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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 (Am Econ Rev 89(3):279–399, 1999). We find that trade, measured in terms of the export ratio, increases productivity, even if country-fixed effects such as the quality of institutions are controlled for, though results are less robust for imports. Estimates at the aggregate manufacturing level turn out much larger, emphasizing the role of inter-industry spillovers.

Keywords Trade · Productivity · Manufacturing

JEL Classification F14 · F43 · L60

1 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 influences productivity: the exploitation of increasing returns from larger markets (e.g. Balassa 1961), externalities and spillovers of the export sector (Feder 1983), the transmission of international technology spillovers (e.g. Coe and Helpman

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1995), as well as the pro-competitive effect of international trade (e.g. Bhagwati 1965).

A recent strand of the literature considers the effects of trade on the distribution of firms in an industry (see Baldwin (2005) for an overview). Melitz (2003) shows that when an economy opens up, the more productive firms self-select in the export market. Competition for scarce labour bids up real wages which drives the least productive firms out of the market. As a result, average productivity increases. Similar selection effects materialize through an increase in imports (import competition) as considered in the theoretical model by Melitz and Ottaviano (2005).

Numerous empirical studies have confirmed a positive correlation between trade and income. Lewer and Van den Berg (2003), in a comprehensive literature survey, find a surprisingly robust result in many cross-section and time series studies: “A one percentage point increase in the growth of exports is associated with a one-fifth percentage point increase in economic growth.” (Lewer and Van den Berg 2003, p. 363). However, endogeneity concerns and the absence of convincing instruments have cast doubts on whether these observed correlation actually reflects a causal relationship.

In recent years substantial progress has been made in overcoming these endogeneity concerns: 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 cross-section of 150 developed and less developed countries for 1985, they find that the least squares results are not invalidated by the instrumental variable estimates. 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.

There are at least two open issues: Rodriguez and Rodrik (2001) and Rodrik et al. (2004) question the validity of the instrument (particularly in cross sections with strongly heterogeneous countries). They also argue that trade becomes insignificant once institutional quality is controlled for; hence, the positive effect of trade in previous studies may simply capture omitted institutional characteristics. Similarly, in Irwin and Terviö (2002) the effect of trade on productivity is not robust against including distance from the equator, a proxy for Western influence according to Hall and Jones (2000). On the other hand, the results in Frankel and Romer (1999) are robust against including this variable (see Baldwin (2003) for a review of the debate).

Parts of these concerns on the relationship between trade and income have been addressed in a recent paper by Alcalá 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. They find (real) trade to be a significant determinant of productivity even when institutions are controlled for.

A further open question refers to the channels via which trade affects productivity. While much care has been devoted to the econometric issues in estimating the productivity effects of trade from reduced form equations, the relevance of the particular mechanisms is still unclear: What are the channels via which trade affects income? Are they mainly of intra- or of inter-industry type? While economic theory has much to say on this, empirically the link between trade and productivity is still subject to debate.

We reinvestigate the relation between trade and productivity, applying the empirical approach suggested by Frankel and Romer (1999). However, we focus on a sample of "institutionally homogenous" industrialized OECD countries and use both data at the industry and the aggregate manufacturing level. This allows us to make two new contributions: first, in the models using industry data we can control for country-specific effects such as institutional quality without requiring an explicit measurement (and instrumentation) of institutions. Second, our industry-specific specification narrow the hypothesis, ruling out effects that materialize across industries; by comparing the industry-specific estimates with more aggregate ones, we can provide a tentative assessment of the relevance of such inter-industry spillovers.

The estimates suggest that trade has a statistically significant effect on productivity in manufacturing. For most models, our instrument—the geographical component of industry trade—is of high quality, yielding comparably precise and highly significant estimates. Results are particularly robust for the export ratio. We also find that inter-industry spillovers between manufacturing industries are quantitatively important, more important than within industry effects.

The remainder of the paper is organized as follows. Section 2 sets up the empirical model. Section 3 constructs the instrument for trade. Section 4 presents the estimates of the relation between trade and productivity. Section 5 summarizes the results and concludes.

2 Trade and productivity: the basic empirical model

Our empirical model to estimate the relationship between trade and productivity is in line with Frankel and Romer (1999). The basic idea is that the effects of openness on productivity can be estimated from a simple model that relates GDP (Y) per worker (L) to country size and trade:

$$\ln(Y/L)_i = \alpha + \beta_1 \, Trade_i + \beta_2 \, Size_i + \varepsilon_i. \quad (1)$$

The parsimonious specification of Eq. 1 and the choice of value added per worker as dependent variable[1] ensure that β_1 captures all channels via which trade effects productivity, including indirect effects such as an induced increase in competition or investment. A drawback is that *Trade* is likely to be correlated with the error term in Eq. 1. Countries that trade more may be more productive for reasons other than trade. As a result, the least squares estimate of the effect of trade on productivity is

[1] An alternative, theoretically maybe more appealing, measure would be total factor productivity. But the use of the variable would have several drawbacks: it would require capital stock data (available only for a much smaller subset of our comprehensive sample) or have to rely on approximations of capital stocks, which is likely to introduce measurement errors. Second, even if capital stock measures were available, the calculation of total factor productivity is problematic: imposing income shares would assume perfect competition, which is certainly violated in a number of industries. On the other hand, estimating the income shares would be aggravated by well known endogeneity problems in estimating production functions.

expected to be (upward) biased due to reverse causality and omitted variables. It has been argued that this upward bias might be attenuated or even dominated by a downward bias due to measurement error, since *Trade* is only a poor proxy for international interactions.

To overcome the endogeneity problem of Eq. 1, Frankel and Romer suggest using an aggregate measure of proximity (Z^{Trade}) as instrument for *Trade*, that is the geographical trade share, which is derived from a bilateral gravity model[2] including geographical variables (distance, country size, dummies for common border or landlockedness) only. The identifying assumption is that there is no direct effect of geography on income other than through trade, once country size is controlled for.[3]

The approach pursued in this paper differs from previous studies in two important respects: First, in contrast to Frankel and Romer (1999) who use a large sample of 150 countries we focus on a sample 14 OECD member states (AUT, BEL, DEU, DNK, ESP, FIN, FRA, GBR, GRC, ITA, NLD, NOR, SWE, USA). The choice of a sample of "homogenous" countries with similar institutions makes it unlikely that our trade variable captures unobserved institutional heterogeneity.

Second, in contrast to previous studies we investigate model (1) at the industry level, using data from 15 manufacturing industries (See Table 6 in the Appendix for an overview). The most important advantage is that this allows us to control for country-specific effects in a cross section setting, while maintaining the time-invariant geography based instrument. Since measurement of institutional quality is surrounded by considerable uncertainty, this is probably the best way to ensure that the estimated effect of trade does not capture (country-specific) institutional characteristics. Our starting point is the following basic empirical model:

$$\ln y_{ik} = \alpha_k + \beta_1 \, Trade_{ik} + \beta_2 \, \ln L_{ik} + \varepsilon_{ik}, \tag{2a}$$

where y_{ik} denotes productivity (in terms of value added per worker), and L_{ik} is employment; i is the country and k the industry index; α_k is an industry-specific intercept, capturing cross-industry variation in labour productivity unrelated to market size and trade, e.g. as a result of differences in capital-labour ratios. Our cross-section data refer to averages over the period 1995–2000.

For *Trade* we will use three alternative measures: the ratio of exports to production (x), the ratio of imports to production (m), and the ratio of exports plus imports to production (mx). At the aggregate level these variables are typically highly correlated and yield the same results; at the industry level, the correlation is less pronounced, so that it is worth considering the alternative results for all three measures.[4]

[2] See, for example, Baier and Bergstrand (2001) for a theoretical derivation of a typical gravity equation.

[3] Rodriguez and Rodrik (2001) have challenged this assumption, arguing that geography may be related to income via (i) its effect on public health, and (ii) the quantity and quality of institutions. This may in fact be a problem in large cross sections including developed and less developed countries, but is less relevant for our sample of fourteen industrialized OECD countries. In addition, we will control for these channels by including country-specific fixed effects.

[4] Since no industry-specific deflators are available we have to use nominal openness rather than 'real' openness as advocated by Alcalá and Ciccone (2004). For our sample, which includes mainly industrial countries with a similar level of development, this is no major drawback, since the trade related Balassa–Samuelson effect is usually much less relevant here.

A natural choice for the size measure at the industry level is employment in the respective industry (L_{ik}). Intuitively, this choice emphasizes the role of economies of scale. What Frankel and Romer (1999) have in mind when including country size, however, is that country size acts as a proxy variable for unobservable within-country trade. Since industries also deliver intermediates to other industries, it is not the size of the own sector but that of the whole economy which is the relevant determinant of within-country trade. Following this logic we go on to include country size (in terms of population and area) in model (2a) as well, yielding

$$\ln\ y_{ik} = \alpha_k + \beta_1\ Trade_{ik} + \beta_2\ \ln\ L_{ik} + \beta_3\ \ln\ Pop_i + \beta_4\ \ln\ Area_i + \varepsilon_{ik}. \qquad (2b)$$

In our final, and most general model, we include country-specific effects μ_i in Eq. 2a:

$$\ln\ y_{ik} = \alpha_k + \beta_1\ Trade_{ik} + \beta_2\ \ln\ L_{ik} + \mu_i + \varepsilon_{ik} \qquad (2c)$$

Of course, population and area, as well as all other country-specific measures such as institutional quality are now captured by μ_i. It will be interesting to observe the change in the parameter estimates (particularly β_1) across the specifications, which gives an idea by how much trade variables capture effects other than that of trade.

It should be borne in mind that models (2) relate industry-specific productivity (in terms of value added per worker) to industry-specific openness. This captures primarily intra-industry effects of trade on productivity, such as firm selection effects considered in the theoretical models by Melitz (2003) and Melitz and Ottaviano (2005). While 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), there are still channels that may operate *across* industries: Spezialization according to comparative advantage would be reflected in an increase in inter-industry rather than intra-industry trade; and as already emphasized by Balassa (1961, p. 131), external economies of scale may also be of inter-industry type. By ruling out these inter-industry and general equilibrium effects, the hypothesis expressed by our industry specific model (2) is clearly narrower than the corresponding model at the aggregate level (1), and one would expect the effect of trade on productivity at the industry level to be smaller. This is another advantage of using industry data: Estimating the model at different levels of aggregation and comparing the results sheds some light on the question, how and via which channels trade affects productivity.

3 Construction of the instruments

3.1 The geographical gravity model

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 as 'geographical component' of aggregate trade, which is calculated from the predicted values of a geographical gravity model, whose regressor matrix ($\mathbf{X}$) includes geographical variables only:

$$\begin{aligned} \ln\ Trade^{j}_{ik} &= \boldsymbol{\alpha}'_k\ \mathbf{X}_{ij} + \vartheta^{k}_{ij} \\ &= \alpha_{0k} + \alpha_{1k}\ \ln\ Dist_{ij} + \alpha_{2k}\ \ln\ Pop_i + \alpha_{3k}\ \ln\ Area_i \\ &+ \alpha_{4k}\ \ln\ Pop_j + \alpha_{5k}\ \ln\ Area_j + \alpha_{6k}\left(LL_i + LL_j\right) + \alpha_{7k}\ CB_{ij} + \vartheta^{k}_{ij} \end{aligned} \quad (3)$$

Our approach differs from Frankel and Romer only by using industry-specific bilateral trade flows instead of total trade; as a result we obtain an industry-specific instrument Z^{Trade}_{ik} as well. In Eq. 3, $Trade^{j}_{ik}$ is the ratio of trade (exports, imports or exports plus imports) between country i and country j to country i's production in industry k, $Dist$ is distance, Pop is population, LL is a dummy for landlocked countries, and CB is a common-border dummy.

To obtain our instrument Z^{Trade}_{ik}, that is the geographical component of (aggregate) trade by industry, the predicted values for the bilateral trade shares are aggregated as follows:

$$Z^{Trade}_{ik} = \sum_{j=1}^{J} \theta_k e^{\mathbf{a}'_k \mathbf{X}_{ij}}, \quad (4)$$

where $\mathbf{a}_k$ is the estimate of $\boldsymbol{\alpha}_k$ from (3); θ_k is a correction factor required to obtain consistent predicted values for the levels of $Trade^{j}_{ik}$ from the estimates in log form.[5] Using (4) we calculate industry-specific trade shares for each of the 14 countries; the summation in (4) runs not only over the (44) countries for which we have bilateral trade data, but over all countries for which data on the variables in $\mathbf{X}$ are available (additional 179 countries).[6]

3.2 Estimation results

Our sample comprises 14 countries (i) and 15 manufacturing industries (k). Equation 3 is estimated separately for each of the 15 industries and aggregate manufacturing. We have bilateral trade data by industry with 44 partner countries (j, $j \neq i$) covering some 90% of trade on average. Trade and production data are averages over the period 1995–2000 and are taken from the STAN database of the OECD. A detailed description of the data is given in the Appendix.

Table 1 shows the estimates of gravity Eq. 3 for 15 manufacturing industries and aggregate manufacturing. Results are given for the export ratio (x), but the estimates using the ratio of imports to production (m) and the ratio of imports and exports to

[5] Under normality θ_k is equal to $E[e^{\vartheta^k_{ij}}] = e^{(\hat{\sigma}^2_k/2)}$,where $\hat{\sigma}^2_k$ is a consistent estimator of the variance of ϑ^k_{ij}. To avoid making distributional assumptions we follow the approach suggested by Wooldridge (2003, p. 207ff.) and estimate θ_k from a regression of $Trade^{j}_{ik}$ on $e^{\mathbf{a}'_k \mathbf{X}_{ij}}$ through the origin. Since industry dummies are included in all our regressions, however, the correction does not affect the coefficients of the variables of our interest (*Trade*, *Pop*, *Area*) in the main model.

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

Table 1 Geography and bilateral trade: estimation results for Model (3) by industry

Industry	15–16	17–19	20	21–22	23	24	25	26	27
Dependent variable: $\ln x_{ik}^{j}$									
Constant	4.563***	6.650***	4.771***	1.272	1.865	2.112***	5.066***	−1.578	2.311**
	(5.376)	(7.278)	(4.194)	(1.342)	(1.317)	(2.815)	(6.271)	(−1.833)	(2.461)
ln *Dist*	−0.835***	−1.186***	−1.100***	−0.903***	−1.327***	−0.762***	−1.016***	−0.793***	−1.000***
	(−14.221)	(−18.771)	(−13.958)	(−13.779)	(−13.185)	(−14.351)	(−18.181)	(−13.318)	(−15.386)
ln Pop_i	0.064	0.070	−0.154	−0.255***	0.267**	0.013	−0.017	0.214***	−0.051
	(1.041)	(1.059)	(−1.865)	(−3.713)	(2.261)	(0.213)	(−0.282)	(3.432)	(−0.752)
ln $Area_i$	−0.376***	−0.253***	−0.070	0.087	−0.072	−0.223***	−0.231***	−0.068	−0.115
	(−5.923)	(−3.707)	(−0.819)	(1.229)	(−0.633)	(−3.721)	(−3.831)	(−1.053)	(−1.636)
ln Pop_j	0.425***	0.466***	0.493***	0.518***	0.533***	0.624***	0.426***	0.536***	0.728***
	(9.511)	(9.682)	(8.192)	(10.384)	(6.962)	(15.404)	(10.008)	(11.800)	(14.716)
ln $Area_j$	−0.039	−0.063	−0.131***	−0.011	−0.122**	−0.061	0.012	−0.078**	−0.095**
	(−1.133)	(−1.685)	(−2.804)	(−0.279)	(−2.043)	(−1.939)	(0.366)	(−2.216)	(−2.476)
LL	−0.822***	−0.619***	−0.441***	−0.298**	−1.635***	−0.456***	−0.477***	−0.591***	−0.794***
	(−6.869)	(−4.803)	(−2.751)	(−2.231)	(−8.051)	(−4.240)	(−4.188)	(−4.870)	(−5.997)
CB	1.472***	1.002***	1.679***	1.426***	1.836***	1.184***	1.335***	1.526***	1.400***
	(5.914)	(3.741)	(5.041)	(5.132)	(4.346)	(5.281)	(5.637)	(6.050)	(5.082)
SE	1.367	1.472	1.829	1.527	2.247	1.194	1.302	1.386	1.513
R^2	0.478	0.511	0.404	0.435	0.416	0.550	0.535	0.457	0.519
Obs	616	616	611	616	567	572	616	615	616

Table 1 Continued

Industry	28	29	30–33	34	35	36–37	Manufacturing
Constant	1.979**	0.484	2.630***	5.180***	−2.430*	1.560	2.122***
	(2.583)	(0.707)	(3.348)	(5.329)	(−1.943)	(1.560)	(3.005)
ln *Dist*	−0.847***	−0.579***	−0.683***	−1.028***	−0.425***	−0.864***	−0.734***
	(−15.980)	(−12.211)	(−12.578)	(−15.285)	(−4.916)	(−12.495)	(−15.023)
ln Pop_i	−0.139**	0.013	−0.122**	−0.160**	0.183**	0.145**	−0.110**
	(−2.497)	(0.270)	(−2.139)	(−2.276)	(2.016)	(2.000)	(−2.150)
ln $Area_i$	−0.070	−0.190***	−0.113	−0.149**	−0.163	−0.150**	−0.088*
	(−1.219)	(−3.700)	(−1.925)	(−2.046)	(−1.748)	(−2.011)	(−1.674)
ln Pop_j	0.522***	0.604***	0.662***	0.499***	0.585***	0.472***	0.588***
	(12.933)	(16.726)	(16.001)	(9.750)	(8.875)	(8.956)	(24.908)
ln $Area_j$	−0.031	−0.039	−0.154***	0.016	−0.124**	−0.082**	−0.094***
	(−0.988)	(−1.402)	(−4.806)	(0.403)	(−2.433)	(−2.005)	(−3.267)
LL	−0.581***	−0.449***	−0.497***	−0.783***	−0.066	−0.340**	−0.550***
	(−5.376)	(−4.647)	(−4.484)	(−5.708)	(−0.372)	(−2.408)	(−5.523)
CB	1.556***	1.273***	1.076***	1.205***	1.721***	1.522***	1.250***
	(6.928)	(6.339)	(4.673)	(4.228)	(4.696)	(5.194)	(6.037)
SE	1.234	1.103	1.266	1.566	2.012	1.610	1.137
R^2	0.536	0.547	0.480	0.464	0.228	0.381	0.537
Obs	616	616	616	616	613	616	616

Notes: *t*-values in parenthesis. ***, **, * indicate significance at the 1, 5, and 10% level, respectively; *x*… export ratio production (*mx*) as dependent variable turned out qualitatively similar and are omitted here for brevity.

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% on average) and that a countries sharing a border trade more (some 140%). Finally, and most importantly, our regressions confirm that geographical variables are an important determinant of international trade. The average R^2 of our regressions is 0.471, ranging from 0.228 to 0.550.

3.3 Implications for aggregate trade and the quality of the instrument

Our instrument Z_{ik}^{Trade} must fulfil two properties. First, it must be uncorrelated with the error term in (2). This assumption has to be made on theoretical grounds—geography has no direct effect on productivity, once country size is controlled for—since our models are exactly identified so that we cannot test for overidentifying restrictions. Second, the instrument must also be relevant, since two stages least squares with weak instruments may yield strongly biased estimates and tests with large size distortions (Staiger and Stock 1997; Stock et al. 2002). Hence, it will be important to check the quality of the instrument.

The correlation between *Trade* and Z^{Trade} amounts to 0.753 for the export ratio (0.579 for *m* and 0.755 for *mx*). However, 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 the control variables (industry-specific effects, *L, Pop, Area* and country-specific effects). To put it differently: What is relevant is the strength of the partial correlation between the actual and the constructed trade share.

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.

Table 2 shows the results of the first stage regressions for the cross-section models (2a), (2b), and (2c). The *F*-test of the excluding restriction for the constructed trade shares generally exceed the critical values by Stock and Yogo (2004) that instrument quality is below the highest quality level.[7] Nevertheless, the predictive power is much stronger for exports and exports plus imports than for the

[7] For exactly identified models, Stock and Yogo provide only critical values for the size criterion (16.38, 8.96, 6.66, and 5.53 for the four quality levels).

Table 2 Quality of instrument: the relevance of geography for (aggregate) industry trade, first stage regressions for models (2a), (2b), and (2c)

	Exports			Imports			Exports plus imports		
	(a)	(b)	(c)	(a)	(b)	(c)	(a)	(b)	(c)
Dependent variable: $Trade_{ik}$									
$D^{Industry}$	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
$D^{Country}$	No	No	Yes	No	No	Yes	No	No	Yes
Z_{ik}^{Trade}	0.924***	0.900***	0.877***	0.854***	0.771***	0.891***	0.930***	0.938***	1.081***
	(11.829)	(8.502)	(6.713)	(4.627)	(4.444)	(4.409)	(10.082)	(9.119)	(8.067)
$\ln L_{ik}$	−0.059***	−0.022	−0.051*	−0.183***	−0.647***	−0.619***	−0.202***	−0.620***	−0.620***
	(−5.681)	(−0.730)	(−1.858)	(−7.879)	(−12.140)	(−11.546)	(−7.911)	(−10.074)	(−9.900)
$\ln Pop_i$	–	−0.039	–	–	0.536***	–	–	0.473***	–
		(−1.089)			(8.925)			(6.779)	
$\ln Area_i$	–	−0.007	–	–	−0.007	–	–	0.016	–
		(−0.372)			(−0.262)			(0.474)	
F-Stat.[a]	139.92	72.29	45.06	21.41	19.75	19.44	101.65	83.15	65.08
F-Stat.[b]	84.23	54.19	23.34	17.60	12.14	14.38	50.77	35.18	25.11
SE	0.186	0.186	0.161	0.392	0.322	0.310	0.422	0.370	0.358
R^2	0.704	0.707	0.794	0.621	0.748	0.781	0.773	0.828	0.849
Obs[c]	193	193	193	193	193	193	193	193	193

Notes: *t*-values in parenthesis; ***, **, * indicate significance at the 1, 5, and 10% level, respectively. [a] *F*-Test on excluding instrument from first stage regression, based on conventional standard errors. [b] F-Test on excluding instrument from first stage regression, based on heteroscedasticity robust standard errors. [c] Of the total $14 \times 15 = 210$ observations, 13 observations were missing (NOR: 23, 24; BEL: 27, 28, 34, 35; GBR: 27, 28, 34, 35; USA: 29, 30–33; NLD: 34, 35); three further observations turned out as outliers (AUT: 23; ESP: 23; GRC: 34), i.e. standardized residuals were larger than three in de facto all models, such that 193 observations remain. This sample is used throughout in the estimation import ratio. This is also true when a heteroscedasticity-robust variant of the Stock and Yogo test is used.[8]

4 Trade and productivity: estimation results

4.1 Estimation for manufacturing industries

Having constructed the instrument and verified its quality we now turn to the estimation of trade's effect on productivity. We start with the most parsimonious specification, i.e. Eq. 2a and give the results for all three trade measures used. Results are given in Table 3. The IV estimates tell the same story for all three measures: Trade turns out to be a statistically and economically significant determinant of productivity.[9] The elasticities implied by the coefficients (when evaluated at the sample mean) are identical for the export ratio and the ratio of exports plus imports to production (0.15), slightly higher for imports (0.22).

It is interesting to consider the bias of the least squares estimates. Highly productive industries tend to export more due to comparative advantage; in contrast, high productivity in domestic industries may keep away imports. As a result one

Table 3 Trade and productivity: least squares and IV results for cross-section Model (2a)

	Exports		Imports		Imports plus exports	
	LS	IV	LS	IV	LS	IV
Dependent variable is ln y_{ik}						
$D^{Industry}$	Yes	Yes	Yes	Yes	Yes	Yes
$D^{Country}$	No	No	No	No	No	No
$Trade_{ik}$	0.409***	0.334***	−0.079*	0.385**	0.042	0.153**
	(4.056)	(3.306)	(−1.783)	(2.061)	(1.082)	(2.382)
ln L_{ik}	0.101***	0.094***	0.047***	0.151***	0.078***	0.113***
	(6.404)	(6.266)	(2.952)	(3.075)	(4.711)	(4.513)
SE	0.230	0.230	0.249	0.315	0.250	0.257
R^2	0.750	–	0.706	–	0.704	–
Obs	193	193	193	193	193	193

Notes: *t*-values in parenthesis based on robust standard errors; ***, **, * indicate significance at the 1, 5, and 10% level, respectively

[8] The results by Stock and Yogo (2004) are based on the assumption of homoscedasticity and have not yet been extended to more general cases. Hence, the critical values may only be regarded as indicative for the robust *F*-test.

[9] For inference, we use heteroscedasticity-robust standard errors, which is clearly important in our cross-country and cross-industry sample. But (in contrast to Frankel and Romer) we do not correct the standard errors to account for the fact that Z^{Trade} is generated from the gravity model, since the asymptotic distribution of the test-statistics is not affected by the use of a generated instrument (see Wooldridge 2002).

would expect the least squares estimates of the export ratio to be upward biased, that of the import ratio to be downward biased. As previous studies emphasized, this endogeneity resulting from omitted variables and simultaneity is likely to be meshed up with a bias due to measurement error, since trade is only a noisy measure for international transactions and openness; this would bias the least squares estimates towards zero. In fact, a comparison of the least squares and IV-estimates suggests that our results are in line with these theoretical presumptions.

We now turn to the estimation of model (2b), which controls for country size, and model (2c), which includes country dummies and thus controls for all country-specific effects including institutional quality. Table 4 shows the IV results for models (2b) and (2c) using the three alternative trade measures.

Turning to the results for model (2b) first, we find that the estimated effect of trade on productivity remains statistically significant and increases in magnitude to roughly twice the value of model (2a). Since country size tends to be positively related to productivity but negatively related to openness this results is not too surprising. The coefficients of the two size measures, however, are less easy to interpret. Area has a positive effect and is significant in two of the three models; population has the wrong (negative) sign, though it is only significant in two models at the five and 10% level respectively. The negative sign of population appears to be largely driven by its correlation with the industry-specific size measure (L_{ik}); if L_{ik} is omitted, the effect of population becomes positive and significant throughout, and the effect of trade on productivity becomes smaller (though it still remains higher than in model (2a)).

For our most general model (2c), which is also our preferred specification, we observe that the results are robust for the export ratio but not for the models using

Table 4 Trade and productivity: IV results for cross-section models (2b) and (2c)

	Exports		Imports		Imports plus exports	
	(2b)	(2c)	(2b)	(2c)	(2b)	(2c)
Dependent variable is ln y_{ik}						
$D^{Industry}$	Yes	Yes	Yes	Yes	Yes	Yes
$D^{Country}$	No	Yes	No	Yes	No	Yes
$Trade_{ik}$	0.709***	0.356**	0.611**	−0.089	0.278***	0.022
	(5.077)	(2.288)	(2.168)	(−0.720)	(3.109)	(0.395)
ln L_i	0.097**	0.052	0.481**	−0.036	0.265***	0.041
	(2.406)	(1.461)	(2.102)	(−0.377)	(2.822)	(0.734)
ln Pop_i	−0.029	–	−0.357*	–	−0.173**	–
	(−0.669)		(−1.793)		(−2.015)	
ln $Area_i$	0.088***	–	0.049	–	0.058**	–
	(4.251)		(1.640)		(2.594)	
SE	0.224	0.177	0.352	0.170	0.268	0.174
Obs	193	193	193	193	193	193

Notes: *t*-values in parenthesis based on robust standard errors; ***, **, * indicate significance at the 1, 5, and 10% level, respectively the two other trade measures, where the effect of trade on productivity becomes insignificant. Apart from sampling variability and (presumably) less reliable import data, the most likely explanation for this discrepancy is that instrument quality is much higher for exports than for imports, particularly in model (2c); as a result the IV estimates for imports cannot eliminate the strong bias of the parameter estimate which remains negative for imports. Using imports plus exports imposes the same coefficient for exports and imports, which implies an averaging towards zero, a tendency that is likely to be enforced for the least squares estimates by measurement errors.

Focussing on the results for exports we find that the results of model (2a) are largely confirmed. Controlling for country size alone (model (2b)) increases the estimated effect, since country size is positively related to productivity but negatively to openness; controlling for institutional quality using country dummies (model (2c)) reduces the effect again, since institutional quality is positively related to productivity and trade. After all, the elasticity of productivity with respect to trade turns out to be 0.156 for the export ratio, de facto the same as for model (2a). While our results confirm that omitting institutional quality is relevant for the results, we still find a genuine effect of trade on productivity once institutions are controlled for. This is a revindication of the Frankel and Romer results and a qualification to the relevance of the Rodriguez–Rodrik critique.

4.2 Estimation for aggregate manufacturing

As already mentioned above, the industry specific specification captures only effects of trade in industry *k* on productivity in industry *k*, but does not capture effects that materialize across industries (inter-industry spillovers) such as reallocations to more productive industries, spezialization according to comparative advantage, and external economies of scale of inter-industry type as described by Balassa (1961) and knowledge spillovers between different industries.

To assess the relevance of these inter-industry spillovers, we turn to an estimation of model (2) at the aggregate level. To ensure comparability of the results we use the same fourteen countries, the same time period (averages over the period 1995–2000), the same base year 1995 for prices and PPPs. Instead of sub-industries of manufacturing, however, we use aggregate manufacturing data which ensures that inter-industry effects are also captured by the regression. Accordingly, the instrument is now constructed from the geographical gravity equation estimated using bilateral trade in total manufacturing (see Table 1 for the results).[10] It should be added that the whole exercise should be regarded as tentative, given the small number of observations. While a comparison with the disaggregated estimates will be interesting the results should not be overstressed.

[10] For reasons of better and more consistent data we use trade in goods (manufacturing, agriculture, mining and quarrying) as explanatory variable in the aggregate models (5). Since manufacturing is by far the most important component of trade in goods this hardly matters for the results.

In our disaggregated specification there was already high correlation between country size and industry size (some 0.80). At the aggregate level this multicollinearity becomes even more pronounced (with a correlation of 0.98), so that we decided to drop one of the two variables. To ensure better comparability with previous studies we decided to drop industry size from the sample, but as can be imagined from the high correlation that this choice is not crucial. Consequently, the aggregate version of model (2b) is

$$\ln\ y_{iM} = \alpha + \beta_1\ Trade_{iM} + \beta_2 \ln\ Pop_i + \beta_3 \ln Area_i + \varepsilon_i, \tag{5b}$$

and model (2c) becomes

$$\ln\ y_{iM} = \alpha_i + \beta_1\ Trade_{iM} + \beta_2 \ln\ Pop_i + \beta_3\ \ln\ Area_i + \varepsilon_i. \tag{5c}$$

The index M indicates that the variables are measured at the aggregate manufacturing level. In contrast to model (5b) where the only problem is the small number of observations, model (5c) cannot be estimated since the number of parameters would exceed the number of observations. We can however, eliminate the country-specific effects (α_i) and estimate β_1 and β_2 using a first differenced variant of model (5c):

$$\Delta \ln\ y_{iM} = \beta_1\ \Delta Trade_{iM} + \beta_2\, \Delta \ln\ Pop_i + \Delta\varepsilon_i. \tag{5c$'$}$$

The time invariant variable *Area* is also eliminated by this transformation. Instead of averages over the period 1995–2000, now differences between the year 1995 and 2000 are used. A larger time span for the difference would be desirable, but this is ruled out by data availability. In addition, the choice of the same time period as for the industry specific model ensures the comparability of the results.

Of course, endogeneity of trade is an issue at the aggregate manufacturing level as well. Again this is addressed using the geographical trade share as instrument (Z_M^{Trade}), which is now calculated from the results of a (bilateral) geographical gravity model at the aggregate manufacturing level.

A note on model (5c′) is in order here. The geographical trade share, an aggregate measure of proximity, is a time invariant variable (at least over short periods such as ours); hence, we cannot use its difference as instrument. But there is nothing that prevents us from using Z_M^{Trade}in levels as instrument for the first differences of the trade variable ($\Delta Trade^M$). One the one hand the economic motivation of the instrument gets a bit lost by this transformation. One the other hand, it should be borne in mind that identification is a technical issue: instrument validity is not affected by this transformation and as long as the correlation between the instrument Z_M^{Trade} and the differenced endogenous variable ($\Delta Trade^M$) is sufficiently strong (in terms of weak instruments diagnostics) this approach will produce reliable results (at least equally reliable as the specification in levels).

Table 5 shows the estimates of (5b) and (5c′) at the aggregate manufacturing level, again for all three trade measures. Instrument quality is fine for model (5c′) as indicated by the F-tests at the bottom of the Table, which always exceed the critical values from Stock and Yogo (2004). Instrument quality is less favourable for model (5b), though we can still reject the hypothesis that instrument quality is below the

Table 5 Trade and productivity: IV results for cross-section models (5b) and (5c′), Aggregate Manufacturing

	Exports		Imports		Imports plus exports	
	(5b)	(5c′)[c]	(5b)	(5c′)[c]	(5b)	(5c′)[c]
Dependent variable is ln y_{iM}						
Constant	7.508***	–	5.477**	–	6.725***	–
	(10.279)		(2.778)		(8.331)	
$Trade_{iM}$	1.374***	1.142**	2.501**	1.298**	0.904***	0.623**
	(3.633)	(2.610)	(2.782)	(2.809)	(4.355)	(2.662)
ln Pop_i	0.043	1.700	0.086	0.723	0.058	1.167
	(1.188)	(1.252)	(0.696)	(0.516)	(0.919)	(0.825)
ln $Area_i$	0.183***	–	0.271	–	0.218**	–
	(3.888)		(1.810)		(2.976)	
F-Stat.[a]	4.997	22.177	4.242	20.362	9.233	29.142
F-Stat.[b]	9.603	43.450	7.664	58.205	8.948	58.797
SE	0.106	0.119	0.365	0.129	0.184	0.122
Obs	14	14	14	14	14	14

Notes: t-values in parenthesis based on robust standard errors; ***, **, * indicate significance at the 1, 5, and 10% level, respectively. [a] F-Test on excluding instrument from first stage regression, based on conventional standard errors. [b] F-Test on excluding instrument from first stage regression, based on heteroscedasticity robust standard errors. [c] Model (5c′): differences between 2000 and 1995 values of the variables

second lowest quality level. Hence, also from an econometric perspective, our preferred model is (5c′), which is more appealing from a theoretical perspective as well since it accounts for potential cross-country heterogeneity (e.g. in the quality of institutions).

Overall, trade again has a significant effect on productivity, now irrespective of the measure used. This buttresses the view that the discrepancy for exports and imports obtained in the disaggregated estimation is due to data reliability and instrument quality, rather then some fundamental economic difference in the effect of the three variables.

As at the industry level, controlling for institutions in addition to country size (5c′) the effect becomes smaller but remains statistically and economically significant. And as expected, the coefficient of trade is clearly larger in the aggregate model (5) than in the industry-specific specification (2). The elasticity of productivity with respect to openness is some 0.6 compared with a value of 0.16 in the disaggregated specification. This suggests that propagation mechanisms, general equilibrium effects and inter-industry spillovers, which are not captured in a disaggregated specification, are important. In our setting, they are actually more important than intra-industry effects: some three quarters of the total effect appear to be of inter-industry type, while intra-industry effects, such as firm selection through increased competition as modelled by Melitz and Ottaviano (2005), appear to be quantitatively less important. Clearly, the relation will also depend on the level of disaggregation chosen. But this result is roughly in line with a related study by

Badinger (2008), who considers a larger cross section of 40 countries with aggregate manufacturing data, and finds that induced competition accounts for approximately one fifth of the total productivity effects of trade.

Considering the average elasticity from the aggregate estimation for manufacturing around 0.6, it is smaller than that of previous studies for the total economy. Frankel and Romer (1999) obtain an average elasticity of 1.8; Alcalá and Ciccone (2004), who control for institutional quality and use the log of real openness, obtain elasticities between 0.91 and 1.49 (and, similarly, elasticities around one if nominal openness is used). There are two likely explanations for this result:

First, moving from the aggregate manufacturing level to the total economy will additionally capture spillover effects between manufacturing and the other sectors of the economy (particularly services). Our tentative estimates suggest that spillovers are important within manufacturing. If this holds true between manufacturing and services as well this might explain the comparably low effect obtained in our study.

Second, the discrepancy could be due to the sample choice. 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.[11]

5 Summary and conclusions

This paper adds to previous studies on the effects of trade on productivity, providing an analysis at both the aggregate level and the manufacturing industry-level for a sample of 14 OECD countries. To deal with endogeneity concerns, we follow the approach by Frankel and Romer (1999) and use the geographical component of (industry) trade as instrument.

The approach pursued here has two main advantages: The use of industry-data allows us to control for country-specific fixed effects such as the quality of institutions, avoiding the delicate issue of constructing a convincing measure (and finding convincing instruments) for institutional quality. Second, relating industry-specific productivity to industry-specific trade narrows the hypothesis of the aggregate specification chosen in previous studies by ruling out productivity effects of trade that materialize across industries. Comparing these results with that obtained using more aggregate data from the same sample allows us to judge the

[11] We also reproduced the Frankel and Romer (1999) estimates using their data and checked whether the coefficient of trade is significantly different for our subsample (by including a dummy for our 14 countries and an interaction of the trade share with that dummy). While the deviation is in fact negative, implying a substantially lower effect of trade on productivity for our sample, the difference is insignificant. In light of the fact that the estimates are rather imprecise, the results are somewhat inconclusive.

relevance of the particular channels via which trade affects productivity, a point hardly addressed in previous studies.

For our sample of OECD manufacturing industries we find that trade turns out to be a significant determinant of productivity, even if institutions are controlled for. The elasticity of productivity with respect to openness is 0.16 in the disaggregated specification, but much larger in the estimation for aggregate manufacturing (0.6). This suggests that propagation mechanisms and inter-industry spillovers, which are not captured in a disaggregated specification, are important. In our setting some three quarters of the total effect appear to be of inter-industry type.

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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 Eq. 8 the dimension j reduces to the 44 partner countries ($j \neq i$) for which bilateral trade data by industry are available. Industry dimension k comprises the 15 manufacturing industries shown in Table 6. In addition, some models are estimated for total manufacturing ($k = M$).

$Trade_{ik}^{j}$ trade share; $Trade_{ik}^{j} = T_{ik}^{j}/PROD_{ik}$,where T_{ik}^{j} is bilateral trade between country i and country j in sector k and $PROD_{ik}$ is the production of country i in sector k. As measures for trade (T), imports (M), exports (X), as well as imports plus exports (MX) are used. Source: OECD Structural Analysis (STAN) Database.

y_{ik} labour productivity; $y_{ik} = VA_{i}^{k}/L_{ik}$,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 L_{ik} is total employment in industry k of country i. Source: OECD Structural Analysis (STAN) Database.

$Dist_{ij}$ simple distance between country i and country j. Source: CEPII (Mayer and Zignago (2006)).

Pop_{i} population of country i in 1000 persons. Source: United Nations: Demographic Yearbook.

$Area_{i}$ area of country i in square kilometres. Source: CEPII (Mayer and Zignago (2006)).

LL_{i} dummy variable taking a value of one if country i is landlocked and zero otherwise. Source: CEPII (Mayer and Zignago (2006)).

CB_{ij} dummy variable taking a value of one if countries i and j share a border. Source: CEPII (Mayer and Zignago (2006)).

Table 6 Overview of manufacturing industries

ISIC Rev3	Industry	Share in value added[a]
15–16	Food products, beverages and tobacco	13.47
17–19	Textiles, textile products, leather and footwear	5.76
20	Wood and products of wood and cork	2.87
21–22	Pulp, paper, paper products, printing and publishing	11.15
23	Coke, refined petroleum products and nuclear fuel	2.11
24	Chemicals and chemical products	10.07
25	Rubber and plastics products	3.86
26	Other non-metallic mineral products	4.62
27	Basic metals	4.53
28	Fabricated metal products, except machinery and equipment	7.87
29	Machinery and equipment, n.e.c.	9.51
30–33	Electrical and optical equipment	11.28
34	Motor vehicles, trailers and semi-trailers	5.54
35	Other transport equipment	3.17
36–37	Manufacturing nec	4.34

Notes: [a] Share in total manufacturing value added in percent. All values are averages of the period 1995–2000 and the 14 countries

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