner could also result from different factors, e.g. through own R&D or learning by doing. However, we focus on technology transfer via trade and FDI as it is known from previous studies that foreign knowledge diffuses via imports and FDI into a country (e.g., Coe and Helpman 1995, Bitzer and Kerekes 2008, van Pottelsberghe and Lichtenberg 2001). Also, these are the channels often cited in the popular debate as well as by Samuelson (2004, p. 145).

$$
\begin{aligned}
ln\ Q_{jct} &= \beta_1 \ln K_{jct} + \beta_2 \ln L_{jct} + \beta_3 \ln M_{jct} + \beta_4 \ln RDS_{jct} \\
&+ \beta_5 \ln RDED_{jct} + \lambda \ln RDF_{ct} + \tau \ln EDS_{jct} \qquad (11) \\
&+ \sigma \ln FDS_{jct} + \nu_{jc} + \iota_t + \epsilon_{jct}
\end{aligned}
$$

where $Q$ is gross production in industry $j$ and country $c$, and $K, L, M$ are the standard production factors capital, labor and materials, respectively.[16] These data are constructed at the industry level from the OECD STAN database. A detailed description of all data used in the estimations is given in the appendix. The capital stock is calculated using the perpetual inventory method and investment data, assuming a ten percent depreciation rate. $L$ is the number of employees and $M$ is measured as the difference between gross output and value added.

$RDS$ measures the R&D capital stock in sector $j$ and country $c$ as a proxy for the sector's own stock of knowledge. In order to control for incoming knowledge spillovers via general R&D activity in other domestic sectors or abroad we include $RDED$ and $RDF$ respectively. Specifically, $RDED$ is the external domestic R&D capital stock in country $c$ (excluding sector $j$) and $RDF$ is the R&D capital stock abroad (excluding country $c$), respectively. All R&D variables are calculated using data from the OECD ANBERD database. Stocks are calculated using the same approach as for the physical capital stock.[17] $RDED$ is constructed summing up all sectoral R&D capital stocks

[16] Note that even though we refer to $Q$ here, it is not produced units as in our theoretical section, but gross production which includes, for example, financial return flows stemming from FDI activities or the gains from outsourcing; thus accounting for possibly compensated knowledge diffusion. Note also that materials $M$ include imported intermediate inputs.

[17] The R&D capital stocks at time $t = 0$ were constructed using the standard procedure

within a country excluding sector $j$ and is assumed to capture knowledge spillovers within a country. The $RDF$ variable is calculated as the sum of all R&D capital stocks in OECD countries apart from country $c$ and is included to capture international knowledge spillovers through R&D activity abroad. Van Pottelsberghe and Lichtenberg (2001) and Coe and Helpman (1995) weight the foreign R&D stock using either FDI or trade data, in order to capture knowledge spillovers transmitted particularly through these channels. By contrast, as proposed by Keller (1998) and Mohnen (1996) we do not place any restrictions in terms of weights on $RDF$, thereby allowing for a general effect of all R&D undertaken abroad on domestic gross production.

Our main variables of interest are $EDS$ and $FDS$, which capture export driven and FDI driven spillovers, respectively. Inspired by the approach of Coe and Helpman (1995) and Lichtenberg and van Pottelsberghe (1998) $EDS$ is constructed as the sectoral R&D capital stock multiplied with the sectoral export share. Note that the export share is constructed as total sectoral exports to the world over gross production. Thus, the $EDS$ variable captures exports to all countries even if they are not OECD members, i.e. exports to, for example, China are included. Similarly, $FDS$ is constructed by multiplying the sectoral R&D capital stock with the total outward FDI capital stock over total domestic capital stock.[18] Hence, these variables may be interpreted as knowledge (R&D) embodied in exports and outward FDI from sector $j$ in country $c$. In extensions to the baseline model described in equation (11) we also distinguish exports by destination, in particular

as described in Goto and Suzuki (1989) or Hall and Mairesse (1995). An alternative approach for the construction of R&D capital stocks is pointed out by Bitzer (2005).

[18]The use of sectoral weighting schemes can not be implemented, because bilateral industry-level FDI data are not available neither for the time period nor for the aggregation level used.

to less technologically advanced regions/countries. Unfortunately, such a distinction is not possible for FDI due to unavailability of bilateral sector-level FDI data. In line with the literature the assumption in our estimation is that the higher are $EDS$ and $FDS$, the higher are potential knowledge spillovers to the foreign country.

While the expected signs of the coefficients for the traditional inputs – physical capital, labor, materials, domestic R&D – are straightforward positive, the expected coefficients for the other variables warrant some discussion. Turning first to the expected signs of the external domestic and the foreign R&D capital stock variables both a positive as well as a negative sign are plausible. A positive sign of $RDED$ ($RDF$) indicates that on average a sector benefits via knowledge spillovers from R&D carried out in other domestic sectors (countries). A negative relationship between $RDED$ ($RDF$) and industry output, on the other hand may suggest that R&D carried out in other domestic sectors (countries) has increased the competitiveness of domestic (foreign) competitors. This may lead to reductions in output as consumers prefer the competitors' products with negative consequences for a sector's output.

Coming to the variables of particular interest to our paper the export driven ($EDS$) and FDI driven spillovers ($FDS$) both positive and negative signs can plausibly be explained. A significant negative sign on $EDS$ ($FDS$) indicates that outward domestic knowledge diffusion takes place via trade (FDI) and has a negative impact on domestic output, e.g. a situation described in our theoretical section. On the other hand both variables might also show significant positive signs indicating that countries benefit in terms of increased domestic output from outward knowledge diffusion – via exports or FDI – through, e.g., outsourcing.[19]

The production function estimation includes full sets of industry-country fixed effects ($\nu_{jc}$) and time dummies ($\iota_t$).

For firm or plant level productivity studies it is frequently argued that factor inputs should be considered endogenous. This is because firms/plants may observe TFP at least partly which, in turn, may influence the choice of factor input combinations in the same period. Hence, there would be a correlation between the error term and the contemporaneous levels of factor inputs, leading to biased estimates of the coefficients.[20] However, following Zellner et al. (1966) one could argue that output at the industry level is stochastic, as the data for individual plants/firms are aggregated up. For the case that output is stochastic Zellner et al. (1966) show that OLS regressions of a Cobb-Douglas production function yields consistent estimates of the output elasticities. However, to be sure, we perform a test for endogeneity of inputs using the approach outlined by Baum, Schaffer and Stillman (2003). The results, which are reported in the appendix, indicate that we cannot reject the hypothesis of exogeneity of the regressors.

# 4 Estimation results

The estimations of equation (11) based on the full sample are carried out using a feasible GLS (FGLS) estimator with a correction for panel specific first order autocorrelation and panel heteroskedasticity, as tests based on residuals from equation (11) indicate that the error term follows an autore-

[19]Recall that a coefficient significantly different from zero implies that at least one sub sector below the aggregation level applied is in partial specialization (cf. footnote 13).

[20]See, for example, Olley and Pakes (1996) and Levinsohn and Petrin (2003) for discussions of the problem and solutions for analyses using micro level data.

gressive process of order 1.[21] Table 1 presents the results. In Column I we report the results of a standard model specification known from the spillover literature (e.g., Coe and Helpman 1995) including the standard input factors capital, labor, materials as well as a sectoral, an external domestic and a foreign R&D capital stock. The coefficients for input factors capital, labor and materials show the expected positive significant signs which survive all model specifications. Furthermore, the coefficients on the external domestic and foreign R&D capital stocks confirm the results of former studies, i.e. showing the existence of positive knowledge spillovers both between domestic sectors and from foreign countries. As in the case of the traditional inputs, the coefficients of the external domestic and foreign R&D capital stocks remain positive and significant throughout all model specifications. Coming to the coefficient of the sectoral R&D capital variable we find a highly significant but negative coefficient implying that, all other things equal, own R&D reduces production in the sector. This is, at first sight, an unexpected result.

[21] As a robustness check and accounting for possible small sample problems as pointed out by Beck and Katz (1995) we also ran regressions using an OLS with panel corrected standard errors, correction for panel specific first order autocorrelation and panel heteroskedasticity arriving at the same results as reported below. Furthermore, simple fixed effects (within-transformed) estimations also produce very similar results. A further concern with the estimation results stems from the fact that some of our covariates only vary at the country level, thus introducing contemporaneous correlation. A correction using within country clusters would be inadequate given our small number of country clusters (17) relative to the number of units in the cluster resulting in inconsistent coefficients (Wooldridge, 2002). However, since we carry out the estimations with sector-specific fixed effects, time dummies, heteroscedasticity-corrected standard errors, and a correction for panel-specific autocorrelation of form 1, we largely eliminate possible contemporaneous correlation within country clusters. As a robustness check we estimated all results reported below also with bootstrapped standard errors which confirm the results reported in our paper. Results of all these robustness checks can be obtained from the authors.

**Table 1: FGLS Estimation Results**

| **Indep. var.** | **I** | **II** | **III** |
|---|---|---|---|
| | dependent variable is $\ln Q$ | | |
| $\ln RDS$ | -0.0108*** | 0.0027 | 0.0144*** |
| | (0.0017) | (0.0031) | (0.0038) |
| $\ln RDED$ | 0.0476*** | 0.0477*** | 0.0539*** |
| | (0.0040) | (0.0040) | (0.0043) |
| $\ln RDF$ | 0.0580** | 0.0792*** | 0.0671*** |
| | (0.0227) | (0.0232) | (0.0234) |
| $\ln EDS$ | | -0.0134*** | -0.0146*** |
| | | (0.0026) | (0.0026) |
| $\ln FDS$ | | | -0.0084*** |
| | | | (0.0018) |
| $\ln K$ | 0.0418*** | 0.0429*** | 0.0364*** |
| | (0.0035) | (0.0035) | (0.0036) |
| $\ln L$ | 0.1406*** | 0.1378*** | 0.1403*** |
| | (0.0056) | (0.0057) | (0.0059) |
| $\ln M$ | 0.7941*** | 0.7913*** | 0.7925*** |
| | (0.0037) | (0.0037) | (0.0038) |
| Wald $\chi^2$ (df) | 1.10e+09 (204) | 1.12e+09 (205) | 7.10e+08 (206) |
| p-value Wald $\chi^2$ | 0.0000 | 0.0000 | 0.0000 |
| Obs. | 3192 | 3192 | 3192 |
| Number of groups | 170 | 170 | 170 |

*Remarks:* Industry-country fixed effects and time dummies are included but not reported and groupwise significant at the one-percent level. Consistent standard errors in parentheses. ***, **, * indicate a significance at the 1%, 5% and 10% levels, respectively.

However, pushing the analysis a step further we include the export driven spillover variable $EDS$ into the model (Column II). It turns out that the coefficient is highly statistically significant and negative. This suggests that R&D embodied in exports acts as a channel for outward diffusion of domestic knowledge and that this knowledge transfer is accompanied by a reduction in domestic output, which is in line with our theoretical discussion. Furthermore, the introduction of the export spillover variable renders the coefficient on the sectoral R&D capital stock statistically insignificant.

Finally, by introducing the FDI driven spillover variable $FDS$ we take into consideration that outward FDI might also act as a channel for outward diffusion of domestic knowledge. The results reported in Column III show that our suspicion was justified as the coefficient turns out to be highly statistically significant and negative. Similar to the case of export driven knowledge diffusion the impact of the FDI driven spillover on domestic output is negative.

It is also worth noting that with the introduction of both the export and FDI spillover variables the coefficient for sectoral R&D capital stock becomes now highly statistically significant and positive. Thus, in the reduced model specification (Column I) the coefficient of the sectoral R&D capital stock variable suffered from a downward omitted variable bias caused by the omission of the negative effects of outward diffusion of domestic knowledge.[22]

Our theoretical model showed that Samuelson Act II-type effects may take place between countries having different technology levels. Thus, the negative sign of our EDS variable should be caused by exports to technologically less advanced countries. Using bilateral trade data we are able to investigate this

[22]Our results may give raise to the question whether our measure of knowledge spillovers in fact captures some other phenomenon, such as for example outsourcing. The EDS and FDS variables could be interpreted as implying that in more open industries increases in R&D are correlated with lower output. However, we argue that outsourcing is not a potential explanation for this relationship. Firstly, our output measure is not measuring units produced, but the value produced of the sectors in question (gross production). Accordingly, even though the locally produced volume may be reduced under outsouring, the value (total industry turnover) of such industries is generally not; after all outsourcing is a business decision aimed at boosting the enterprises' value, not reducing it (e.g., Amiti and Wei, 2009; Görg, Hanley and Strobl, 2008). Secondly, and perhaps more importantly, our full specification clearly shows that increases in R&D activity in fact are correlated with higher output. Thus an interpretation of our results in an 'outsourcing scenario' where firms keep R&D functions in the home country while shredding actual productions, implying a negative correlation between R&D and home output, does not appear compatible with the data.

question further.[23] However, since bilateral OECD-STAN trade data are only available from 1988 onwards, our sample is significantly reduced resulting in some 1360 observations. To avoid problems caused by the smaller sample size and the lower number of time periods, following Beck and Katz (1995) the estimations were carried out using OLS with panel corrected standard errors and a correction for panel heteroskedasticity, while still controlling for industry-country fixed effects and year dummies.

Using these data we differentiate the EDS variable by separating exports to countries or groups of countries. Accordingly $EDS^{net}$ captures the remaining exports to the rest of the world in each of the following model specifications.

We start by analysing the effect of exports to the G7-countries ($EDS^{G7}$) i.e. technological advanced countries. Results are presented in Table 2 Column I and show that the coefficient is statistically insignificant. This implies, in line with theory, that exports to countries with a similar or advanced technological level have no negative impact on domestic output in the home country.

In a second step we distinguish exports to less advanced countries from three regions: South and Latin America ($EDS^{SAM}$), Central and Eastern Europe ($EDS^{CEEC}$), and Asia ($EDS^{ASIA}$).[24] The results are presented in Table 2 Column II and show that only exports to technological less advanced countries in Asia have a negative impact on domestic output. Exports to countries in South and Latin America and Central and Eastern Europe have no such effect. For the latter one possible explanation is that 8 of the 9 included countries have been preparing their accession to the EU since the

[23] Unfortunately, corresponding bilateral FDI on sectoral level are not available to us and, hence, we are unable to conduct a similar analysis for *FDS*.

[24] More specifically, $EDS^{SAM}$ includes exports to Mexico, Argentina, Brasil, and Chile. $EDS^{CEEC}$ includes exports to Czech Republic, Estonia, Hungary, Latvia, Lithuania, Russia, Slovakia, and Slovenia. $EDS^{ASIA}$ includes exports to China, Taiwan, Hong Kong, India, Indonesia, Malaysia, Philippines, Singapore, Thailand.

early 1990s and thus adopted EU patent laws and enforcing the protection of intellectual property.

The negative coefficient on $EDS^{ASIA}$ may fuel anxieties that trade with Asian countries has the potential to be particularly detrimental due to problems with intellectual property rights protection. Such concerns have been particularly expressed by politicians and media in the US and also subject of academic debate (e.g., Leamer, 2007). To relate to this debate more directly we carry out another extension to our analysis where we investigate whether the US suffers particularly from exports to Asia. We do so by interacting $EDS^{ASIA}$ with a dummy equal to one if the home country is the US (Table 2, Column III). However we do not find any evidence for such an effect.

Finally, as discussed in Section 2, our interpretation of the negative coefficient as a reduction in welfare is based on the assumption of no full specialization. This is difficult to validate for all our trade partners. However, in order to provide a more convincing case, we focus in particular on one country where full specialization is unlikely: China. This is of course also a highly policy relevant case, since the open up of the Chinese economy, its implications for the world economy have been heavily debated. In order to see how the inclusion of China drives our results, we distinguish $EDS^{ASIA}$ into exports to China (including mainland China, Hong Kong and Taiwan) and the rest of Asia. The results in Table 2, Column IV show that the negative impact of exports to Asia is driven entirely by China. Removing exports to China from the $EDS^{ASIA}$ variable renders the impact of exports to the remaining technological less advanced countries in Asia ($EDS^{ASIA-CHN}$) statistically insignificant. By contrast, export driven knowledge transfers to China ($EDS^{CHN}$) have a significant and negative impact on the output of the countries in the sample. This may suggest that China is particularly good at absorbing knowledge spillovers which then lead to output reductions in the exporting country.

**Table 2: OLS with PCSE Estimation Results**

| **Indep. var.** | **I** | **II** | **III** | **IV** |
|---|---|---|---|---|
| | dependent variable is $\ln Q$ | | | |
| $\ln RDS$ | 0.0176** | 0.0192** | 0.0185** | 0.0184** |
| | (0.0078) | (0.0080) | (0.0078) | (0.0078) |
| $\ln RDED$ | 0.0409*** | 0.0416*** | 0.0421*** | 0.0421*** |
| | (0.0064) | (0.0064) | (0.0064) | (0.0064) |
| $\ln RDF$ | 0.0199 | 0.0274 | 0.0281 | 0.0260 |
| | (0.0508) | (0.0522) | (0.0500) | (0.0500) |
| $\ln EDS^{net}$ | -0.0218*** | -0.0178*** | -0.0174*** | -0.0178*** |
| | (0.0081) | (0.0052) | (0.0049) | (0.0049) |
| $\ln EDS^{G7}$ | 0.0007 | | | |
| | (0.0057) | | | |
| $\ln EDS^{SAM}$ | | -0.0003 | | |
| | | (0.0013) | | |
| $\ln EDS^{CEEC}$ | | -0.0002 | | |
| | | (0.0009) | | |
| $\ln EDS^{ASIA}$ | | -0.0046** | -0.0045*** | |
| | | (0.0018) | (0.0017) | |
| $\ln EDS^{ASIA} * D^{USA}$ | | | 0.0223 | |
| | | | (0.0188) | |
| $\ln EDS^{ASIA-CHN}$ | | | | -0.0011 |
| | | | | (0.0019) |
| $\ln EDS^{CHN}$ | | | | -0.0029* |
| | | | | (0.0015) |
| $\ln FDS$ | -0.0162*** | -0.0151*** | -0.0159*** | -0.0159*** |
| | (0.0041) | (0.0042) | (0.0041) | (0.0041) |
| $\ln K$ | 0.0500*** | 0.0510*** | 0.0493*** | 0.0503*** |
| | (0.0065) | (0.0065) | (0.0064) | (0.0065) |
| $\ln L$ | 0.1327*** | 0.1245*** | 0.1280*** | 0.1282*** |
| | (0.0098) | (0.0098) | (0.0098) | (0.0099) |
| $\ln M$ | 0.8115*** | 0.8118*** | 0.8135*** | 0.8133*** |
| | (0.0076) | (0.0074) | (0.0073) | (0.0073) |
| Wald $\chi^2$ (df) | 281281.86 (172) | 604961.18 (174) | 1.25e+06 (173) | 490677.53 (172) |
| p-value Wald $\chi^2$ | 0.000 | 0.000 | 0.000 | 0.000 |
| Observations | 1367 | 1356 | 1367 | 1365 |
| Number of groups | 160 | 160 | 160 | 160 |

*Remarks:* Industry-country fixed effects and time dummies are included but not reported and groupwise significant at the one-percent level. Panel corrected standard errors in parentheses. ***, **, * indicate a significance at the 1%, 5% and 10% levels, respectively.

# 5 Conclusion

Our paper analyses theoretically and empirically whether under certain circumstances technological progress in the trade partner country might be harmful for the home country. In the theoretical part we illustrate this notion (Samuelson's, 2004, Act II effect) in a simple Ricardian model, where we examine the effects from foreign gaining a fraction of home's technology via international outward knowledge spillovers. We examine the effects on home welfare and on home output in the industry where the knowledge diffusion takes place. In the empirical part we investigate econometrically whether exports and outward FDI are significant channels for outward knowledge diffusion. Both are channels that have frequently been pointed at in the debate that followed after Samuelson's (2004) arguments, yet previous literature has mainly examined effects for knowledge spillover receiving countries. We borrow the methods of this substantial international knowledge diffusion literature, in order to examine the impact on the knowledge emitting countries. Estimations based on industry level panel data for seventeen OECD countries for the period 1973 to 2000, show that on average R&D embodied in both exports and outward FDI act as a channel for outward knowledge diffusion resulting in a decrease of home gross production for the knowledge emitting sector.

In extensions we estimate whether the Samuelson Act II effect occurs in particular between trade partners of different technological levels. Refining our analysis by controlling for exports to technological less advanced countries are in line the implications of our theoretical model. Furthermore, in line with the recent debate on growth in Asia and specifically China we investigate whether exports to less advanced countries in Asia in general and specifically to China are main channels for the Act II effect. Our results show that the negative effect of export driven knowledge spillovers to Asian countries can be attributed solely to exports to China. Finally, we investigate whether the US – as a technological leader – suffers particularly from export driven outward diffusion of domestic knowledge. Our data provides no support for such a hypothesis.

To sum up: the empirical evidence presented indicates that outward diffusion of domestic knowledge can have negative effects for the spillover sending country, thus supporting some of the concerns raised by Samuelson (2004). The question remains, what the alternative no-trade benchmark would look like. Or put differently, even though the present paper has established the possibility of negative output effects stemming from outward knowledge diffusion, the alternative – autarky existence – is hardly a preferable situation. If anything, the present paper has shown that the impact of outward knowledge diffusion from trade and FDI activity on the knowledge emitting countries deserve further investigation.

# References

Agion, Philippe, Alberto Alesina and Francesco Trebbi (2007), Democracy, technology, and growth, NBER Working Paper 13180.

Amiti, Mary, and Shang-Jin Wei (2009), Service offshoring and productivity: Evidence from the United States, *The World Economy*, vol. 32, pp. 203-220.

Baltagi, Badi H. (2001), Econometric Analysis of Panel Data (2nd ed.), John Wiley & Sons.

Baum, Christopher F., Mark E. Schaffer and Steven Stillman (2003), Instrumental variables and GMM: Estimation and testing, Working Paper no. 545, Boston College.

Beck, Nathaniel; Katz, Jonathan N. (1995), What to Do (and Not to Do) with Time-Series Cross-Section Data, *American Political Science Review*, vol. 89, pp. 634-647.

Bernard, Andrew B. and J. Bradford Jensen (2004), Why Some Firms Export, *Review of Economics and Statistics*, vol. 86, pp. 561-569.

Bitzer, Jürgen (2005), Measuring Knowledge Stocks: A Process of Creative Destruction, *Kyklos*, vol. 58, no. 3, pp. 379-393.

Bitzer, Jürgen and Ingo Geishecker (2006), What Drives Trade-related R&D Spillovers? Decomposing Knowledge-Diffusing Trade Flows, *Economics Letters*, vol. 93, no. 1, pp. 52-57.

Bitzer, Jürgen and Monika Kerekes (2008), Does Foreign Direct Investment Transfer Technology Across Borders? New Evidence, in: *Economics Letters*, vol. 100, no. 3, pp. 355-358..

Coe, David T. and Elhanan Helpman (1995), International R&D Spillovers, *European Economic Review*, vol. 39, no. 5, pp. 859-887.

Criscuolo, Chiara and Ralf Martin (2010), Multinationals and US Productivity Leadership: Evidence from Great Britain, *Review of Economics and Statistics*, forthcoming.

Eaton, Jonathan and Samuel Kortum (2001), Trade in capital goods, *European Economic Review*, vol. 45, pp. 1195-1235.

Eaton, Jonathan and Samuel Kortum (2006), Innovation, Diffusion, and Trade, *NBER Working Paper Series*, no. 12385.

Girma, Sourafel and Holger Görg (2007), Multinationals' productivity advantage: Scale or technology?, *Economic Inquiry*, vol. 45, pp. 350-362.

Gomory, Ralph E. and William J. Baumol (1997), Productivity differences, world-market shares and conflicting national interests in linear trade models, *Japan and the World Economy*, vol. 9, pp. 123-150.

Gomory, Ralph E. and William J. Baumol (2000), *Global Trade and Conflicting National Interests*, MIT Press.

Görg, Holger and David Greenaway (2004), Much ado about nothing? Do domestic firms really benefit from foreign direct investment?, *World Bank Research Observer*, Vol. 19, pp. 171-197.

Görg, Holger, Aoife Hanley and Eric Strobl (2008), Productivity effects of international outsourcing: Evidence from plant level data, *Canadian Journal of Economics*, vol. 41, pp. 670-699.

Görg, Holger, Michael Henry and Eric Strobl (2008), Grant support and exporting activity, *Review of Economics and Statistics*, vol. 90, pp. 168-174.

Goto, Akira and Kazuyuki Suzuki (1989), R&D Capital, Rate of Return on R&D Investment and Spillover of R&D in Japanese Manufacturing Industries, *Review of Economics and Statistics*, vol. 71, no. 4, pp. 555-564.

Gros, Daniel (1987), Protectionism in a Framework with Intra-industry Trade: Tariffs, Quotas, Retaliation, and Welfare Losses, *International Monetary Fund Staff Papers*, vol. 34 (1), pp. 86-114.

Hall, Bronwyn H. and Jaques Mairesse (1995), Exploring the Relationship Between R&D and Productivity in French Manufacturing Firms, *Journal of Econometrics*, vol. 65, no. 1, pp. 263-293.

Helpman, Elhanan (1993), Innovation, Imitation, and Interlectual Property Rights, *Econometrica*, vol. 60, pp. 1247-1280.

Johnson, George E. and Frank P. Stafford (1993), International Competition and Real Wages, *American Economic Review*, vol. 83 (2), pp. 127-130.

Jones, Ronald W. and Roy J. Ruffin (2008), The Technology Transfer Paradox, *Journal of International Economics*, vol. 75, no. 2, pp. 321-328.

Jørgensen, J.G., and P.J.H. Schröder (2005), Welfare Ranking Ad Valorem and Specific Tariffs under Monopolistic Competition, *Canadian Journal of Economics*, vol. 38 (1), pp. 228-241.

Keller, Wolfgang (2004), International Technology Diffusion, *Journal of Economic Literature*, vol. 42, pp. 752-782.

Keller, Wolfgang (1998), Are International R&D Spillovers Trade-Related? Analyzing Spillovers among Randomly Matched Trade Partners, *European Economic Review*, vol. 42, no. 8, pp. 1469-1481.

Krugman, Paul (1980), Scale Economies, Product Differentiation, and the

Pattern of Trade, *American Economic Review*, vol. 70 (5), pp. 950-959.

Krugman, Paul (1996), Pop Internationalism, MIT Press.

Leamer, Edward E. (2007), A Flat World, a Level Playing Field, a Small World After All, or None of the Above? A Review of Thomas L Friedman's The World is Flat, *Journal of Economic Literature*, vol. 45, no. 1, pp. 83-126.

Levinsohn, J. and A. Petrin (2003), Estimating production functions using inputs to control for observables, *Review of Economic Studies*, vol. 70, pp. 317-341.

Lichtenberg, F. and B. van Pottelsberghe de la Potterie, 1998, International R&D Spillovers: A Comment, *European Economic Review* 42, pp. 1483-1491.

Maddala, G.S. and Shaowen Wu (1999), A Comparative Study of Unit Root Tests with Panel Data and a New Simple Test, *Oxford Bulletin of Economics and Statistics*, vol. 61, pp. 631-652.

Markusen, James R. (2002), Multinational firms and the theory of international trade, Cambridge, M.A.: MIT Press.

Maskus, Keith E. (2000), *Intellectual Property Rights in the Global Economy*, Washington, DC: Institute for International Economics.

Mohnen, Pierre (1996), R&D Externalities and Productivity Growth, *STI Review*, vol. 18, pp. 39-66.

Olley, S. and A. Pakes (1996), The dynamics of productivity in the telecommunications equipment industry, *Econometrica*, vol. 64, pp. 1263-1297.

Redding, Stephen (2002), Specialization dynamics, *Journal of International*

*Economics*, vol. 58, pp. 299-334.

Ruffin, Roy J. and Ronald W. Jones (2007), International Technology Transfer: Who Gains and Who Loses, *Review of International Economics*, vol 15 (2), pp. 209-222.

Samuelson, Paul A. (2004), Where Ricardo and Mill Rebut and Confirm Arguments of Mainstream Economists Supporting Globalization, *Journal of Economic Perspectives*, vol 18 (3), pp. 135-146.

Samuelson, Paul A. (1977), International Trade for a Rich Country, in: *The collected Scientific Papers of Paul A. Samuelson*, vol. 4, chapter 250, MIT Press.

Schröder, P.J.H. (2007), Cartel Stability and Economic Integration, *Review of International Economics*, vol. 15 (2), pp. 313-320.

van Pottelsberghe de la Potterie, Bruno and Frank Lichtenberg (2001), Does Foreign Direct Investment Transfer Technology Across Borders?, *Review of Economics and Statistics*, vol. 83, no. 3, pp. 490-497.

Wooldridge, Jeffrey M. (2002), *Econometric Analysis of Cross Section and Panel Data*, MIT Press: Cambridge, MA.

Zellner, A., J. Kmenta and J. Dreze (1966), Specification and Estimation of Cobb-Douglas Production Function Models, *Econometrica*, vol. 34, no. 4, pp. 784-795.

# Appendix

## Data description

The estimations have been carried out on the basis of data for ten manufacturing industries in the 17 countries Canada (CAN), Czech Republic (CZE), pre-unification (till 1990) West Germany (DEW), post-unification (1991 onwards) Germany (DEU), Denmark (DNK), Finland (FIN), France (FRA), Italy (ITA), Japan (JPN), South Korea (KOR), Netherlands (NLD), Norway (NOR), Polen (POL), Spain (ESP), Sweden (SWE), the United Kingdom (GBR) and the United States (USA). The data were taken from the OECD databases ANBERD and STAN and the IMF database IFS.

The annual time series are available for the years 1973 to 2001 in ISIC Rev. 3 classification. Due to data constraints the length of the available time series differ across countries. The panel is therefore unbalanced.

The data was deflated to constant prices of 1995 using the OECD value-added deflator for the manufacturing sector and was then converted into USD using the exchange rates from 1995. To this end, Euro-data was converted back into national currency. From this data, output Q is measured as gross production. All stocks, i. e. the physical capital stock, the R&D capital stock and the FDI stocks, are calculated using the perpetual inventory method where a depreciation rate of ten percent is assumed. Labor L is measured as the number of employees, and material/intermediate inputs M are calculated as the difference between gross output and value added.

Table A1 reports the correlation between the used variables. Table A2 reports some descriptive statistics of the data used.

**Table A1: Correlation matrix**

| | $K$ | $L$ | $M$ | $RDS$ | $RDED$ | $RDF$ | $EDS$ | $FDS$ |
|---|---|---|---|---|---|---|---|---|
| $K$ | 1.0000 | | | | | | | |
| $L$ | 0.7364 | 1.0000 | | | | | | |
| $M$ | 0.9037 | 0.8113 | 1.0000 | | | | | |
| $RDS$ | 0.6847 | 0.6835 | 0.7286 | 1.0000 | | | | |
| $RDED$ | 0.5197 | 0.5813 | 0.6231 | 0.3416 | 1.0000 | | | |
| $RDF$ | -0.1350 | -0.2964 | -0.1961 | -0.0909 | -0.1743 | 1.0000 | | |
| $EDS$ | 0.5969 | 0.5805 | 0.6074 | 0.9006 | 0.2254 | 0.0032 | 1.0000 | |
| $FDS$ | 0.6296 | 0.5344 | 0.6416 | 0.8816 | 0.2997 | 0.0178 | 0.8452 | 1.0000 |

**Table A2: Summary statistics**

| **Variable** | **Units** | **Mean** | **Std. Dev.** | **Min** | **Max** |
|---|---|---|---|---|---|
| $Q$ | (million \$) | 72556.94 | 124422.3 | 883.1189 | 1049124 |
| $K$ | (million \$) | 31522.1 | 56972.44 | 241.6378 | 585548.2 |
| $L$ | (1,000 persons) | 535.6361 | 726.0073 | 13.5 | 5389 |
| $M$ | (million \$) | 47593.4 | 81429.54 | 542.6823 | 631966.5 |
| $RDS$ | (million \$) | 10955.71 | 37949.93 | .1621025 | 450584.9 |
| $RDED$ | (million \$) | 99045.38 | 178439.7 | 970.7566 | 1002304 |
| $RDF$ | (million \$) | 1439878 | 636354.7 | 321618 | 2608893 |
| $EDS$ | (million \$) | 2923.403 | 9649.159 | .0105308 | 147636.8 |
| $FDS$ | (million \$) | 643.3193 | 2434.256 | .0005083 | 41043.45 |

## Unit root test

The panel is unbalanced since data are missing for a few sectors in some years. Thus, the Fisher method, which was proposed by Maddala and Wu (1999), appears suitable. Another benefit of it is its flexibility regarding the specification of individual effects, individual time trends and individual lengths of time lags in the ADF regressions (Baltagi, 2001, p. 240). The $P_\lambda$-statistic is distributed chi-square with $2 \cdot N$ degrees of freedom, where $N$ is the number of panel groups. As Table A1 shows, the tests do not indicate evidence of unit roots, either in the output series $\ln Q$ or in the factor input series.

**Table A3: Results for the Fisher-type Unit Root Test for Panel Data**

| Variable | $P_\lambda$-statistic | p-value |
|---|---|---|
| $\ln Q$ | 615.74282 | 0.000 |
| $\ln K$ | 469.90825 | 0.000 |
| $\ln L$ | 502.01711 | 0.000 |
| $\ln M$ | 511.05298 | 0.000 |
| $\ln RDS$ | 532.95463 | 0.000 |
| $\ln RDED$ | 649.085 | 0.000 |
| $\ln EDS$ | 611.21475 | 0.000 |
| $\ln FDS$ | 550.91663 | 0.000 |

## Exogeneity tests

With exception of labor and intermediate/material inputs all other production factors are stock variables. The latter have been constructed by using the perpetual inventory method with a constant depreciation rate of ten percent. This implies that depreciation of investments takes longer than 20 years and thus investments remain in the stock variable for that time. Thus, endogeneity is unlikely to be an issue for the used stock variables.

Therefore, the only suspicious variables are labor and intermediate/material inputs. To test for exogeneity of these two variables we apply a General Method of Moments (GMM) regression using lagged values of labor and intermediate/material inputs as instruments (Baum et al., 2003). We prefer the use of GMM over instrumental variable (IV) estimation because the latter is not consistent in the presence of heteroskedasticity. As pointed out in the main text the latter is an issue in our data.

Although $EDS$ and $FDS$ are constructed using the stock variable $RDS$ – and therefore the capital stock argument from above applies. Thus, the stock variable is not contemporaneously determined with the sectoral output and therefore endogeneity is unlikely to arise for $EDS$ and $FDS$. However, some uncertainty concerning endogenity of the $EDS$ variable might arise form the used weight. The $EDS$ variable might be endogenous by construction as the used weight contain sectoral output in the denominator.[25]

To dispel the last concerns due to the $EDS$ variable, which is constructed using a weight of total sectoral exports over sectoral gross production we carry out an test for exogenity of the $EDS$ (and $FDS$) variables (Table A4, Column II and III) . Following the procedure described above. We additionally test for the endogenity of the flow variables $L$ and $M$ simultaneously (Table A4, Column I – III). In all cases we can not reject exogenity for all tested variables $L$, $M$, $EDS$ and $FDS$. However, to show that our results are robust we furthermore report the results of the second step of the IV regression in Table A5. It turns out that the results are very similar to those achieved by GLS (compare Column GLS for GLS results based on the same sample as IV regression).

[25]For the $FDS$ variable the sectoral output is not part of the weight, because the weight ist constructed by total manufacturing FDI capital stock over total capital stock of the manufacturing sector. Thus, the capital stock argument applies (see above). Furthermore, the weight for $FDS$ is constructed using a higher aggregation level (cf. p. X).

**Table A4: Exogeneity tests for *ln L*, *ln M*, *ln EDS*, and *ln FDS***

| **Test statistic** | | **Table 1** | |
|---|---|---|---|
| | **I** | **II** | **III** |
| Test of predictive power of instruments | | | |
| Instruments ln L | | | |
| F-Test | 67.19 | 27.76 | 28.99 |
| P-value | 0.0000 | 0.0000 | 0.0000 |
| Instruments ln M | | | |
| F-Test | 14.01 | 16.74 | 15.39 |
| P-value | 0.000 | 0.0000 | 0.0000 |
| Instruments ln EDS | | | |
| F-Test | | 21.49 | 21.40 |
| P-value | | 0.0000 | 0.0000 |
| Instruments ln FDS | | | |
| F-Test | | | 22.96 |
| P-value | | | 0.0000 |
| Overidentification test of all instruments | | | |
| Hansen J-Statistic | 4.026 | 11.689 | 13.654 |
| P-value | 0.1336 | 0.1656 | 0.1352 |
| Test for exogeneity: H0: Variables are exogenous | | | |
| $\chi^2$ | 2.203(2) | 5.766(3) | 6.021(4) |
| P-value | 0.3324 | 0.1236 | 0.1976 |
| Exogeneity rejected | no | no | no |

**Table A5: IV regression results**

| VARIABLES | I | II | III | GLS |
|---|---|---|---|---|
| | dependent variable is $\ln Q$ | | | |
| $\ln RDS$ | -0.0155*** | 0.0190* | 0.0538*** | 0.0215*** |
| | [0.005] | [0.010] | [0.014] | [0.005] |
| $\ln RDED$ | 0.0373*** | 0.0363*** | 0.0689*** | 0.0317*** |
| | [0.008] | [0.008] | [0.011] | [0.005] |
| $\ln RDF$ | 0.0736* | 0.1574*** | 0.0928** | 0.0960*** |
| | [0.042] | [0.045] | [0.044] | [0.020] |
| $\ln EDS$ | | -0.0309*** | -0.0326*** | -0.0269*** |
| | | [0.008] | [0.008] | [0.003] |
| $\ln FDS$ | | | -0.0297*** | -0.0086*** |
| | | | [0.007] | [0.002] |
| $\ln K$ | 0.0598*** | 0.0701*** | 0.0515*** | 0.0387*** |
| | [0.013] | [0.011] | [0.010] | [0.004] |
| $\ln L$ | 0.1340*** | 0.1393*** | 0.1358*** | 0.1516*** |
| | [0.020] | [0.019] | [0.019] | [0.007] |
| $\ln M$ | 0.7740*** | 0.7378*** | 0.7615*** | 0.7809*** |
| | [0.027] | [0.018] | [0.018] | [0.004] |
| Observations | 2264 | 2264 | 2264 | 2264 |
| R-squared | 0.977 | 0.978 | 0.978 | |
| Number of ind | 139 | 139 | 139 | 139 |

*Remarks:* Industry-country fixed effects and time dummies are included but not reported and groupwise significant at the one-percent level. Panel corrected standard errors in parentheses. ***, **, * indicate a significance at the 1%, 5% and 10% levels, respectively.