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International Firm Activities and Innovation: Evidence from Knowledge Production Functions for German Firms

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International Firm Activities and Innovation:
Evidence from Knowledge Production Functions for German Firms

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Abstract:

Using a knowledge production framework and a rich set of plant level data this study demonstrates that in Germany firms that are active on international markets as exporters or foreign direct investors do generate more new knowledge than firms which sell on the national market only. These differences are not only due to a larger firm size, or different industries, or the use of more researchers in these firms, but due to the fact these globally engaged firms learn more from external sources, too. The importance of these knowledge sources varies with the type of innovation. These results, which are broadly in line with the findings of a recent study using UK firm level data, can help to explain the strong positive correlation between productivity and international activities of firms. Firms that are active on markets beyond the national borders generate higher levels of new knowledge that feed into higher productivity.

Keywords: Exports, foreign direct investment, knowledge production function, Germany

JEL classification: F14; F23, O31

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1. Motivation

One of the stylized facts emerging from the literature on the microeconometrics of international firm activities is that firms which engage in foreign trade are more productive than firms selling on the national market only, and that firms with foreign direct investments are even more productive than exporters.[1] Germany is a case in point: Using different data sets, Bernard and Wagner (1997), Wagner (2006c), and Arnold and Hussinger (2005a) show that exporters are more productive than non-exporters from the same industry. Wagner (2006b) and Arnold and Hussinger (2005b), again using different data sets, find that the productivity distribution of firms selling on the national market only is stochastically dominated by the productivity distribution of exporters, which is in turn dominated by the productivity distribution of firms that are foreign direct investors; this shows that the productivity differences do not only exist at the mean, but all over the distribution.

As regards the direction of causality between productivity and international firm activities, the picture emerging from the empirical literature is less clear, but, details aside, the evidence points to self-selection of more productive firms into export markets, while exporting does not necessarily improve productivity.[2] Note that in the theoretical models of heterogeneous firms engaging in international trade and foreign direct investment that are inspired by the empirical literature on the microeconometrics of international firm activities, firm level productivity is modeled as random, taking a draw from a given distribution (see

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[1] Wagner (2006a) surveys the empirical strategies applied, and the results produced, in 54 microeconometric studies of exports and productivity with data from 34 countries that were published between 1995 and 2005; exporters are found to be more productive than non-exporters in nearly all of these studies. Studies showing that foreign direct investors have a higher productivity than exporters, which in turn have a higher productivity than firms selling on the national market only, include Girma, Kneller and Pisu (2005), Wagner (2006b), and Arnold and Hussinger (2005b).

[2] See the survey by Wagner (2006a). Comparing German export starters and matched non-starters, and using different data sets, Wagner (2002, 2006c) and Arnold and Hussinger (2005a) do not find evidence that exporting improves productivity.

Bernard, Eaton, Jensen and Kortum 2003, Melitz 2003, and Helpman, Melitz and Yeaple 2004).

Recently, Criscuolo, Haskel and Slaughter (2005) (henceforth, CHS) suggested an innovative way to better understand these productivity differences between firms with a different degree of international engagement. They argue that one of the main drivers of differences in productivity are differences in knowledge. To investigate the differences in knowledge between different groups of firms, they use the *knowledge production function* (KPF) framework (see Griliches 1979, 1990) linking output of new knowledge to two types of input, viz. investment in discovering new knowledge (e.g., spending on research and development) and flows of ideas from existing stock of knowledge. CHS use this framework to look at the role of different forms of global engagement of firms for the link between the output of new knowledge and these inputs into the process of its generation in an econometric study using firm level UK data. Their core findings are summarized as follows (CHS, p. 5): Globally engaged firms do generate more innovative outputs. This is not only due to the use of more researchers, but also due to more learning from more sources such as suppliers and customers, universities, and the intra-firm worldwide pool of information. The relative importance of these knowledge sources varies systematically with the type of innovation – for patents, information flows from universities are important, while flows from customers and suppliers are not. For broader process or product innovations, the reverse is true. Productivity in more globally engaged firms, therefore, is higher because these firms generate more innovations that feed into higher productivity, in large part because these firms learn more from a wider range of sources rather than just employing more knowledge workers.[3]

[3] A different way to look at the relationship between innovation and international activities of firms that is standard in the literature is to consider the role of patents, new products, and new production processes (and the inputs used to generate these innovations) for the international competitiveness of firms, for exporting, and for foreign direct investment. Empirical evidence using plant level data for Germany includes Wagner (1996, 1998, 2001, 2006d) for exports, and Wagner (1998) for foreign direct investments.

The aim of this paper is to contribute to the literature by adopting the CHS approach and using a rich set of German plant level data to test whether the main findings of CHS hold for Germany, too, following Daniel Hamermesh's (2000, p. 376) dictum that "the credibility of a new finding that is based on carefully analyzing two data sets is far more than twice that of a result based only on one." The rest of the paper is organized as follows: Section 2 sketches the framework of the study; section 3 introduces the data used and gives some descriptive statistics; section 4 reports the results of the econometric investigation; and section 5 concludes.

2. Framework of the study

Like a production function for goods and services, the knowledge production function (KPF) links inputs into the innovation process with outputs. A general form of the KPF can be written as

$$\Delta K_i = f\,(H_i, K_{ii}, K_{i\_i}, X_i) \qquad (1)$$

where ΔK_i is growth of knowledge in firm i, H_i is input in discovering new knowledge in this firm (e.g., persons working in research and development, or R&D), and K_{ii} and K_{i_i} indicate the flow of ideas to firm i from within and outside that firm, respectively (see CHS, p. 7), and X_i is a vector of other variables that might be important for the creation of new knowledge (like industry, or firm size, or type of international activity).

This way to look at the production of knew knowledge in a firm takes care of the fact that, as Paul Stoneman (1995, p.5f.) put it, "R&D is not the only source of technological improvement. A firm may generate its own technology through R&D. It may also generate technological advance through learning of various kinds, design, reverse engineering and imitation. In addition, licensing agreements and collaboration agreements will allow firms to innovate locally on the basis of technology generated by other firms. New process technologies may also be acquired from the suppliers of capital goods. The relevant importance of these different sources will depend upon the nature of the firm, its industrial sector and its technological base."

Following CHS, several variants of (1) are estimated: Regression of ΔK on dummy variables indicating different types of firms (home market producers, exporters, foreign direct investors) alone can show whether firms that are active on international markets generate more knowledge output than do purely domestic firms. If so, additionally controlling for H tests whether this reflects just greater investments in H in these internationally active firms. By adding direct measures of knowledge flows from within and outside the firm we can see what residual variation, if any, is explained by export or foreign direct investment activities.[4]

3. Data and descriptive results

The data used in this study were collected in personal interviews with firm owners or top mangers as part of the *Hannover Firm Panel* project. The population covered encompasses all manufacturing establishments with at least five employees in the German state of Lower Saxony (Niedersachsen). From this population a random sample (stratified by industry and size classes) was interviewed. Detailed information on the data set and how it can be accessed by researchers is given in Gerlach, Hübler and Meyer (2003). For this study we use data

[4] Other studies using the knowledge production function approach and German data include Fritsch (2002) and Fritsch and Slavtchev (2005). Fritsch (2002) uses data for some 700 firms from 11 European regions and regresses the number of patents on R&D inputs, and industry and regional dummies. Fritsch and Slavtchev (2005) base their study on data from 327 West German districts, regressing the number of patents on R&D inputs. However, to the best of my knowledge there is no knowledge production function study with German firm level data that includes indicators of international firm activities.

collected in the second wave in 1995 because this wave has a focus on both international cooperation and innovation.

Three types of establishments are distinguished according to their range of international activities in 1994/95:[5] Firms that sold their products on the German market only; firms that exported parts of their production but that were no foreign direct investors; and firms with foreign direct investments. Note that all but two firms with foreign direct investments were exporters, too.[6] From the 848 firms we have information for 313 (or 37 percent) sold their products in Germany only, 427 (or 50 percent) exported without having foreign direct investment, and 108 (or 13 percent) had foreign direct investments. Note that the high share of firms with international activities is in part due to the oversampling of larger firms in the *Hannover Firm Panel* study.

The growth of knowledge in firm i, ΔK_i (see formula 1 above), is measured by three variables: A dummy variable indicating whether or not the firm registered new patents; the share of new products in total sales, and a dummy variable indicating whether or not the firm introduced new production processes.

Input in discovering new knowledge in this firm, H_i, is measured by the percentage of employees working in research and development (R&D). K_{ii}, the flow of ideas to firm i from within, is represented by a dummy variable taking the value One if the firm cooperates in R&D with other parts of the enterprise the firm belongs to. K_{i_i}, the flow of ideas to firm i from outside that firm, is measured by five dummy-variables indicating whether or not the firm cooperates in R&D activities with universities or other research institutions, with customers, with suppliers, with service providers, or with competitors.

[5] See the appendix for the exact wording of the questions used in the survey to collect information on the international activities of firms, and on knowledge outputs and inputs into its production.

[6] In this paper, establishment and firm is used to describe the units in the sample. Note that we have no information whether the firm was owned by a foreign firm or not in 1994/95.

Besides the type of international activity defined above, X_i, the vector of other variables that might be important for the creation of new knowledge, includes the firm's size (measured by the number of employees, and also included in squares), a dummy variable indicating whether the establishment is a branch plant of a multi-plant enterprise or not, information on firm age (young firms aged five years or less; adolescent firms aged 6 to 10 years; and old firms aged 11 years or more), and industry affiliation (19 industries at the two-digit-level).

Descriptive statistics by type of firm are given in table 1. Both knowledge output and input to generate new knowledge tend to increase with increasing international activities: The share of firms with new patents registered and new production processes installed is considerably higher among exporters and foreign direct investors than among firms selling their products on the German market only, and the share of sales due to new products is higher in internationally active firms (see panel A of table 1). Exporters and firms with foreign direct investments have higher shares of employees in R&D (see panel B). Furthermore, these firms report more often to cooperate with other firms from inside the enterprise (panel C), and with external institutions (universities and research institutes; customers; suppliers; service providers; and competitors – see panel D). Note that internationally active firms tend to be larger on average, more often branch plants, and older (see panel E). Among internationally active firms, innovation activities tend to be lower in firms that only export compared to those who engage in foreign direct investment activities, too.

[Table 1 near here]

From the prob-values reported in table 2 it follows that nearly all of these differences in group means are statistically significant at an error level of five percent or better for the knowledge variables; the exceptions are the share of new products in total sales when firms with foreign direct investments are compared with exporters, and differences between all groups in the share of firms that cooperate in R&D with competitors.

[Table 2 near here]

In accordance with the big picture reported by CHS (p. 14) in their study using UK data, we conclude from the descriptive statistics given in table 1 that firms differ along all three dimensions of the knowledge production function: knowledge outputs, knowledge investment, and use of flows from existing knowledge. The value of all these three dimensions tends to increase with the level of global engagement.

This is in accordance with findings reported from studies mentioned above (see Wagner 2006b, and Arnold and Hussinger 2005b) comparing the productivity of German firms that are active on the national market only, that are exporters (but not foreign direct investors), and that are foreign direct investors: Patents, and new products in general, allow firms to sell their products at higher prices (at least for a period of time) than their competitors without such innovations, and this drives productivity up if it is measured as sales per employee or value added per employee (as it usually is in studies looking at productivity and international firm activities), and process innovations are linked to increases in productivity by definition.

4. Estimation results

In the econometric investigation various versions of the knowledge production function given in equation (1) are estimated. Regression of ΔK on dummy variables indicating different types of firms (home market producers, exporters, foreign direct investors) and a set of control variables for firm size, branch plant status, firm age, and industry can show whether firms that are active on international markets generate more knowledge output than do purely domestic firms of the same size, age and industry. If so, additionally controlling for inputs to knowledge production inside the firm tests whether this reflects just greater investments in H in these internationally active firms. Adding measures of knowledge flows from within and outside the firm we can see what residual variation, if any, is explained by export or foreign direct investment activities.

Results are reported in tables 3 through 5. In each table results for one of our three measures of ΔK_i are presented. Given that new patents registered and new production processes implemented are measured as binary variables only (due to a lack of information on the number of new patents and production processes in the survey the data are taken from), the empirical models for these variables are estimated using Probit. The share of new products in total sales is a percentage variable that is by definition limited between zero and one (or zero and one hundred percent), and it is zero for about half of the firms without any new product. The empirical models for the share of new products in total sales, therefore, are estimated by Fractional Logit, a method that takes care of both the limitations in the values this variables can take, and the fact that this value is zero for a large number of firms.[7]

For each measure of ΔK_i four model specifications are estimated. Column 1 in each table reports results for a regression of the measure on two dummy variables indicating whether the firm is a foreign direct investor, or an exporter without foreign direct investment, taking firms that sell on the German market only as a benchmark, plus a vector of control variables (made of the number of employees, which is also included in squares, a branch plant dummy, two dummies for different age groups using the youngest firms as the benchmark,

[7] This estimator was developed by Papke and Wooldridge (1996) in a paper on 401(k) plan participation rates; for a textbook treatment of this fractional logit regression model see Wooldridge (2002, p. 661ff.). The models were estimates using Stata 8.2 by glm with fam(bin) and link(logit), using the industry as a cluster to calculate robust standard errors.

and a full set of industry dummies). In column 2 the model is augmented by the measure of H_i, input to knowledge production inside the firm, namely, the share of employees in R&D. In column 3 the indicator for K_{ii}, knowledge flows inside the enterprise (measured by a dummy variable indicating whether or not the firm cooperates in R&D with other firms from the enterprise), is added. Finally, in column 4 the model is further augmented by a set of five dummy variables representing K_{i_i}, the knowledge inflow from outside the firm, which indicate whether or not a firm cooperates in R&D with universities or other research institutes, customers, suppliers, service providers (like consultants), and competitors.

4.1 New patents registered

Table 3 reports results for *new patents registered*. In column 1 only the two indicators for international activities of firms are included in the model (besides the set of control variables). Both coefficients are statistically significant, indicating that the differences between exporters and foreign direct investors on the one hand and firms that sell on the German market only on the other hand reported in table 1 is not only due to the fact that internationally active firms are larger or from different industries than purely domestic firms. Following the approach suggested by CHS we proceed by checking whether these indicators for international activities are proxying for superior innovation inputs, or superior information flows from inside the enterprise or from outsiders.

In column 2 the indicator for input to knowledge production inside the firm, the share of employees working in R&D activities, is added. The estimated coefficient is positive and statistically significant as expected. Note that adding the H_i indicator leaves both coefficients of the global-engagement indicators statistically significant; this shows that the fact that firms that are active on international markets generate more knowledge output than do purely domestic firms does not only reflect just greater investments in H in these internationally active firms. The next two columns add our information-flow variables. Using the fact whether or not a firm cooperates in R&D with other parts of its enterprise to proxy internal information flows K_{ii} it can be seen from results reported in column 3 that this does not matter at all for the probability that a firm registered new patents; the results for the other variables in the empirical model are not affected by the inclusion of the K_{ii} indicator. Adding the five indicators for information flows from outside changes the picture drastically (see column 4). The estimated coefficients for both being an exporter and being a foreign direct investor are reduced in size and statistical significance, the one for the exporter dummy is no longer significantly different from zero at a conventional error level. The superior output of new patents registered by internationally engaged firms, therefore, is to a large degree accounted for by their superior use of information from existing knowledge from outside. According to the results reported in column 4 important sources of information are universities and other research institutes, and service providers, while customers, suppliers and competitors do not play a role.

[Table 3 near here]

To look beyond statistical significance of the estimated coefficients, and to illustrate the economic relevance of the variables included in the knowledge production function, a simulation exercise can be helpful. We start from the information given in table 1. According to the first line in panel A the share of firms with new patents registered was 4.2 percent among the firms that sell their products on the German market only (henceforth, *locals*), 17.3 percent among those firms that did export but that did not invest in a foreign country (henceforth, *exporters*), and 42.6 percent among firms with foreign direct investments (henceforth, *foreign direct investors*). Therefore, new patents are found 4.21 (10.14) times more often among exporters (foreign direct investors) than among locals.

To illustrate that a large part of this difference in patenting among the groups is due to differences in the control variables, we can use the results reported in column 1 of table 3 to estimate the probability that a local firm, or an exporter, or a foreign direct investor *of a given size and age, from a given industry, and that is no branch plant* has registered at least one new patent. To state it differently, we control for firm size, firm age, branch plant status, and industry, and vary the degree of international firm activity. If the firm has 179.61 employees (the overall average size of firms in the sample), is no branch plant, is at least 11 years old, and from the chemical industry, the estimated probability of registering a new patent is 10.1 percent for locals, 21.9 percent for exporters, and 37.8 percent for foreign direct investors. This means that new patents are found 2.14 (3.71) times more often among exporters (foreign direct investors) than among locals – these are much lower ratios than those reported above computed from the raw data (4.21 and 10.14 times, respectively).

To shed light on the economic importance of differences in knowledge inputs for explaining the differences in the share of firms with new patents registered between the three groups of firms, we perform another simulation experiment, this time based on the results reported in column 4 of table 3. We look at a firm has 179.61 employees (the overall average size of firms in the sample), is no branch plant, is at least 11 years old, from the chemical industry, has 0.38 percent of employees in R&D (the average share for all firms in the sample), and has all types of cooperation in R&D, and we compute the estimated probability of registering a new patent when this firm is either a local, or an exporter, or a foreign direct investor. The estimated probability of registering a new patent is 45.0 percent for locals, 58.1 percent for exporters, and 72.4 percent for foreign direct investors. This means that new patents are found 1.29 (1.61) times more often among exporters (foreign direct investors) than among locals – these are much lower ratios than those reported above computed from the raw data (4.21 and 10.14 times, respectively) or based on a model that controls for firm size, firm age, branch plant status, and industry only (2.14 and 3.71 times, respectively).

The bottom line, then, is that both the control variables, and the knowledge input variables, explain large parts of the difference in patenting between locals, exporters, and foreign direct investors.

4.2 Share of new products in total sales

Results for *share of new products in total sales* are reported in table 4. In column 1 only the two indicators for international activities of firms are included in the model (besides the set of control variables). Both coefficients are statistically significant, indicating that the significant differences between exporters and foreign direct investors on the one hand and firms that sell on the German market only on the other hand reported in table 1 are not only due to the fact that internationally active firms are larger or from different industries than purely domestic firms. Again, it remains to bee seen whether these indicators for international activities are proxying for superior innovation inputs, or superior information flows from inside the enterprise or from outsiders.

In column 2 the indicator for input to knowledge production inside the firm, the share of employees working in R&D activities, is added. As expected, the estimated coefficient is positive, though not statistically significant. Adding the H_i indicator leaves both coefficients of the global-engagement indicators statistically significant; this shows that the fact that firms that are active on international markets have significantly larger shares of new products in total sales than purely domestic firms does not reflect the significantly higher share of employees in R&D in these internationally active firms. The next two columns add our information-flow variables. Using information on whether or not a firm cooperates in R&D with other parts of its enterprise as a proxy variable for internal information flows K_{ii} results reported in column 3 show that these information flows do not matter at all for the share of new products in total sales; the coefficient estimates for the other variables in the empirical model are not affected by the inclusion of the K_{ii} indicator. Adding the five indicators for information flows from outside has only a small impact on the estimates of the coefficients of the other variables, too (see column 4). The higher share of new products in total sales realized by internationally engaged firms, therefore, is not only due to their superior use of information from existing knowledge from outside. According to the results reported in column 4 suppliers and service providers are an important sources of information (although the estimated regression coefficient of the latter group is statistically significant from zero with at an error level of 8 percent only), while universities and customers do not play a role. Note that firms which cooperate in R&D with competitors have significantly lower shares of new products in total sales, ceteris paribus.

[Table 4 near here]

Like in the case of patents, we will next take a look at the economic relevance of the variables included in the knowledge production function, and perform a simulation exercise to do so. According to the second line in panel A of table 1 the average share of new products in total sales was 1.8 percent among locals, 6.4 percent among exporters, and 7.1 percent among foreign direct investors. This means that the share of sales due to new products was 3.56 (3.94) times higher among exporters (foreign direct investors) than among locals.

To illustrate which part of this difference among the groups is due to differences in the control variables, we use the results reported in column 1 of table 4 to compute the estimated share of sales due to new products in total sales for a local firm, an exporter, and a foreign direct investor *of a given size and age, from a given industry, and a firm that is no branch plant*. If the firm has 179.61 employees (the overall average size of firms in the sample), is no branch plant, is at least 11 years old, and from the chemical industry, the estimated share of new products in total sales is 1.9 percent for locals, 5.7 percent for exporters, and 5.2 percent for foreign direct investors. This means that for exporters (foreign direct investors) this share is 3.00 (2.74) times the share estimated for locals – these ratios are lower, but not drastically lower, than those reported above computed from the raw data (3.56 and 3.94, respectively).

To shed light on the economic importance of differences in knowledge inputs for explaining the differences in the share of sales due to new products between the three groups of firms, we perform another simulation experiment, this time based on the results reported in column 4 of table 4. Like in the case of patents, we look at a firm has 179.61 employees (the overall average size of firms in the sample), is no branch plant, is at least 11 years old, from the chemical industry, has 0.38 percent of employees in R&D (the average share for all firms in the sample), and has all types of cooperation in R&D. The estimated share of sales due to new products is 1.9 percent for locals, 5.3 percent for exporters, and 4.8 percent for foreign direct investors. Note that these shares are only slightly lower than those estimated when only the control variables are used. For exporters (foreign direct investors) this share is 2.78 (2.53) times the share estimated for locals – these ratios are only slightly lower than those reported above computed from a model with the control variables only (3.00 and 2.74, respectively).

The bottom line, then, is that the relative differences in the shares of new products in total sales between locals, exporters, and foreign direct investors are reduced by controlling for firm size, firm age, branch plant status, industry, and knowledge production inputs, but that these differences are still substantial.

4.3 New production processes introduced

Estimation results for the third indicator of new knowledge output, *new production processes introduced,* are given in table 5. Again, in column 1 only the two indicators for international activities of firms are included in the model (besides the set of control variables). Both coefficients turn out not to be statistically significantly different from zero at any conventional level of testing, indicating that the significant differences between exporters and foreign direct investors on the one hand and firms that sell on the German market only on the other hand reported in table 1 are partly due to differences in firm size and industry (while branch plant status and firm age do not play a role).

In column 2 the indicator for input to knowledge production inside the firm, the share of employees working in R&D activities, is added. As expected, the estimated coefficient is positive and statistically significant. This shows that the fact that firms that are active on international markets have a significantly higher probability of introducing new production processes than purely domestic firms does partly reflect the significantly higher share of employees in R&D in these internationally active firms. The next two columns add our information-flow variables. First, information on whether or not a firm cooperates in R&D with other parts of its enterprise is included in the model as a proxy variable for internal information flows K_{ii}. Results reported in column 3 show that these information flows do not matter at all for the probability of installing new production processes. Next, the five indicators for information flows from outside are added. According to the results reported in column 4 suppliers are an important source of information, while neither universities nor customers, service providers or competitors do play a role.

[Table 5 near here]

To check for the economic relevance of the variables included in the knowledge production function, the same procedure as in the case of patents and the share of new products in total sales was applied. From the third line in panel A of table 1 we know that the share of firms with new production processes introduced was 12.9 percent among locals, 18.2 percent among exporters, and 29.6 percent among foreign direct investors. This means that the share of firms with new production processes was 1.41 (2.29) times higher among exporters (foreign direct investors) than among locals.

To illustrate which part of this difference among the groups is due to differences in the control variables, the results reported in column 1 of table 5 are used to estimate the probability that a local firm, an exporter, or a foreign direct investor *of a given size and age, from a given industry, and a firm that is no branch plant* introduce a new production process. If the firm has 179.61 employees (the overall average size of firms in the sample), is no branch plant, is at least 11 years old, and from the chemical industry, the estimated probability is 19.1 percent for locals, 21.6 percent for exporters, and 25.6 percent for foreign direct investors. This means that for exporters (foreign direct investors) this probability is 1.13 (1.34) times higher than for locals – these ratios are lower than those reported above computed from the raw data (1.41 and 2.29, respectively), and they are close to 1.00 when exporters and locals are compared.

To look at the economic importance of differences in knowledge inputs for explaining the differences in the share of firms with new production processes installed between the three groups of firms, a second simulation is used, this time based on the results reported in column 4 of table 5. Like in the case of patents, we look at a firm has 179.61 employees (the overall average size of firms in the sample), is no branch plant, is at least 11 years old, from the chemical industry, has 0.38 percent of employees in R&D (the average share for all firms in the sample), and has all types of cooperation in R&D. The estimated probability of introducing a new production process is 19.3 percent for locals, 19.0 percent for exporters, and 22.8 percent for foreign direct investors. For exporters (foreign direct investors) this share is 0.98 (1.18) times the share estimated for locals – these ratios are lower than those reported above computed from a model with the control variables only (1.13 and 1.34, respectively), and they are both very close to 1.00.

The bottom line, then, is that the relative differences in the shares of firms with new production processes between locals, exporters, and foreign direct investors – that are statistically significantly different from zero according to line three of panel A in table 2 - are (nearly) completely explained by differences in firm size, firm age, branch plant status, industry, and knowledge production inputs.

To sum up, a large part of the superior innovative output of globally engaged firms is accounted for by differences in firms size and industry, by their higher share of employees in R&D (in the case of new patents registered and new production processes installed), and by their more intensive cooperation in R&D with universities and other research institutes (in the case of patents), suppliers (in the case of the share of new products in total sales and new production processes introduced), and service providers (in the case of new patents registered and the share of new products in total sales). According to the results from the estimations of the most comprehensive specification of the knowledge production function reported in column 4 of tables 3 to 5, the innovation output advantage of globally engaged firms is not at all linked to international activities per se when new production processes are considered. For new patents registered, only foreign direct investors show a higher probability ceteris paribus. For the share of new products in total sales we conclude from column 4 of table 4 that both forms of international activities go hand in hand with a higher level of innovation output even after controlling for firm size and age, branch plant status, industry, and the various innovation inputs.

5. Concluding remarks

Using a knowledge production framework and a rich set of plant level data this study demonstrates that in Germany firms that are active on international markets as exporters or foreign direct investors do generate more new knowledge than firms which sell on the national market only. These differences are not only due to a larger firm size, or different industries, or the use of more researchers in these firms, but due to the fact these globally engaged firms learn more from external sources, too. The importance of these knowledge sources varies with the type of innovation – for example, cooperation in R&D with universities and other research institutes matters in the case of new patents registered, while suppliers are important in the case of the share of new products in total sales and new production processes introduced.

These results, which are broadly in line with the findings by CSH in their study using UK firm level data, can help to explain the strong positive correlation between productivity and international activities of firms. Firms that are active on markets beyond the national borders generate higher levels of new knowledge that feed into higher productivity. At least for the case of Germany we may conclude from the evidence reported in studies on productivity and exporting that higher levels of productivity, and higher levels of new knowledge, are a precondition for success on foreign markets (see the survey in Wagner 2006a). The "rough winds on the world market", therefore, serve as a strong incentive to innovate, and foster economic growth this way.

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Table 1: International firm activities and innovation - Descriptive statistics

	Firms selling in Germany only	Exporters	Firms with foreign direct investments
Share in all firms in the sample (percent)	36.9	50.4	12.7
A: Knowledge output			
New Patents registered (percent)	4.2	17.3	42.6
Share of new products in sales (percent, mean)	1.8	6.4	7.1
New production processes introduced (percent)	12.9	18.2	29.6
B: Inputs to knowledge production inside the firm			
Share of employees in R&D (percent; mean)	0.04	0.5	1.0
C: Knowledge flow inside enterprise			
Firms that cooperate in R&D with other firms that belong to the same enterprise (percent)	3.9	14.5	34.2
D: Knowledge flow from outside			
Share of firms that cooperate in R&D with			
... universities or other research institutes (percent)	6.8	21.1	44.4
... customers (percent)	6.8	31.8	46.3
... suppliers (percent)	5.8	23.0	36.1
... service providers (percent)	5.1	10.7	19.4
... competitors (percent)	2.9	4.0	6.5
E: Control variables			
Firm size (number of employees; mean)	61.6	176.4	538.5
Branch plant (percent)	7.7	14.7	21.3
Share of firms that are ...			
... less than 6 years old (percent)	4.8	2.4	3.7
... between 6 and 10 years old (percent)	5.8	3.8	3.7
... at least 11 years old (percent)	89.4	93.9	92.6

Table 2: Significance tests for differences between groups of firms

	Firms selling in Germany only *compared with* exporters	Firms selling in Germany only *compared with* firms with foreign direct investments	Firms with foreign direct investments *compared with* exporters
A: Knowledge output			
New Patents registered (percent)	0.0000	0.0000	0.0000
Share of new products in sales (percent)	0.0000	0.0000	0.5746
New production processes introduced (percent)	0.0460	0.0006	0.0185
B: Inputs to knowledge production inside the firm			
Share of employees in R&D (percent)	0.0000	0.0000	0.0011
C: Knowledge flow inside enterprise			
Firms that cooperate in R&D with other firms that belong to the same enterprise (percent)	0.0000	0.0000	0.0001
D: Knowledge flow from outside			
Share of firms that cooperate in R&D with			
... universities or other research institutes (percent)	0.0000	0.0000	0.0000
... customers (percent)	0.0000	0.0000	0.0074
... suppliers (percent)	0.0000	0.0000	0.0110
... service providers (percent)	0.0050	0.0005	0.0350
... competitors (percent)	0.4025	0.1651	0.3427
E: Control variables			
Firm size (number of employees)	0.0000	0.0015	0.0163
Branch plant (percent)	0.0026	0.0017	0.1282
Share of firms that are ...			
... less than 6 years old (percent)	0.0848	0.6104	0.4975
... between 6 and 10 years old (percent)	0.2160	0.3567	0.9694
... at least 11 years old (percent)	0.0343	0.2990	0.6518

Note: The table reports the prob-values of t-tests (with unequal variances) on the equality of means of the two groups of firms. A prob-value of 0.05 or smaller indicates that the null-hypothesis of equal means can be rejected at an error level of 5 percent or smaller against the hypothesis of differences in means.

Table 3: Estimation results for new patents registered

Endogeneous variable: at least one patent registered; dummy, 1 = yes; Probit estimates

	(1)	(2)	(3)	(4)
Exporter (Dummy, 1 = yes)	0.495 (2.34)*	0.432 (2.15)*	0.435 (2.13)*	0.330 (1.49)
Foreign direct investor (Dummy, 1 = yes)	0.959 (3.01)**	0.857 (2.70)**	0.861 (2.68)**	0.721 (2.32)*
Number of employees	1.69e-3 (3.20)**	1.33e-3 (3.34)**	1.33e-3 (3.45)**	1.05e-3 (2.64)**
Number of employees (squared)	-4.37e-7 (1.94)	-2.44e-7 (2.84)**	-2.43e-7 (2.94)**	-2.09e-7 (2.79)**
Branch plant (Dummy, 1 = yes)	-0.159 (1.30)	-0.213 (1.60)	-0.211 (1.57)	-0.241 (1.40)
Firm aged 6-10 years (Dummy, 1 = yes)	-0.607 (1.45)	-0.519 (1.20)	-0.522 (1.19)	-0.468 (1.06)
Firm aged 11 or more years (Dummy, 1 = yes)	0.034 (0.11)	0.064 (0.19)	0.064 (0.18)	0.001 (0.00)
Share of employees in R&D (percent)		0.187 (3.02)**	0.188 (2.89)**	0.135 (2.63)**
Cooperation in R&D with ...				
other firms from enterprise (Dummy, 1 = yes)			-0.011 (0.06)	-0.213 (1.14)
universities (Dummy, 1 = yes)				0.535 (3.01)**
customers (Dummy, 1 = yes)				0.265 (1.64)
suppliers (Dummy, 1 = yes)				0.234 (1.38)
service providers (Dummy, 1 = yes)				0.446 (3.08)**
competitors (Dummy, 1 = yes)				0.198 (0.71)
Constant	-1.594 (4.32)**	-1.814 (4.31)**	-1.813 (4.28)**	-1.966 (5.03)
Observations	833	822	821	821

Note: All models include a full set of industry dummies.
Robust z statistics in parentheses; * significant at 5%; ** significant at 1%

Table 4: Estimation results for share of new products in total sales

Endogeneous variable: share of new products in total sales in percent; Fractional Logit estimates

	(1)	(2)	(3)	(4)
Exporter	1.137	1.126	1.125	1.069
(Dummy, 1 = yes)	(4.09)**	(4.14)**	(4.11)**	(3.72)**
Foreign direct investor	1.034	0.982	0.977	0.959
(Dummy, 1 = yes)	(3.19)**	(3.23)**	(3.24)**	(2.65)**
Number of employees	9.25e-4	8.82e-4	8.57e-4	6.41e-4
	(3.54)**	(3.41)**	(3.11)**	(2.75)**
Number of employees	-9.33e-8	-8.81e-8	-8.56e-8	-5.90e-8
(Dummy, 1 = yes)	(3.18)**	(3.01)**	(2.82)**	(2.33)*
Branch plant	0.397	0.388	0.377	0.361
(Dummy, 1 = yes)	(1.43)	(1.40)	(1.50)	(1.43)
Firm aged 6-10 years	0.472	0.530	0.529	0.818
(Dummy, 1 = yes)	(0.53)	(0.58)	(0.58)	(1.02)
Firm aged 11 or more years	-0.067	-0.029	-0.025	0.146
(Dummy, 1 = yes)	(0.18)	(0.07)	(0.06)	(0.56)
Share of employees in R&D		0.089	0.087	0.016
(percent)		(1.22)	(1.17)	(0.20)
Cooperation in R&D with ...				
other firms from enterprise			0.044	-0.142
(Dummy, 1 = yes)			(0.18)	(0.61)
universities				-0.023
(Dummy, 1 = yes)				(0.16)
customers				0.200
(Dummy, 1 = yes)				(1.26)
suppliers				0.516
(Dummy, 1 = yes)				(3.12)**
service providers				0.456
(Dummy, 1 = yes)				(1.76)
competitors				-0.763
(Dummy, 1 = yes)				(2.36)*
Constant	-4.043	-4.170	-4.174	-4.459
	(8.70)**	(8.97)**	(9.02)**	(11.75)**
Observations	700	693	692	692

Note: All models include a full set of industry dummies.
Robust z statistics in parentheses: * significant at 5%; ** significant at 1%

Table 5: Estimation results for new production processes introduced

Endogeneous variable: at least one new production process installed; dummy, 1 = yes; Probit estimates

	(1)	(2)	(3)	(4)
Exporter (Dummy, 1 = yes)	0.088 (0.79)	0.064 (0.56)	0.056 (0.50)	-0.010 (0.09)
Foreign direct investor (Dummy, 1 = yes)	0.217 (1.03)	0.181 (0.88)	0.184 (0.82)	0.122 (0.59)
Number of employees	1.44e-3 (4.67)**	1.35e-3 (4.13)**	1.40e-3 (4.42)**	1.29e-3 (4.10)**
Number of Employees (squared)	-2.56e-7 (3.42)**	-2-25e-7 (4.56)**	-2.33e-7 (4.99)**	-2.08e-7 (4.24)**
Branch plant (Dummy, 1 = yes)	-0.110 (0.58)	-0.124 (0.65)	-0.113 (0.61)	-0.088 (0.47)
Firm aged 6-10 years (Dummy, 1 = yes)	-0.454 (0.94)	-0.411 (0.88)	-0.414 (0.88)	-0.368 (0.79)
Firm aged 11 or more years (Dummy, 1 = yes)	-0.046 (0.13)	-0.026 (0.07)	-0.036 (0.10)	-0.019 (0.05)
Share of employees in R&D (percent)		0.079 (2.44)*	0.079 (2.21)*	0.062 (1.77)
Cooperation in R&D with ...				
other firms from enterprise (Dummy, 1 = yes)			-0.048 (0.22)	-0.177 (0.74)
universities (Dummy, 1 = yes)				-0.072 (0.50)
customers (Dummy, 1 = yes)				0.172 (1.18)
suppliers (Dummy, 1 = yes)				0.383 (2.12)*
service providers (Dummy, 1 = yes)				0.107 (0.48)
competitors (Dummy, 1 = yes)				-0.291 (1.27)
Constant	-1.078 (2.89)**	-1.179 (3.40)**	-1.162 (3.30)**	-1.218 (3.34)**
Observations	838	826	825	825

Note: All models include a full set of industry dummies.
Robust z statistics in parentheses; * significant at 5%; ** significant at 1%

Appendix: Questions from the Hannover Firm Panel Study

1. International activities of firms

Exports

Did you sell products in a foreign country in 1994?

[Haben Sie im Jahr 1994 Produkte ins Ausland verkauft?]

Foreign direct investments

Does your firm own (parts of) one or more firms in a foreign country?

[Ist Ihr Betrieb an einem oder mehreren Unternehmen im Ausland beteiligt?]

2. Output of knew knowledge

Patents

Did you register patents in 1994?

Haben Sie im Jahr 1994 Patente angemeldet?]

Share of new products in total sales

What was the share of sales due to these [new] products in total sales in 1994?

[Welchen Anteil am Gesamtumsatz haben Sie 1994 mit diesen [gemeint: im Jahr 1994 neu eingeführten, J.W.] Produkten erwirtschaftet?

New production processes

Did you introduce new production processes in 1994?

[Haben Sie im Jahr 1994 neue Produktionsverfahren eingeführt?]

3. Inputs in discovering new knowledge in this firm

Percentage of employees working in research and development (R&D)

How many employees in your firm are working exclusively or most of the time in research or development activites – irrespective of the existence or not of a research and development department in the firm?

[Wie viele Beschäftigte sind in Ihrem Betrieb ausschließlich bzw. überwiegend mit Forschungs- und Entwicklungsaktivitäten befasst – unabhängig davon, ob es für Forschung und Entwicklung eine eigene Abteilung gibt?]

4. Cooperation in Research and Development

Partners in research and development activities

Research and development activities are often performed in cooperation with others. How about you: With which of the following partners do you cooperate? Parts of your own enterprise; customers; suppliers; competitors; universities / other research institutions; service providers (e.g., engineering bureaus); none.

[Forschungs- und Entwicklungsaktivitäten werden häufig in Kooperation mit anderen durchgeführt. Wie ist das bei Ihnen: Mit welchen der folgenden Partner arbeiten Sie zusammen? Betriebseinheiten der eigenen Unternehmens-Gruppe; Kunden; Lieferanten / Zulieferer; Wettbewerber; Universitäten / (Fach-)Hochschulen / Sonstige Forschungseinrichtungen; Betriebsnahe Dienstleister (z.B. Ingenieurbüros); Trifft nicht zu, keine Kooperation.]

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