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Trade and Productivity:
An Industry Perspective

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Trade and Productivity: An Industry Perspective[*]

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Abstract:

We use a sample of 14 OECD countries and 15 manufacturing industries to test for the effect of trade on productivity. Endogeneity concerns are accounted for using the geographical component of trade as instrument as suggested by Frankel and Romer (1999). Our results are in line with previous studies: Trade increases productivity. What is puzzling, however, is the size of the effect: An increase in the export ratio by one percentage point increases productivity in manufacturing by 0.6 percent on average. This is less than half of the effect obtained in previous studies. We discuss likely explanations for this discrepancy.

JEL Classification: F14, F43, L60

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I. Introduction

The relation between trade and productivity has always been at the heart of international economics. Theoretical arguments can be traced back at least to Adam Smith's famous dictum that the division of labour is limited through the size of the market. The literature has emphasized several additional channels via which trade may influence productivity: the exploitation of increasing returns from larger markets (e.g. Balassa, 1961), the transmission of international technology spillovers (e.g. Coe and Helpman, 1995), the exchange of ideas through travel and communication, as well as the pro-competitive effect of international trade (e.g. Bhagwati, 1965).

Numerous empirical studies have confirmed a positive correlation between trade and income (see Lewer and Van den Berg (2003) for a comprehensive survey), but endogeneity concerns and the absence of convincing instruments have cast doubts on whether these observed correlation actually reflects a causal relationship. Frankel and Romer (1999) argue that geography affects income only via trade and suggest using the geographical component of aggregate trade as instrument. Using data from a large cross-section of countries referring to the year 1985, they find that the least squares estimates are not invalidated by the results of the instrumental variable estimation. In contrast, the estimated effect of trade on productivity even increases if endogeneity is accounted for, though the estimates turn out only moderately significant. These results were basically confirmed by Irwin and Terviö (2002) for alternative reference years from the twentieth century, ranging from 1913 to 1990. Nevertheless, the academic debate is yet unsettled: Rodrik et al. (2002) find that trade is insignificant once institutional quality is controlled for and argue that the positive effect of trade in previous studies may simply capture omitted institutional characteristics. Also, Irwin and Terviö (2002) note that the effect of trade on productivity is not robust to the inclusion of distance from the equator, a proxy for Western influence according to Hall and Jones (2002). Another critique of the geographical instrument suggested by Frankel and Romer (1999) was put forward by Durlauf (2001). Part of these concerns on the relationship between trade and income have been addressed in a recent paper by Alcala and Ciccone (2004). They advocate the use of real rather than the nominal openness, which may be a distorted measure of openness as a result of the trade-related Balassa-Samuelson effect, and find trade to be a significant determinant of productivity even when institutions are controlled for.

This paper takes an alternative approach to addressing the concerns on the relationship between trade and productivity. We follow the approach by the Frankel and Romer (1999), but rather than including proxies for institutional characteristics or latitude (as control for Western influence) we focus on a sample of 'Western', institutionally largely homogenous countries (14 OECD countries) and use industry data (15 manufacturing industries). Providing an industry perspective on the relationship between trade and productivity is not only of interest in itself; it also allows to control for country-specific effects that are invariant over industries, providing an additional robustness check against the possible omission of (unobservable) institutional characteristics.

The results suggest that trade has a statistically significant and robust effect on productivity in manufacturing. Our instrument, the geographical component of trade, is of high quality yielding comparably precise and highly significant estimates. The size of the effect, however, appears to be fairly low compared with previous estimates. We discuss likely explanations for this difference, raising several points that deserve further attention. The remainder of the paper is organized as follows. Section II sets up the empirical model. Section III constructs the instrument for trade. Section IV presents the estimates of the relation between trade and productivity. Section V summarizes the results and concludes.

II. Trade and Productivity: The Empirical Model

Trade may affect productivity in various ways: through specialization and the exploitation of economies of scale from larger markets, by increasing the incentive to innovate as a result of enhanced competition, and through knowledge spillovers by exposure to new goods and technologies. The logic of these arguments is not confined to international trade but applies equally to within-country trade. In line with Frankel and Romer (1999), equation (1) sets up the hypothesis that economic interactions of country *i* with other countries (international trade) and economic interactions within the country (within-country trade) have a (positive) effect on productivity:

$$\ln y_i = \alpha + \beta T_i + \gamma W_i + \varepsilon_i . \tag{1}$$

Here y_i is GDP per worker, T_i is international trade, and W_i is within-country trade. Equation (1) cannot be estimated by least squares since trade (T_i) is likely to be endogenous.

International and within-country trade are in turn modelled as functions of proximity to other countries (P_i) and country size (S_i) respectively.

$$T_i = \psi + \phi P_i + \delta_i , \tag{2}$$

$$W_i = \eta + \lambda S_i + \nu_i . \tag{3}$$

The problem that within-country trade is not observable is addressed by substituting (3) into (1), yielding

$$\ln y_i = (\alpha + \gamma\eta) + \beta T_i + \gamma\lambda S_i + (\gamma\nu_i + \varepsilon_i)\text{, or equivalently} \tag{4}$$

$$\ln y_i = \mu + \varphi T_i + \tau S_i + u_i \tag{5}$$

Under the identifying assumptions that the geographical variables P_i and S_i are uncorrelated with the composite error term $(\gamma\nu_i + \varepsilon_i)$, equation (4) can be estimated consistently using S_i and P_i as instruments for T_i. We use two measures of size, population (N) and area (A), such that equation (4) becomes

$$\ln y_i = \mu + \varphi T_i + \tau_1 N_i + \tau_2 A_i + u_i \tag{6}$$

This basic setup follows Frankel and Romer (1999). Our final model differs in several respects. First, Frankel and Romer (1999) use a large sample of 150 (and 98) countries, including many developing countries. We focus on a sample 14 OECD countries (AUT, BEL, DEU, DNK, ESP, FIN, FRA, GBR, GRC, ITA, NLD, NOR, SWE, USA). Besides the availability of more reliable data, focussing on countries with similar institutions makes it unlikely that our trade variable captures unobserved institutional heterogeneity, a point prominently raised by Rodrik et al. (2002). Similarly, Durlauf's (2003) critique of the geography-based instrument by Frankel and Romer (1999) is less relevant for our sample.[1]

Second, we use industry data comprising 15 manufacturing industries (See Table A1 in the Appendix for an overview). That is, equation (6) becomes

$$\ln y_{ik} = \mu_k + \varphi T_i + \tau_1 N_i + \tau_2 A_i + u_{ik}\,, \tag{7}$$

where *k* denotes industry. Productivity (y_{ik}) is now measured in terms of value added per worker. While the instrument P_i^k becomes industry-specific as well (since it is derived from industry-specific gravity estimates as will be outlined below) the size measures N_i and A_i are still country-specific rather than industry-specific. Since industries also deliver intermediates to other industries, it not the size of the own sector but that of the whole economy which is the relevant determinant of within-country trade. A further advantage of using industry data is that we have several observations per county, which enables us to include country dummies as an additional robustness check.

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[1] The point raised by Durlauf is that the error term in (6) or here in (7) captures omitted variables such as taxes and democracy. Area, so the argument, is related to military expenditures, which are in turn correlated with tax levels and democracy. While this may in fact be a serious concern in a large sample of countries including many developing and non-democratic countries, this argument vanishes for our sample of high-income countries with similar democratic institutions.

As most common measure for openness at the industry level we use the export share of production.[2] Since no industry-specific deflators are available we have to use nominal openness rather than 'real' openness as advocated by Alcala and Ciccone (2004). For our sample, which includes mainly countries with a similar level of development, this is no major drawback, since the trade related Balassa-Samuelson effect is less relevant here.

Equation (7), which relates industry-specific productivity to industry-specific openness, still reflects the main channels via which the effects of trade on productivity materialize: intra-industry specialization, intra-industry Economies of Scale, technology-spillovers through exchange of similar goods and the effects of increased competition between firms producing similar goods. Since our productivity measure is value added per worker, increases in productivity in industry *i* do not necessarily increase productivity in industry *j*, even if *i* uses the output of *j* as intermediate good. Still there are channels that may operate *across* industries: Specialization according to comparative advantage would be reflected in an increase in inter-industry rather than intra-industry trade; and (external) Economies of Scales may also be of inter-industry type (Balassa, 1961, p. 131).[3] By ruling out these inter-industry effects, the hypothesis expressed by equation (7) is somewhat narrower than the corresponding model at the aggregate level (6).

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[2] Imports are less preferable since a large import share may also reflect intensive use of imported intermediates, not necessarily a high exposure to international trade in final goods. We do not use alternative measures such as import penetration which have a different interpretation and would make our results less comparable with previous studies that use openness.

[3] Part of these inter-industry effects is transmitted through interactions within the country ("within-country" trade) and should thus be captured by the coefficient of the within-country variable. This is another rationale for including aggregate rather then industry size measures in equation (7).

III. Construction of the Instrument

a) The geographical gravity model

For the instrument P_i to be valid is must not be correlated with the error term in (7); to be useful it must also be strongly correlated with trade. Frankel and Romer (1999) argue that geography is an important determinant not only of bilateral but also of overall trade. At the same time it is difficult to think of any channel other than international trade via which geographical characteristics may affect income. This is the rationale for constructing the instrument P_i as 'geographical component' of aggregate trade ($\hat{T}_i^k$). This geographical component of trade is calculated from the predicted values of the following gravity model, whose regressor matrix (**X**) includes geographical variables only:

$$\begin{aligned}\ln T_{ij}^k &= \boldsymbol{\alpha}_k^{'}\mathbf{X}_{ij} + \vartheta_{ij}^k = \\ &= \alpha_{0k} + \alpha_{1k}d_{ij} + \alpha_{2k}N_i + \alpha_{3k}A_i + \alpha_{4k}N_j + \alpha_{5k}A_j + \alpha_{6k}(LL_i + LL_j) + \alpha_{7k}CB_{ij} + \vartheta_{ij}^k\end{aligned} \quad , (8)$$

where T_{ij}^k is the ratio of exports from county i to country j to country i's production in industry k, d_{ij} is distance, N is population, A is area, LL is a dummy for landlocked countries, and CB is a common-border dummy.[4] Our sample comprises 14 countries (i) and 15 manufacturing industries (k); we have bilateral trade data by industry with 44 partner countries ($j, j \neq i$) covering some 90 percent of trade on average. Trade data are averages of the period 1995 to 2000. A detailed description of the data is given in the Appendix.

b) Estimation results

Equation (8) is estimated separately for each of the 15 industries. Table 1 summarizes the results.

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[4] Frankel and Romer (1999) also include interactions between the common border dummy and all other variables; in our estimation these interactions all turned out insignificant; moreover, they induced collinearity problems such that we omit these interactions from the beginning.

< Table 1 here >

As expected distance has a large negative effect on trade (defined as ratio of exports to production). The elasticity of trade with respect to distance ranges from -0.425 to -1.327; for industries with a larger weight/value ratio (e.g. 23: Coke, refined petroleum products and nuclear fuel) the effect is more pronounced than for industries producing more sophisticated goods (e.g. 30-33: Electrical and optical equipment). Trade is strongly increasing in country *j*'s population with an average elasticity of 0.540 and decreasing in both country *i*'s and country *j*'s area. The impact of country *i*'s population is insignificant or negative for most industries. In line with previous studies we find that, all else being equal, landlocked countries trade considerably less (some 60 percent on average) and that a countries sharing a border trade more (some 140 percent). Finally, and most importantly, our regressions confirm that geographical variables are an important determinant of international trade. The values of the R^2 of our regressions range from 0.228 to 0.550.

c) Implications for aggregate trade and the quality of the instrument

To obtain our instrument $\hat{T}_i^k$, that is the geographical component of aggregate (rather than bilateral) trade by industry, the predicted values for the bilateral export ratios are aggregated as follows:

$$\hat{T}_i^k = \sum_{j=1}^{J} \theta_k e^{\mathbf{a}_k' \mathbf{X}_{ij}} , \tag{9}$$

where $\mathbf{a}_k$ is the estimate of $\boldsymbol{\alpha}_k$ from (8). To obtain consistent predicted values for the levels of T_{ij}^k from the estimates in log form, a correction factor θ_k is required. Under normality θ_k is equal to $E[e^{\vartheta_{ij}^k}] = e^{(\hat{\sigma}_k^2/2)}$, where $\hat{\sigma}_k^2$ is a consistent estimator of the variance of ϑ_{ij}^k. To avoid making distributional assumptions we follow the approach suggested by Wooldridge (2003, p.

207ff.) and estimate θ_k from a regression of T_{ij}^k on $e^{\mathbf{a}'_k \mathbf{X}_{ij}}$ through the origin. Using (9) we calculate industry-specific trade shares for each of the 14 countries; the summation in (9) runs not only over the (44) countries for which we have bilateral trade data, but over all countries for which the variables in **X** are available (additional 179 countries).[5]

Our instrument $\hat{T}_{ij}^k$ must fulfil two properties. First, it must be uncorrelated with the error term in (7), an assumption made here for theoretical reasons. Second, the instrument must also be relevant. The issue of 'weak instruments' has received considerable attention in the recent literature (Staiger and Stock, 1997; Stock, Wright, and Yogo, 2002; Andrews, Moreira, and Stock, 2004). Two stages least squares with weak instruments may yield strongly biased estimates and tests with large size distortions. Hence it will be important to check the quality of the instrument.

< Figure 1 here >

The scatter plot of the constructed against the actual trade share in Figure 1 suggests a strong association between our instrument and the endogenous variable. The quality of the instruments can also be judged more formally. Stock and Yogo (2004) work out a definition of weak instruments (based on bias and size distortion) and develop a test for weak instruments. For our case of one endogenous regressor, the test statistic amounts to the F-statistic on excluding the instrument in the first stage regression. Stock and Yogo (2004) provide critical values depending on the maximum tolerable bias and size distortion.

< Table 2 here >

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[5] As mentioned above, however, more than 90 percent of trade is covered by the countries for which bilateral trade data are available.

The first column in Table (2), which shows the results from regressing the actual on the constructed trade share and industry-specific constants (Table 2 gives only the average value), confirms the strong association illustrated in Figure 1. In the two-stage least squares estimation of equation (7), however, N_i and A_i have to be included as instruments anyway. Hence our constructed trade share is useful only insofar, as it contains information about the endogenous variable (the trade share) that goes beyond that contained in country size (N and A). To put it differently: what is relevant is the strength of the partial correlation between the actual and the constructed trade share, controlling for country size. As can be seen from columns (2) and (3) of Table 2, adding the constructed trade share to the model including only population and area (as well as industry-specific constants) increases the R^2 from 0.579 (column (2)) to 0.708 (column (3)). Moreover, the F-test of the excluding restriction for the constructed trade share in column (3), which is the first stage regression in the two-stages least squares estimation of equation (7), amounts to 83.5. This value by far exceeds the critical values provided by Stock and Yogo (2004). Hence the hypothesis that our two stages least squares estimates are flawed by weak instruments is strongly rejected.

IV. Trade and Productivity: Estimation Results

a) Basic results

Having constructed the instrument and verified its quality we can now turn to the estimation of trade's effect on productivity using equation (7). Again, the data are averages over the period 1995 to 2000; a detailed description is given in the Appendix. The first column of Table 3 shows the results of the OLS estimation. Trade turns out as both statistically and economically significant determinant of productivity; its t-value is 6.34 and the coefficient implies that a one-percentage-point increase in trade (the export ratio) increases productivity by 0.543 percent. The regression also confirms a positive relationship between country size and productivity; increasing both area and population by one percent raises productivity by 0.138 percent.

Turning to the IV-estimates in column (2) we observe only a minor change in the parameter estimates; in contrast there is a huge increase in the effect of trade in the Frankel and Romer (1999) study. Moreover, due to the high quality of our instrument – the first stage F-statistic on the excluded instrument amounts to 83.5 – our estimates are still very precise: the standard error of the coefficient of trade ‘only’ doubles (while it quadruples in the Frankel and Romer (1999) analysis), leaving the coefficient on trade significant at the one per cent level with a *t*-value of 3.05 (while it remains only marginally significant in the Frankel and Romer analysis).[6] So far we have allowed for industry-specific differences only by letting the intercept vary across industries. This is a minimum requirement, as a Wald-test for restricting the constants to be equal across industries is strongly rejected. This is not surprising, given the huge variation in productivity across industries which is due to very different production technologies and cannot be expected to be explained by variations in national and international trade.[7]

< Table 3 here >

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[6] Throughout, we account for the fact that the instrument depends on the parameters of the bilateral gravity equations using the delta method. That is, the covariance matrix of **b** (the vector containing the coefficients of equation (7)), is given by $Var[\mathbf{b}(\mathbf{a})]$, that is the usual two stages least squares variance-covariance matrix for given **a** (which is the stacked vector of coefficients $\mathbf{a}_k$ from the industry-specific gravity models) plus $\sum_k (\partial\mathbf{b}(\mathbf{a})/\partial\mathbf{a}_k)\hat{\Omega}_k(\partial\mathbf{b}(\mathbf{a})/\partial\mathbf{a}_k)'$, where $\hat{\Omega}_k = \hat{\sigma}_k^2(\mathbf{X}'\mathbf{X})^{-1}$ is the variance-covariance matrix of $\mathbf{a}_k$. The summation over industries results from the block-diagonality of the regressor matrix in the ‘stacked’ gravity model with industry-specific coefficients. This correction has only a moderate effect on the precision of the parameter estimates: On average the standard errors increase by less than 10 percent.

[7] We note that using the log of the export ratio yields de facto identical results. Typically, the size of the coefficient is halved (as expected since the average export-ratio is some 50 percent).

b) Testing for cross-industry heterogeneity

In a next step we investigate whether there are also significant differences in the effect of trade on productivity across industries. We include interaction terms between the trade variable and (*k*-1) industry dummies; the parameters of the interactions terms thus have the interpretation of deviations from an arbitrary benchmark industry, whose parameter is that of the unweighted trade variable. The test for parameter homogeneity can then be carried out with a simple Wald-test that the parameters of all interaction terms are zero. The detailed results are given in Table A2 in the Appendix. The Wald test for parameter homogeneity is only slightly rejected at the 10 percent level (see bottom of Table A2). Taking a closer look at the interaction terms it becomes evident that the significant test statistic can be traced back to two industries: 23 (coke, refined petroleum products and nuclear fuel) and 34 (motor vehicles, trailers and semi-trailers). The effect of trade on productivity in these two industries is -1.089 (-2.136+1.047) and -0.539 (-1.586+1.047) respectively. As a result of fairly large standard errors, a Wald-test that these two coefficients are equal to zero cannot be rejected, neither separately where the test statistics amount to 1.16 (p-value: 0.282) and 1.49 (p-value: 0.222) respectively, nor when tested jointly (test statistic: 2.23, p-value: 0.328).

This is not implausible: Both industries are largely dominated by a few large multinational companies. Hence the trade variable reflects a large share of intra-firm trade and is thus a less proper measure of openness here. As a consequence we exclude these two industries from our sample. Repeating the heterogeneity test (see Table A1 in the appendix, column (2)), only one of the interaction terms is significant. However, the zero restriction for this industry is now rejected. Moreover, the Wald-test for parameter homogeneity cannot be rejected any more with a value of 17.06 (p-value: 0.148).

Hence we proceed with the reduced sample model, excluding the two industries 23 and 34. This implies that our sample still covers 92.3 percent of manufacturing. The corresponding OLS and two stages least squares estimates of the homogenous model are given in columns (3) and (4) of Table 3. The effect of trade on productivity in column (3) is now somewhat larger as expected, since the effect is averaged down by the two industries where the effect is close to zero in columns (1) and (2).[8]

It suggests itself to test for cross-country heterogeneity as well; unfortunately, this leads to multicollinearity problems of the interactions of the countries dummies with population (N) and area (A), which are country-specific variables as well. The only way to allow for more heterogeneity across countries is the inclusion of 'selected' country dummies, a point that will be taken up in the subsequent robustness check.

c) Robustness

Before relating our results to previous estimates, we now provide some robustness checks of our results. We proceed with the reduced (homogenous) sample.[9] The first two columns in Table 3 reproduce the estimates of the reduced model to facilitate the comparison.

As a first robustness check we exclude obvious outliers, defined as observations where the standardized residuals exceed the value of two. This reduces our sample by 11 observations. The corresponding results are given in columns (3) and (4) of Table 4. The standard error falls considerably (by 30 percent) and the fit in terms of the R^2 increases from 0.704 to a remarkable 0.818. The main results are not affected; in fact the coefficient of trade increases to 0.720.

< Table 4 here >

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[8] Since the OLS estimates are potentially flawed by endogeneity of the trade variable, we focussed on the two stages least squares results in testing for heterogeneity. The price is larger standard errors, of course. Hence the interpretation should not be overstressed. We cannot rule out heterogeneity; it is rather that at our level of precision we cannot detect significant differences. From an econometric perspective, however, it is valid to proceed with the homogeneity assumption.

[9] The results are very similar, if the full sample is used.

In a next step we include country dummies to control for remaining institutional heterogeneity; since population (*N*) and area (*A*) in equation (7) are country-specific as well, including a full set of country dummies is not possible due to perfect collinearity. As compromise we include only 11 of the 14 country dummies. This means the remaining countries are assumed to have the same intercept; accordingly one should choose the most homogenous group of three countries. To avoid making ad hoc assumptions about the similarity of countries, we estimated (7) including all possible combinations of 11 of the 14 country dummies. It turns out that, while the coefficients of area and population vary considerably across the estimates, the effect on the coefficient of trade is very similar across the specifications. Columns (5) and (6) of Table 4 show one example, which may be regarded as representative. Here three Nordic countries (Denmark, Finland, and Sweden) have been grouped together; for all other countries a separate dummy was included. As a consequence, the coefficient of trade falls to 0.392 but remains significant at the five percent level. If outliers are excluded as before, the coefficient increases to 0.528 again and turns out significant at the 1 percent level. We conclude our results are not driven by unobserved country-specific heterogeneity.

Finally, we check the sensitivity of the results with respect to the construction of the instrument. In line with Frankel and Romer (1999) we use alternative specifications of the gravity model excluding variables which might be regarded as endogenous in the very long run. In particular, we omit the common border dummy, the landlocked dummy, area and population respectively from the gravity equation and re-estimate (7) with the so constructed instrument. The results of the two stages least squares estimates are given in the last four columns of Table 4. As expected the F-statistic of the first stage regression falls, when less information is used in the construction of the instrument. Nevertheless, the F-statistics are high enough to reject the hypothesis of weak instruments. The coefficient of trade varies somewhat across the specifications from 0.482 to 0.859 but always remains significant.

d) Relation to previous estimates

Our estimates suggest that an increase in openness (in terms of the export ratio) by one-percentage point increases productivity by approximately two third of a percent on average; the IV estimates range from 0.39 to 0.86. How do these estimates of trade's effect on productivity compare with previous results in the literature? The most comprehensive survey on the relation between trade and growth is Lewer and Van den Berg (2003). The studies surveyed do not exactly match our setup; they are primarily specified in growth rates, do not use trade relative to GDP and – if specified in intensive form at all – use per capita values; nevertheless the results are suggestive. Lewer and Van den Berg (2003) find that many empirical studies yield surprisingly consistent results: a one percentage point increase in growth of exports is a associated with a one-fifth percentage point increase in economic growth. The results by Frankel and Romer (1999) are not directly comparable; they find that openness (defined as imports plus exports as share of GDP as measure) increases income by 0.5 to 2 percent; the estimates of Irwin and Terviö (2002) vary somewhat over the samples but are of a similar size. For a rough comparison, we can translate the estimates of the Frankel and Romer (1999) study into elasticities by evaluation them at the sample mean of openness (73.4 per cent): this yields an average value of 0.92. Alcala and Ciccone (2004), who use the log of real openness, obtain much elasticities between 0.91 and 1.49 (and, similarly, elasticities around one if nominal openness is used).

Translating our estimates into elasticities by evaluating them at the sample mean of the export ratio (43.5 per cent, see Table A1 in the Appendix) we obtain an average value of 0.37 for manufacturing (which makes up only roughly one fifth of total value added). As we argued in section II, the industry-specific specification (7) narrows the effects captured by the coefficient of the trade variable, ruling out effects that materialize *across* industries (inter-industry productivity spillovers within manufacturing and from manufacturing to services). In order to roughly account for this fact we assume that trade in manufacturing goods affects productivity in services equally[10]; even then the implied aggregate effect of 0.37 is still less than half of the Frankel and Romer (1999) estimates. Hence, the different setup of the hypotheses can only partially account for this large gap.

There are two further explanations for this discrepancy in the size of the estimated effect. First, it could be due to the choice of our sample of countries. If there are decreasing returns to economic (trade) integration, the small effect of our estimates could be due to the fact that ours sample consists of highly integrated countries with comparably large trade shares. One possible reason for such decreasing returns is that trade may have a larger effect on productivity for countries which are more distant from the technology frontier, since trade facilitates the catching-up process by transmitting technological know-how for imitation. This effect diminishes as countries are moving closer to the technology frontier. Using aggregate data, the cross section of our sample would reduce to fourteen countries, which is too small to yield sensible estimates. We can, however, consider whether our sample of countries has a significantly different coefficient in the Frankel and Romer (1999) sample. Table A3 in the Appendix gives the estimation results. Columns (1) and (2) reproduce the Frankel and Romer (1999) estimates; columns (3) and (4) show the results when a dummy for our group of 14 countries (D_{OECD}) is included along with an interaction of the trade ratio and D_{OECD}, which measures the deviation of trade's productivity effect in our sample from the average.[11] While the deviation is in fact negative, implying a substantially lower effects of trade on productivity, the difference is insignificant. The same holds true if the restricted sample of 98

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[10] This assumption requires some justification: As Frankel and Romer argue it is not the "literal shipping of goods between countries" that raises income. Rather, trade may be viewed as a proxy for the many ways in which interactions between countries raise income. From this perspective, one would expect that any impact of trade in goods on productivity in manufacturing would also be associated with an impact on productivity in services.

[11] Since the 14 OECD countries may have a higher productivity for reasons other than their trade share (again, institutions) including a separate constant is a minimum requirement for the heterogeneity tests.

countries is used as reference (see columns (5) and (6)). Hence, there is no strong support for the presumption of ‘decreasing returns to trade’, but in light of the fact that the estimates are rather imprecise, the results are somewhat inconclusive.

Second, the effect of trade in productivity on trade in previous studies is likely to be biased upwards. Most studies use aggregate productivity but trade in *goods* as explanatory variable. Services make up more than two third of GDP and trade in services has risen considerably over the last years. Since trade in goods is likely to be highly correlated with trade in services, the coefficient could also capture productivity effects of trade in services. For studies, which use many developing countries (where service trade is negligible) or use time periods where services have been less important (such as 1985 in the Frankel and Romer paper), this is an unlikely explanation. Even today and for developed countries, where trade in services make up only little more than 20 percent of total trade this may again provide a partial explanation at best. Anyway, considering the effect of trade on productivity in service sectors is a worthwhile line for future research.

A priori, none of these explanations can be favoured on grounds of theory or existing studies. In light of the recent evidence, the link between trade and productivity appears to be fairly robustly established. Nevertheless, the size and the transmission channels of the effect deserve further attention.

V. Summary and Conclusions

This paper complements previous studies on the productivity effects of trade, providing an analysis at the industry-level for a sample of 14 OECD countries. Following Frankel and Romer (1999) we use the geographical component of aggregate trade, which is constructed from the predicted values of a ‘purely’ geographical gravity model, as instrument for trade to deal with the likely endogeneity of a country’s (industry’s) openness.

The effect of trade on productivity turns out to have a statistically and economically significant effect on productivity: On average, an increase in openness (in terms of the export to production ratio) by one percentage point increases the productivity in manufacturing by 0.6 percent. Since we use a sample of institutionally largely 'homogenous' countries, our results are unlikely to be driven by unobserved institutional heterogeneity. This is also confirmed by a robustness check including country dummies. Comparing the OLS with the IV estimates, the OLS estimates appear to be downward biased (due to measurement error, since trade is a poor proxy for international interactions) rather than upward biased (due to reverse causality). This is in line with Frankel and Romer (1999) and Irwin and Terviö (2002), but the difference between our OLS and IV estimates is much smaller than that in previous studies.

One puzzling result is the size of the estimated effect on aggregate productivity, which amounts to less than half of previous estimates. We offer three explanations all of which deserve further investigation: i) Using industry data our coefficient of trade does not capture effects of trade that operate across industries such as external Economies of Scale of inter-industry type within manufacturing. ii) Using a sample of developed countries with high trade integration may result in low estimates if there are decreasing returns to the gains from trade. iii) The size of previous estimates may be upward-biased, if the trade (in goods) variable also captures productivity effects of trade in services (which is likely to be highly correlated with trade in goods).

The contribution of each of these arguments is unclear. Providing a convincing explanation for the large discrepancy between our estimates and that of previous studies is an important further step to gain a deeper understanding of the economic significance of trade in enhancing productivity and the channels via which these effects materialize.

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Appendix

Data description

All data are averages over the period 1995-2000. Cross-country dimension *i* comprises 14 countries (AUT, BEL, DEU, DNK, ESP, FIN, FRA, GBR, GRC, ITA, NLD, NOR, SWE, USA); dimension of partner countries *j* ($j \neq i$) comprises the 223 countries contained in the CEPII dataset; for the estimation of the gravity equation (8) the dimension *j* reduces to the 44 partner countries ($j \neq i$) for which bilateral trade data by industry are available.

T_{ij}^{k}	export ratio; $T_{ij}^{k} = X_{ij}^{k} / PROD_{ik}$, where X_{ij}^{k} is bilateral exports from country *i* to country *j* in sector *k* and $PROD_{ik}$ is the production of country *i* in sector *k*. Source: OECD Structural Analysis (STAN) Database.
y_{ik}	labour productivity; $y_{ik} = VA_{i}^{k} / EMPL_{i}^{k}$, where VA_{i}^{k} is real valued added of country *i* in sector *k* in 1995$ (base year 1995, converted into $ with average PPPs exchange rate over the period 1995-2000) and $EMPL_{i}^{k}$ is total employment in industry *i* of country *k*. Source: OECD Structural Analysis (STAN) Database.
d_{ij}	simple distance between country *i* and country *j* (simple distance 'dist'). Source: CEPII (Clair et al., 2004).
N_{i}	population of country *i* in 1000 persons. Source: United Nations: Demographic Yearbook.
A_{i}	area of country *i* in square kilometres. Source: CEPII (Clair et al., 2004).
LL_{i}	dummy variable taking a value of one if country *i* is landlocked and zero otherwise. Source: CEPII (Clair et al., 2004).
CB_{ij}	dummy variable taking a value of one if countries *i* and *j* share a border. Source: CEPII (Clair et al., 2004).

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Table 1. Geography and Bilateral Trade: Estimation Results for Model (8) by Industry

Dependent variable: $\ln T_{ij}^{k}$

industry	15-16	17-19	20	21-22	23	24	25	26
constant	4.563***	6.650***	4.771***	1.272	1.865	2.112***	5.066***	-1.578
	(0.849)	(0.914)	(1.138)	(0.948)	(1.416)	(0.750)	(0.808)	(0.861)
ln distance	-0.835***	-1.186***	-1.100***	-0.903***	-1.327***	-0.762***	-1.016***	-0.793***
	(0.059)	(0.063)	(0.079)	(0.066)	(0.101)	(0.053)	(0.056)	(0.060)
ln population	0.064	0.070	-0.154	-0.255***	0.267**	0.013	-0.017	0.214***
(country *i*)	(0.062)	(0.066)	(0.082)	(0.069)	(0.118)	(0.062)	(0.059)	(0.062)
ln area	-0.376***	-0.253***	-0.070	0.087	-0.072	-0.223***	-0.231***	-0.068
(country *i*)	(0.063)	(0.068)	(0.085)	(0.071)	(0.113)	(0.060)	(0.060)	(0.064)
ln population	0.425***	0.466***	0.493***	0.518***	0.533***	0.624***	0.426***	0.536***
(country *j*)	(0.045)	(0.048)	(0.060)	(0.050)	(0.077)	(0.041)	(0.043)	(0.045)
ln area	-0.039	-0.063	-0.131***	-0.011	-0.122**	-0.061	0.012	-0.078**
(country *j*)	(0.035)	(0.037)	(0.047)	(0.039)	(0.060)	(0.031)	(0.033)	(0.035)
landlocked	-0.822***	-0.619***	-0.441***	-0.298**	-1.635***	-0.456***	-0.477***	-0.591***
	(0.120)	(0.129)	(0.160)	(0.134)	(0.203)	(0.108)	(0.114)	(0.121)
common border	1.472***	1.002***	1.679***	1.426***	1.836***	1.184***	1.335***	1.526***
	(0.249)	(0.268)	(0.333)	(0.278)	(0.422)	(0.224)	(0.237)	(0.252)
SE of regression	1.367	1.472	1.829	1.527	2.247	1.194	1.302	1.386
R^2	0.478	0.511	0.404	0.435	0.416	0.550	0.535	0.457
observations	616	616	611	616	567	572	616	615

Table 1 (continued). Geography and Bilateral Trade: Estimation Results for Model (8) by Industry

Dependent variable: $\ln T_{ij}^{k}$

industry	27	28	29	30-33	34	35	36-37
constant	2.311**	1.979**	0.484	2.630***	5.180***	-2.430	1.560
	(0.939)	(0.766)	(0.685)	(0.786)	(0.972)	(1.251)	(1.000)
ln distance	-1.000***	-0.847***	-0.579***	-0.683***	-1.028***	-0.425***	-0.864***
	(0.065)	(0.053)	(0.047)	(0.054)	(0.067)	(0.087)	(0.069)
ln population (country *i*)	-0.051	-0.139**	0.013	-0.122**	-0.160**	0.183**	0.145**
	(0.068)	(0.056)	(0.050)	(0.057)	(0.071)	(0.091)	(0.073)
ln area (country *i*)	-0.115	-0.070	-0.190***	-0.113	-0.149**	-0.163	-0.150**
	(0.070)	(0.057)	(0.051)	(0.059)	(0.073)	(0.093)	(0.075)
ln population (country *j*)	0.728***	0.522***	0.604***	0.662***	0.499***	0.585***	0.472***
	(0.049)	(0.040)	(0.036)	(0.041)	(0.051)	(0.066)	(0.053)
ln area (country *j*)	-0.095**	-0.031	-0.039	-0.154***	0.016	-0.124**	-0.082**
	(0.038)	(0.031)	(0.028)	(0.032)	(0.040)	(0.051)	(0.041)
landlocked	-0.794***	-0.581***	-0.449***	-0.497***	-0.783***	-0.066	-0.340**
	(0.132)	(0.108)	(0.097)	(0.111)	(0.137)	(0.177)	(0.141)
common border	1.400***	1.556***	1.273***	1.076***	1.205***	1.721***	1.522***
	(0.275)	(0.225)	(0.201)	(0.230)	(0.285)	(0.366)	(0.293)
SE of regression	1.513	1.234	1.103	1.266	1.566	2.012	1.610
R^2	0.519	0.536	0.547	0.480	0.464	0.228	0.381
observations	616	616	616	616	616	613	616

Notes: Standard errors are in parenthesis. *** significant at 1 percent, ** 5 percent, * 10 percent.

Table 2. Quality of Instrument: The Relevance of Geography for Aggregate Trade

dependent variable: exports (T_i)

	(1)	(2)	(3)
constant[1)]	8.024	198.072	74.795
constructed trade share	0.988^{***}		0.871^{***}
	(0.071)		(0.095)
ln population		-1.130	-5.723^{***}
		(1.747)	(1.544)
ln area		-11.471^{***}	-0.443
		(0.655)	(0.569)
SE of regression	20.311	22.792	19.046
R^2	0.664	0.579	0.708
observations[2)]	208	208	208

Notes: [1)] average of industry-specific constants. [2)] data for Norway (23,24) are missing. *** significant at 1 percent, ** 5 percent, * 10 percent.

Table 3. Trade and Productivity: Estimation Results for Model (7)

dependent variable: productivity (y_{ik})

	full sample		reduced sample (excl. 23, 34)	
	LS	IV	LS	IV
constant[1)]	9.043	9.079	8.872	8.855
export ratio	0.543^{***}	0.524^{***}	0.679^{***}	0.688^{***}
	(0.086)	(0.172)	(0.078)	(0.144)
ln population	0.067^{***}	0.067^{**}	0.050^{***}	0.050^{***}
	(0.021)	(0.021)	(0.019)	(0.019)
ln area	0.072^{***}	0.070^{**}	0.088^{***}	0.089^{***}
	(0.021)	(0.027)	(0.019)	(0.025)
SE of regression	0.265	0.265	0.224	0.224
R^2	0.735	0.735	0.704	0.711
observations	196	196	172	172
First stage F-Test		83.532		80.840

Notes: 1) average of industry-specific constants. *** significant at 1 percent, ** 5 percent, * 10 percent. R^2 in IV regressions calculated as squared correlation between dependent variable and predicted values.

Table 4. Trade and Productivity: Robustness

dependent variable: exports

	baseline		outliers		country dummies		alternative gravity models omitting[2]			
	LS	IV	LS	IV	LS	IV	CB_{ij}	LL_i+LL_j	N_i, N_j	A_i, A_j
constant[1]	8.872	8.855	9.122	8.996	10.271	10.314	8.855	8.524	9.251	8.727
export ratio	0.679***	0.688***	0.655***	0.720***	0.242***	0.392**	0.661***	0.859***	0.482***	0.754***
	(0.078)	(0.144)	(0.064)	(0.113)	(0.073)	(0.179)	(0.164)	(0.166)	(0.175)	(0.187)
Ln population	0.050***	0.050***	0.048***	0.048***	-0.140	-0.173	0.050***	0.049**	0.050***	0.049***
	(0.019)	(0.019)	(0.013)	(0.013)	(0.123)	(0.130)	(0.019)	(0.019)	(0.019)	(0.019)
Ln area	0.088***	0.089***	0.072***	0.080***	0.130***	0.144***	0.086***	0.110***	0.064**	0.097***
	(0.019)	(0.025)	(0.014)	(0.017)	(0.030)	(0.034)	(0.026)	(0.027)	(0.028)	(0.029)
SE of regression	172	172	161	161	172	172	172	172	172	172
R^2	0.704	0.711	0.819	0.818	0.865	0.861	0.704	0.694	0.693	0.703
observations	0.224	0.224	0.157	0.157	0.157	0.159	0.224	0.227	0.228	0.224
First stage F-Test		80.840		84.558		54.261	63.968	63.793	60.062	34.775

Notes: 1) average of industry-specific constants. *** significant at 1 percent, ** 5 percent, * 10 percent. [2] IV-estimates, when the respective variables are omitted from the gravity equation for the construction of the instruments. The corresponding LS regression is that given in the first column.

Table A1. Overview of Manufacturing Industries

ISIC Rev3	industry	share in value added[1)]	export ratio[2)]
15-16	Food products, beverages and tobacco	13.47	23.71
17-19	Textiles, textile products, leather and footwear	5.76	64.18
20	Wood and products of wood and cork	2.87	24.38
21-22	Pulp, paper, paper products, printing and publishing	11.15	24.46
23	Coke, refined petroleum products and nuclear fuel	2.11	29.36
24	Chemicals and chemical products	10.07	55.71
25	Rubber and plastics products	3.86	43.27
26	Other non-metallic mineral products	4.62	22.34
27	Basic metals	4.53	52.43
28	Fabricated metal products, except machinery and equipment	7.87	21.50
29	Machinery and equipment, n.e.c.	9.51	60.03
30-33	Electrical and optical equipment	11.28	75.53
34	Motor vehicles, trailers and semi-trailers	5.54	76.14
35	Other transport equipment	3.17	58.87
36-37	Manufacturing nec	4.34	38.71

Notes: 1) Share in total manufacturing value added in percent. 2) Ratio of exports to production in percent. All values are averages of the period 1995-2000 and the 14 countries.

Table A2. Trade and productivity: Heterogeneity tests

dependent variable: exports		
	full sample	reduced sample (excl. 23, 34)
constant[1)]	8.975	8.197
export ratio	1.047^{**} (0.523)	1.319^{***} (0.444)
ln population	0.057^{**} (0.023)	0.064^{***} (0.019)
ln area	0.084^{***} (0.032)	0.120^{***} (0.029)
Interaction of export ratio *with*		
17-19	-0.246 (0.534)	-0.386 (0.449)
20	0.389 (0.780)	0.474 (0.659)
21-22	0.312 (0.762)	0.414 (0.638)
23	-2.136^{**} (1.037)	
24	-0.431 (0.550)	-0.521 (0.462)
25	-0.056 (0.576)	-0.126 (0.483)
26	1.139 (1.689)	1.319 (1.431)
27	-0.669 (0.641)	-0.726 (0.539)
28	-0.125 (1.780)	0.558 (1.513)
29	-0.397 (0.579)	-0.532 (0.487)
30-33	-0.798 (0.527)	-0.983^{**} (0.445)
34	-1.586^{**} (0.624)	
35	-0.243 (0.836)	-0.394 (0.704)
36-37	-0.379 (0.580)	-0.496 (0.487)
SE of regression	0.254	0.212
R^2	0.777	0.754
Observations	196	172
Wald-test for parameter homogeneity	22.238^{*}	17.055

Notes: [1)] average of industry-specific constants. *** significant at 1 percent, ** 5 percent, * 10 percent.

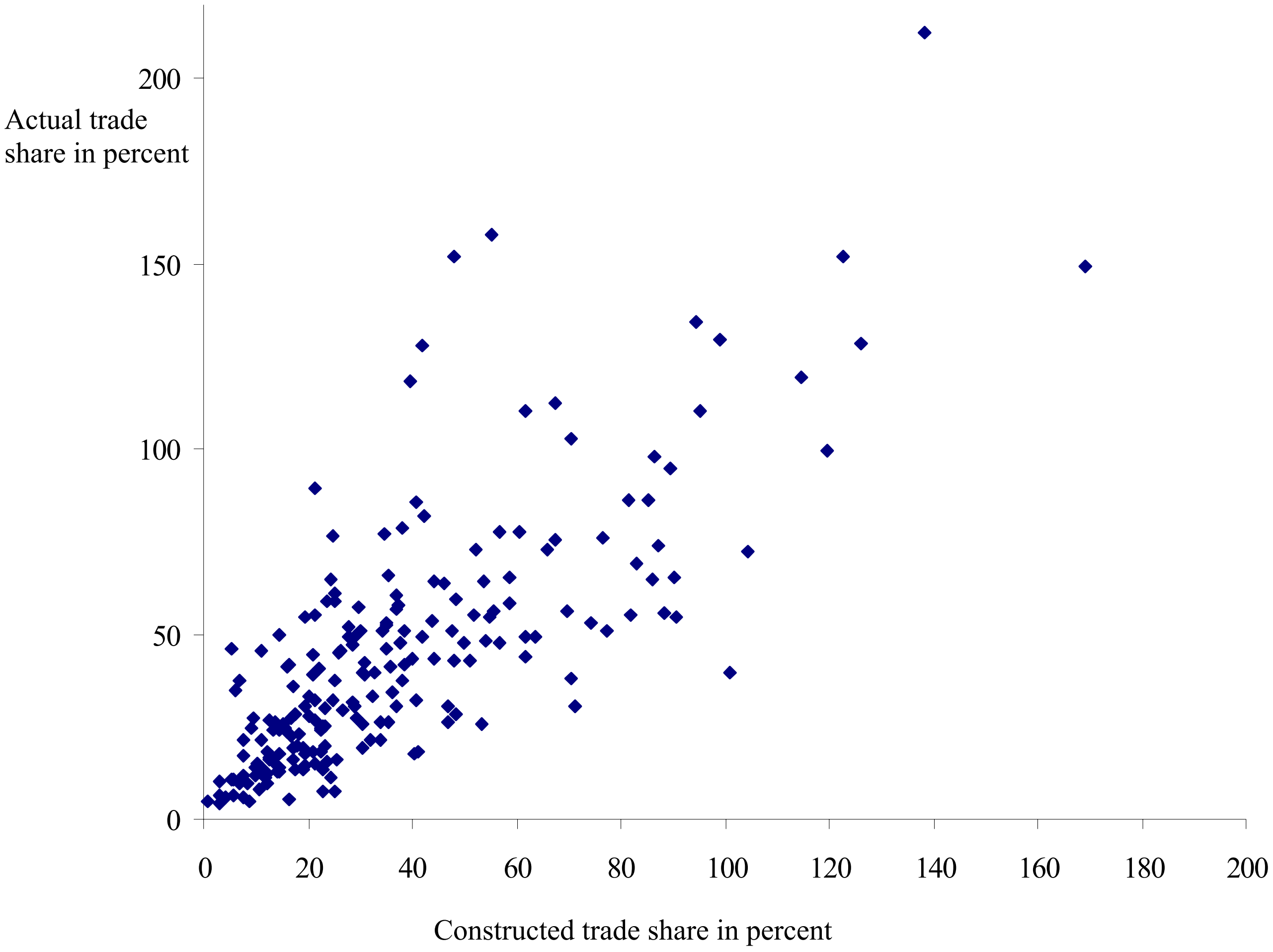
Table A3. Heterogeneity Tests in Frankel and Romer (1999) sample

dependent variable: productivity (y_i)

	Baseline: Frankel and Romer (1999)		Heterogeneity Test Full Sample (150)		Heterogeneity Test Reduced Sample (98)	
	LS	IV	LS	IV	LS	IV
constant	8.141^{***}	6.883^{***}	8.053^{***}	6.966^{***}	7.986^{***}	6.653^{***}
	(0.332)	(0.912)	(0.306)	(0.971)	(0.430)	(1.502)
trade	0.853^{***}	1.966^{**}	0.762^{***}	1.745^{**}	0.693^{**}	1.187
	(0.332)	(0.912)	(0.229)	(0.865)	(0.284)	(1.238)
Ln population	0.121^{*}	0.192^{**}	0.034	0.104	0.073	0.152
	(0.064)	(0.088)	(0.061)	(0.087)	(0.090)	(0.129)
Ln area	-0.132	0.086	0.009	0.091	0.004	0.119
	(0.055)	(0.098)	(0.051)	(0.088)	(0.068)	(0.144)
D_{OECD}			1.856^{***}	2.134^{***}	1.821^{***}	2.050^{***}
			(0.596)	(0.701)	(0.617)	(0.741)
D_{OECD} × trade			-0.600	-1.116	-0.468	-0.989
			(0.776)	(0.977)	(0.801)	(1.054)
SE of regression	0.996	1.065	0.913	0.970	0.919	0.996
R^2	0.094	0.089	0.250	0.213	0.323	0.319
observations	150	150	150	150	98	98

Notes: Estimates based on the data of Frankel and Romer (1999), provided in the Appendix. *** significant at 1 percent, ** 5 percent, * 10 percent. The standard errors of the IV estimates have not been corrected to account for the variance of the gravity estimates; hence, the heterogeneity tests (slightly) tend to overreject.

Figure 1. Actual versus Constructed Trade Share



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