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Trade performances and technology in the enlarged European Union

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Abstract

Purpose – The purpose of this paper is to analyse the role of the enlargement process of the European Union as a factor fostering international competitiveness of EU Member States. The paper argues that the economic integration process has reduced the technological gap between old and new EU Member States, and this pattern of technological innovation can partially explain the strong impulse on the export dynamics of European countries.

Design/methodology/approach – The paper builds an augmented gravity model by including the role of technological innovation, proxied by the stock of knowledge at the sector level. The authors gather together information on patents applied to international offices and bilateral export flows available from COMTRADE dataset.

Findings – By using a dynamic panel data estimator the authors find three main empirical evidences. First, the enlargement process has produced an overall larger positive impact on export flows for new Members than for old ones, and more importantly that sectors with the higher technological content have received the strongest impulse. Second, the augmented gravity model allows shaping the crucial role of technological innovation in fostering export competitiveness. Third, this impact seems to be stronger for old EU Member States than for new ones.

Research limitations/implications – The major limitation concerns time span adopted in this work. By expanding the dataset to further years it could be possible to better disentangle the effects also related to the new wave of the EU enlargement.

Social implications – The policy implication derived is that the more the new EU Members catch up technologically as a result of the integration process, the more they will benefit in terms of economic development.

Originality/value – The major originality of this paper is the construction of an augmented gravity model by including the role of technological innovation, applied to distinguished manufacturing sectors in a dynamic panel setting.

Keywords EU enlargement, Gravity model, International trade, Economic integration, Technological innovation, European Union, Trade, Innovation

Paper type Research paper

JEL classification – F14, F15, O14

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1. Introduction

The European Union (EU) enlargement process is an attractive case study for economists of different disciplines, from international to development economics. Sometimes the challenges for new EU Member States to adopt the economic and institutional settings of the EU have been considered a potential barrier for their economic development, rather than an opportunity to stimulate the growth process (Baldwin, 1995; Daviddi and Ilzkovitz, 1997). The difficulties in adopting the *acquis communautaire* of the EU, combined with the structural divergences in the economic systems of old and new Members, have created concerns about the real opportunities of the enlargement process for Central and Eastern European Countries (CEECs).

One specific point is CEECs' high dependence on low-technology sectors characterized by divergent factor endowments with respect to old EU Members (EU15). As emphasized by Filippetti and Peyrache (2010) and Kutan and Yigit (2007), the relative contribution of capital deepening has been a crucial driver of labour productivity growth and catch-up. The combination of a fragile institutional setting with high dependence on economic sectors with a higher unskilled labour force and a persistently low capital-labour ratio, was the basis of concerns that the overall effect of the EU enlargement process would lead to substantial improvement for EU15 export flows towards the European market, rather than to an increase of the economic integration of CEECs (Rollo, 1995). More precisely, the real potential failure of the integration process would be a deeper specialization pattern into low value added sectors for CEECs, related to the expansion of the final market, and a simultaneous increase of imports of high value added goods from the EU15.

Previous studies on trade effects related to actions to prepare transition economies for new EU countries (in particular the Europe Agreements for CEECs) have found that such actions have generally spurred trade flows of CEECs. But little has been said about whether, and how, the enlargement process has produced changes in the quality and composition of these trade flows, and which factors have had greater influence on these trade patterns.

What we analyse in this paper is the impact of the enlargement process on the export dynamics of the EU as an extreme case study of economic integration, specifically by considering whether being able to compete in an integrated market has forced less developed economic structures of new EU countries to begin a convergence process of the specialization pattern geared to economic sectors with greater technological content. To some extent, we have followed major contributions on the existence of technologically revealed comparative advantages, as in Archibugi and Pianta (1992) and Pavitt and Patel (1988), where the higher efforts in technological innovation activities in more advanced sectors produce positive impacts on international trade dynamics due to increasing export competitiveness.

The econometric strategy is based on an augmented gravity model, by including the role of technological innovation in the gravity equation. A dynamic panel approach has been adopted due to potential autocorrelation of trade flows and endogeneity of some explanatory variables. Working on a panel-based gravity dataset allows us to explore the dynamics of export flows, addressing structural features of multiple importing markets, while considering factors on both the demand and supply sides.

While traditional factor endowment has been analysed in depth in a gravity context, the literature has only begun to address the trade potential of the enlargement process, related to converging technological capabilities of CEECs as one of the leading factors fostering the economic performance of these transition economies. Furthermore, gravity models assessing sector-specific trade patterns related to the enlargement process are rather rare in general (Baldwin *et al.* (2005) is the most complete contribution for the EU15), and almost absent for CEECs. More importantly, to the best of our knowledge, there are no contributions at all in the gravity literature that explicitly consider the role of technological innovation as a leading factor influencing export dynamics.

The rest of the paper includes a broad literature review on the linkages between technological innovation and international competitiveness, with special attention to the enlargement process in Section 2. Section 3 provides some methodological and econometric issues on gravity models for international trade, while Section 4 describes the dataset built for this purpose and the econometric strategy here adopted. The main results are reported in Section 5, while Section 6 provides some conclusive remarks.

2. International trade, technological innovation, and the EU enlargement

The standard Hecksher-Ohlin-Vanek (HOV) model, which focused on the relationship between factor endowments and patterns of specialization, tended to ignore questions of location (by treating trade as costless) and the role of technology (by assuming that it is common worldwide). While new trade theories have largely reduced the gap for the first issue, the relevance of technology composition has been extensively considered in seminal contributions by Dosi *et al.* (1990), Feder (1983), Kaldor (1981), Pasinetti (1981) and Pavitt and Soete (1980).

To some extent, pure neoclassical trade theory finds some difficulties in explaining trade flows, by assuming homogenous technologies among countries. Fagerberg (1994) criticized this assumption, finding strong evidence in favour of patterns of trade essentially determined by technology gaps, as in earlier contributions from Vernon (1966, 1970) to Kaldor (1963). More recently, Hakura (2001) empirically showed the contribution of international differences in production techniques towards explaining the empirical failure of the strict version of the HOV model. Hence, international differences in technological and innovative capabilities play a fundamental role in explaining the differences in both productivity and export competitiveness.

According to Grossman and Helpman (1991), many of the interactions in the global economy generate forces that may accelerate growth, such as the exchange of technical information and, more generally, the diffusion of knowledge between technologically advanced countries and those that lag behind.

More recently, specific attention has been devoted to the composition of exports. Relying on the empirical contributions by Cuaresma and Worz (2005), Hausmann *et al.* (2007), Lall *et al.* (2006) and Rodrik (2006), the empirical evidence reveals a strong impact on economic growth performance related not only to export dynamics, but more importantly to changes in the composition of exports. Countries experiencing higher growth rates are those with a well-defined specialization process towards economic sectors with higher value added, mainly sectors with a more dynamic technological innovation path (Amable, 2000).

The specific role of technological innovation in trade-growth relationships has been empirically analysed by Eaton and Kortum (2002), who have clearly shown that countries' relative productivities vary substantially across industries, so that in a model of international trade based on differences in technology, technological specialization affects export dynamics, in a sense that each country's state of technology influences absolute advantages, while heterogeneity of technological specialization governs comparative advantages.

In the context of these strands of literature, the EU enlargement process clearly represents an interesting and useful case study for evaluating the relationship between trade and technological innovation. In our work, we can easily assume that economic integration of CEECs into the European market has led to a convergence in technological specialization patterns, thanks to a significant reduction of barriers to the diffusion of technology and knowledge, as well addressed by the empirical evidence provided by Krammer (2009) on the patenting activities of five CEECs during the enlargement process. The improvement in the institutional settings of CEECs, as the outcome of the progressive adoption of the *acquis communautaire* of the EU, has also raised the capacity of new EU Members to attract FDI inflows, especially from Western Europe, as shown in the case of France by Disdier and Mayer (2004).

At the same time, Yang and Maskus (2009) argue that empirical evidence supports the view that multinational firms expand technology flows through greater FDI and licensing, as local patents rights are improved in less developed economies. This evidence reinforces the assumption that the enlargement process has led to increasing technological spillovers thanks to the reduction of barriers to the knowledge flows, regarding both increased FDI inflows and improved legal protection of property rights.

It is also worth noting that an increase in level and scope of FDI inflows of CEECs coming from EU15, combined with offshoring and outsourcing activity, would bear consequences on the patterns of trade, especially on the level and quality of intra-industry trade flows. To some extent, when bilateral relationships between old and new EU Members are oriented towards a high-tech industry, the likelihood of new EU Members to catch-up is greater than in the case where pure inter-industry trade flows prevail. The propensity to specialize into inter or intra-industry trade flows is strongly driven by country features as well as geographical issues, where proximity to a strong commercial partner is clearly a big opportunity to be exploited[1]. To this purpose, as emphasized by Los and Timmer (2005), a specific analysis to the role played by absorptive capacity in explaining successful knowledge spillover effects should be developed, but it is out of the scope of this paper and food for thought for further research.

Some evidence on the positive impact of technological innovation on the vertical specialization at the sector level for new EU Members has also been proven by Barba Navaretti *et al.* (2004) and Cavallaro and Mulino (2008). More generally, Kejak *et al.* (2004) have emphasised the crucial role played by rapidly improving social infrastructure of three CEECs (Czech Republic, Hungary and Poland) as a result of the enlargement process, and the consequent cost reduction of adopting knowledge, leading to a catching-up process towards higher technological frontiers for CEECs. While these contributions provide empirical evidence of the positive role of the enlargement process on technological catching-up and vertical innovation for CEECs, the linkages between innovation and trade have yet to be investigated in depth.

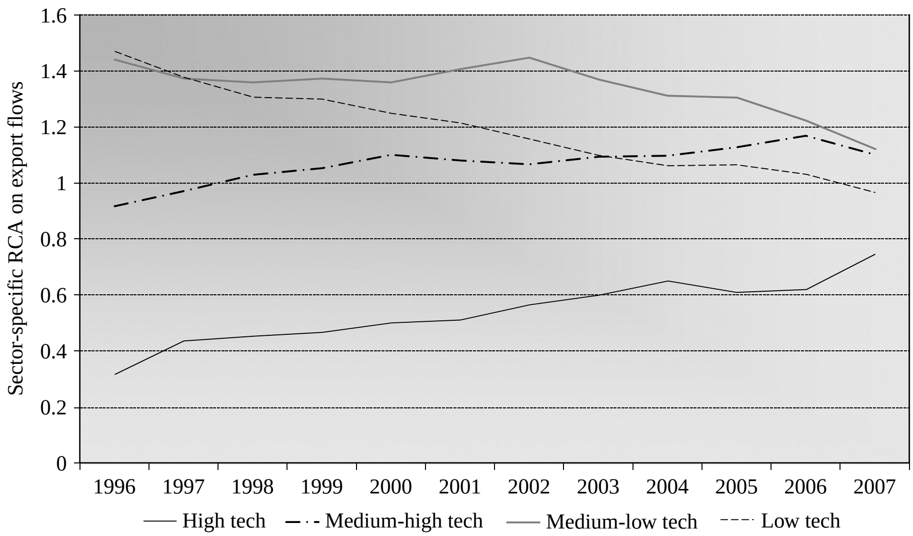
Giving some rough stylized facts, CEECs experienced a higher per capita growth rate of GDP during the period 1996-2007 compared to the EU15, where the largest gap can be found during the period 2001-2007, when the average annual growth rate for the EU15 was less than 1 per cent, while figures for CEECs were about 2.3 per cent.

While the overall effect may be mainly explained by the transition from planned to market economies, it is also worth noting that the highest performance shold be ascribed to the enlargement period, giving to this process a specific role in explaining remarkable economic performance of CEECs.

Nonetheless, the most significant effects can be found in trade patterns. On average, export flows from CEECs have increased by more than 14 per cent yearly in the period 2001-2007, compared to an average annual growth rate of 3.6 per cent in the period 1996-2001. During this time span the export performance of CEECs was much higher than for the EU15 generally, and, more importantly, the export flows increased comparably towards both the European market and the rest of the world. This latter event reveals that the enlargement process has led to an overall increase in the international competitiveness of CEECs, without producing a trade diversion effect confining the rise of export flows within the European market.

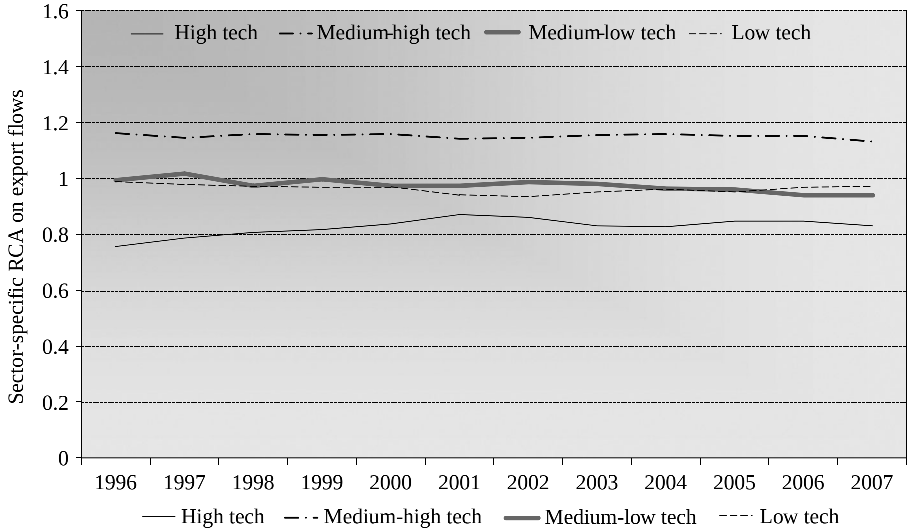
According to the OECD (2008) technological classification of industrial sectors, by considering four aggregated economic sectors as high, medium-high, medium-low, and low technology industries, it is possible to synthesize a picture of differences in export patterns for EU15 and CEECs based on the Revealed Comparative Advantage (RCA) index developed by Balassa (1965)[2] (Figures 1 and 2).

Together with trade dynamics, on average, the ratio of R&D expenditure to GDP increased in the CEECs, from 2001 to 2007 by nearly 13 per cent, compared to the 0.5 per cent growth rate of the EU15. As a result, knowledge stocks in different economic sectors have experienced highly divergent patterns, especially when comparing CEECs with EU15 performances (Figures 3 and 4). Building a specialization index of knowledge stocks (here calculated on patent data as explained in Section 4), it is worth noting that innovation dynamics for CEECs are quite volatile and a structural



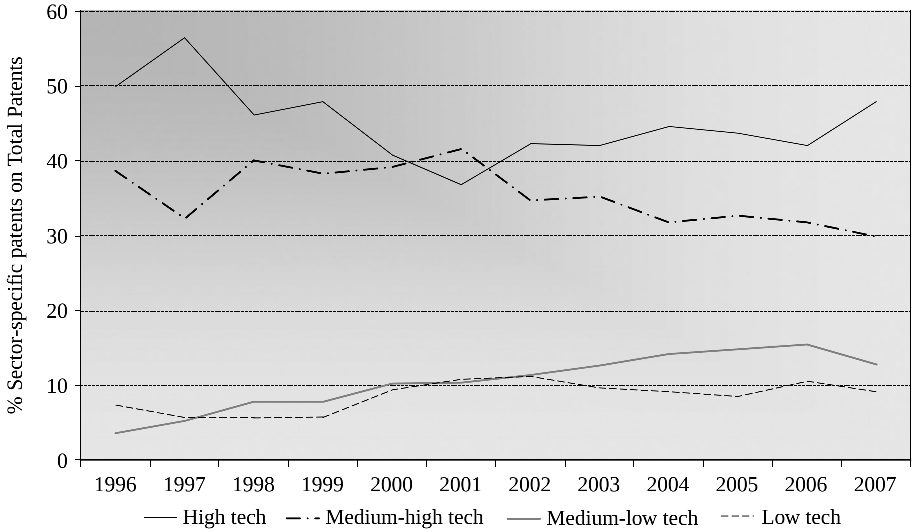
Source: Authors' elaboration on UN-COMTRADE data

Figure 1.
RCA on export flows for CEECs 1996-2007



Source: Authors' elaboration on UN-COMTRADE data

Figure 2.
RCA on export flows for EU15 1996-2007

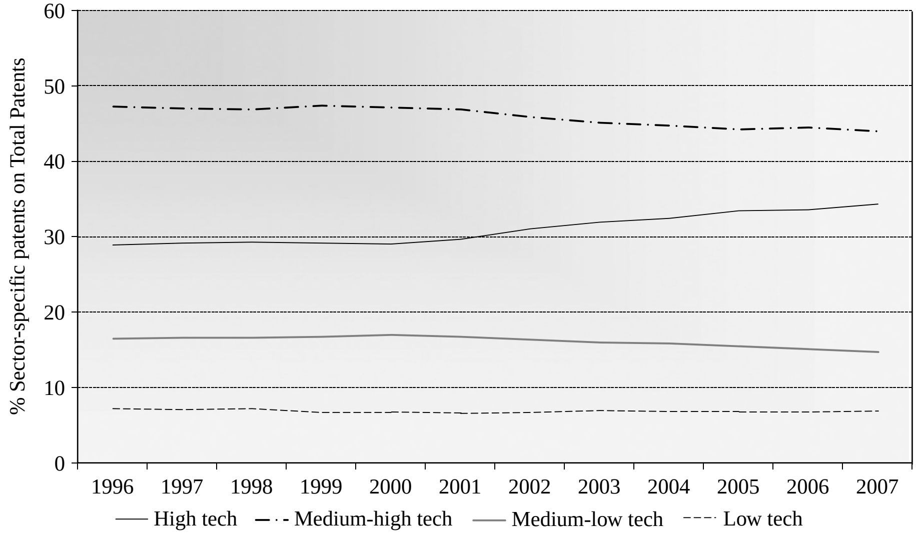


Source: Authors' elaboration on OECD-PATSTAT data

Figure 3.
Distribution of the knowledge stocks (patents) for CEECs

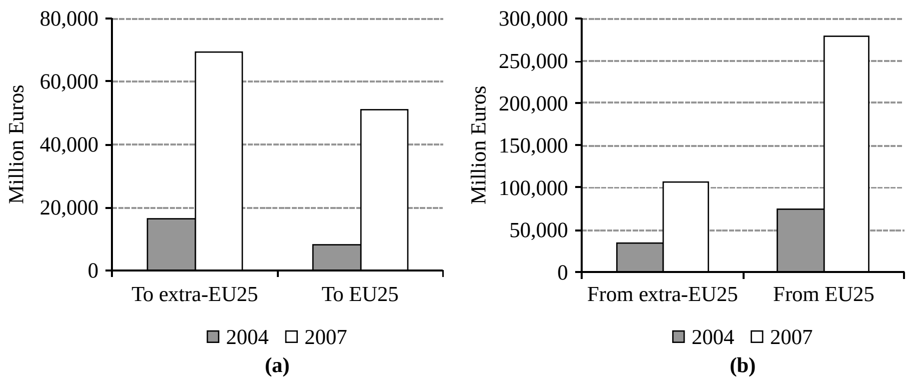
break could be assigned to the period 2000-2002. On the contrary, EU15 shows a quite stable situation for all sectors in the whole time period.

Parallel to the positive dynamics in R&D, during the enlargement process a significant increase in the FDI stocks of CEECs, both inward and outward, has occurred (Figure 5(a) and (b)).



Source: Authors' elaboration on OECD-PATSTAT data

Figure 4.
Distribution of the knowledge stocks (patents) for EU15



Source: Own calculations on Eurostat (2008)

Figure 5.
(a) FDI: outward stocks by CEECs; (b) FDI: inward stocks to CEECs

Starting from the idea that countries can take advantage of technology transfers from FDI (Saggi, 2000), we have seen that in the period 2004-2007, the percentage change of FDI outward stocks by CEECs to EU15 was around 521 per cent, while towards non-EU countries was 322 per cent. Comparing to the same changes for old EU Members, 48 and 54 per cent, respectively, it is clear the relevance of the impact of the EU enlargement especially for new Member States.

From these general observations it seems that the enlargement process has led to an acceleration of the development path of CEECs, mostly driven by positive export dynamics and technological innovation. A deeper investigation is needed on how the integration process has influenced export flows for CEECs and the EU15, and how technological innovation and trade flows are interrelated. More specifically, if integration into the European market has brought about an increased capacity among CEECs to adopt new technologies, due to imitation processes and knowledge transfer via FDI inflows from European firms, and to produce technological innovation directly thanks to public and private commitment to R&D expenditures and human capital accumulation (Allard, 2009), what we would investigate is the specific linkages between these features and the export performance of CEECs.

General analyses of CEECs' trade patterns during the enlargement process are few. As a general consideration, structural features of new accession countries are so different in some cases that the evolution of individual new Members States could be dissimilar. Therefore, empirical analyses should carefully take structural differences among new accession countries into account (De Benedictis and Tajoli, 2007, 2008). Two empirical works on trade potential for CEECs at the disaggregated sector level have used a gravity equation framework, finding some early evidence about the divergent effects on distinct sectors related to the pre-accession period (Jakab *et al.*, 2001; Nahuis, 2004). However, inadequate attention has been devoted to a specific analysis of the role of the enlargement process, and the related increase in CEECs' capacity to produce knowledge, in enhancing trade flows while inducing a specialization of export flows into high value added sectors.

3. The gravity equation for trade flows

According to a generalized gravity model of trade, the volume of trade between pairs of countries X_{ij} is a function of their incomes, populations, geographical distance, and a set of dummies representing such various aspects as the existence of free trade agreements (FTAs) or past colonial relationships or many other specific features, as shown by equation (1):

$$X_{ij} = Y_i^{\beta_1} Y_j^{\beta_2} POP_i^{\beta_3} POP_j^{\beta_4} DIST_{ij}^{\beta_5} Z_{ij}^{\beta_6} F_i^{\beta_7} F_j^{\beta_8} \exp(\alpha_{ij} + \gamma D_{ij}) u_{ij} \qquad (1)$$

where Y_i and Y_j indicate the GDPs of the reporter and the partner, respectively, POP_i and POP_j are reporter and partner populations, $DIST_{ij}$ measures the geographical distance between the two countries' capitals (or economic centres) and Z_{ij} represents any other factor aiding or preventing trade between each pair of countries. F_i and F_j represent all other specific reporter and partner features which may affects trade flows. The model may also include dummy variables (D_{ij}) for trading partners sharing a common language, a common border, or the existence of past colonial relationships, as well as trading blocs' dummy variables, which evaluate the effects of preferential trading agreements or integrated economic areas. Finally, α_{ij} represents the specific effect associated with each bilateral trade flow (country pairs' fixed effects), as a control for all the omitted variables that are specific to each trade flow and that are time-invariant, while u_{ij} is the error term.

Early theoretical contributions attempted to derive the gravity equation from a model that assumed product differentiation (Anderson, 1979), monopolistic competition (Bergstrand, 1985, 1989), and product differentiation with increasing returns to scale (Helpman, 1987). More recently, Anderson and van Wincoop (2003) derived an operational gravity model based on the manipulation of the constant elasticity of substitution (CES) system that can be easily estimated and helps to solve the so-called border puzzle. According to these authors, multilateral trade resistance terms (MRTs) should be added into the empirical estimation to correctly estimate the theoretical gravity model. A simple and intuitive way to do this in cross-section studies is to proxy these terms with country dummy variables or, in a panel data framework, with bilateral fixed effects. The empirical contributions by Baldwin and Taglioni (2006) and Baier and Bergstrand (2007) suggest that, by including specific country-pairs' time-variant fixed effects, the multilateral resistance terms (MRTs) can be represented in an appropriate way. As we are considering a panel version of a gravity equation, with a temporal dimension added to the cross-section one, the log-linear form of equation (1) accounting for country fixed effects is given by equation (2)[3]:

$$\ln\ \mathrm{X_{ijt}} = \alpha_{\mathrm{ij}} - \sum_{\mathrm{i}} \ln \mathrm{P_{it}^{1-\sigma}} - \sum_{\mathrm{j}} \ln \mathrm{P_{jt}^{1-\sigma}} + \gamma \mathrm{D_{ij}} + \beta_1 \ln \mathrm{Y_{it}} + \beta_2 \ln \mathrm{Y_{jt}} + \beta_3 \ln \mathrm{POP_{it}} + \beta_4 \ln \mathrm{POP_{jt}} + \beta_5 \ln DIST_{ij} + \beta_6 \ln Z_{ijt} + \beta_7 \ln F_{it} + \beta_8 \ln F_{jt} + \upsilon_{ijt} \qquad (2)$$

The theoretical gravity equation proposed by Anderson and van Wincoop (2003) requires explicit consideration of the effects of the existence of MRTs, which are represented by $\ln P_{it}^{1-\sigma}$ and $\ln P_{jt}^{1-\sigma}$ as time-varying multilateral (price) resistance terms for each ith reporter and jth partner, respectively. As suggested by Baldwin and Taglioni (2006) the MRTs will be proxied with 2NT (N = countries, T = years) dummies for unidirectional trade.

Recent econometric advancements have addressed another crucial problem related to the existence of a large number of zero trade flow values, which may produce significant biases in the statistical procedure. Recent contributions have proposed two main alternative solutions.

The first suggests the adoption of a non-linear estimator, such as the Poisson-pseudo maximum likelihood (PPML) estimator as proposed by Santos-Silva and Tenreyro (2006) and Westerlund and Wihelmsson (2006).

The second is a Heckman's two-stage procedure (Heckman, 1976) consisting of a first-stage probit selection equation where the dependent variable is a binary variable, assuming value 0 means there is no trade flow and 1 means otherwise. The estimated parameters are used to calculate the inverse Mills ratio, which is then included as an additional explanatory variable explaining sample selection biases in the second-stage standard gravity model with trade flows in absolute value (Chevassus-Lozza *et al.*, 2008; Olper and Raimondi, 2008)[4].

Following Martin and Pham (2008), the PPML estimator is not efficient when there are many zeroes, and the two-step approach is somewhat preferable. Moreover, the theoretical foundation of this procedure was recently established by Helpman *et al.* (2008) (hereafter referred to as HMR), who showed that a large part of statistical bias produced by zero trade flows is not due to a sample selection problem but to neglecting the impact of firms' heterogeneity. In particular, Heckman's two-step sample-selection procedure may give very poor results if the selection and estimation equations are estimated by using exactly the same explanatory variables. Hence, HMR suggest that there are some variables related to the fixed costs of establishing trade flows that should be appropriately included only in the first-stage selection equation. The model yields a generalized gravity equation that accounts for self-selection of firms into export markets and their impact on trade volumes, where the decision to export is not independent from the volume of exports. The authors derive from this theory a two-stage estimation procedure that enables one to decompose the impact on trade volumes of trade resistance measures into its intensive (trade volume per exporter) and its extensive (number of trading firms) margins. Empirically, in addiction to the inverse Mills ratio (explaining sample selection bias, or the intensive margins of trade) a second variable related to the impact of firms' heterogeneity (the extensive margins) is constructed as the predicted probability of trade from country i to country j.

Last recent development in the gravity equation econometric modelling concerns a dynamic specification of trade flows that allows for addressing two additional problems. The first one arises from the autocorrelation of the residuals caused by a strong hysteresis in trade flows related to the presence of trade sunk costs (Bun and Klaassen, 2002; De Benedictis *et al.*, 2005; De Benedictis and Vicarelli, 2005; Martìnez-Zarzoso *et al.*, 2009). The second one is given by the existence of endogenous regressors as in the case of FTAs (Baier and Bergstrand, 2007; Carrere, 2006).

System GMM proposed by Blundell and Bond (1998) is useful for the estimation of a theoretically based gravity model, making it possible to use endogenous variables and correct for autocorrelation of residuals. Moreover, System GMM also makes it possible not to exclude fixed effects for importing and exporting countries, as well as country pairs and all other time invariant variables. Finally, Bond and Windmeijer (2002) show that it is more efficient than the GMM if the panel is short in time (T) and large in cross-section units (N) and if it includes persistent time series.

Some specific characteristics of our panel dataset justify the econometric strategy we have adopted. Trade flows in our dataset include many zero values, especially for CEECs when specific sectors are considered, and at the same time trade series appear to be quite persistent over time. The best way to solve these problems seems to be the adoption of the HMR procedure, by including in the second-stage equation the two variables for firm heterogeneity (the extensive margin) and selection bias (the intensive margin). Second, our dataset is large in cross-section units and short in time, and trade flows show strong persistence in the short-run. More importantly, the technological innovation variable included among the regressors is typically endogenous, due to the high correlation with trade dynamics[5]. In order to cope with all these features, the System GMM estimator does help us in reducing biases related to autocorrelation and endogeneity problems.

4. The technology-augmented gravity equation

The final equation we have estimated for the trade flows of EU countries is based on the Helpman (1987) factor-based gravity model, considering export flows as dependent variables. This is a usual assumption when the purpose of the analysis is to understand factors driving international competitiveness associated with a certain event, as in the case of the enlargement process.

From a purely econometric point of view, we have adopted the version of Anderson and van Wincoop (2003) by including countries' fixed effects, in a slightly different way from suggestions by Baldwin and Taglioni (2006) and Baier and Bergstrand (2007), because the number of observations for the CEECs sample provides insufficient degrees of freedom for the estimation of 2NT (N = countries, T = years) dummies for unidirectional trade in a System GMM. Hence, we have adopted the approach suggested by De Benedictis *et al.* (2005) by including exporting and importing countries' time variant effects (α_{it} and δ_{jt}, respectively), and a country-pair time-variant trend variable calculated as the interaction between temporal trends and fixed effects for country pairs ($trend_{ijt}$).

We have also adapted the HMR two-stage procedure in a panel setting, by also including a time-variant control variable for firms' heterogeneity in the first-stage probit selection equation. In order to include specific transaction costs related to firms' heterogeneity that are not included among the regressors of the second-stage estimation, we have used a standard dummy variable for the existence of a common language, which strongly affects the formation of trading relationships. More importantly, unlike the HMR approach, we must consider how to shape this propensity to trade as it varies over time (whereas the original HMR was applied to a pure cross-section dataset). The best way to deal with this problem is to consider a quantification of the regulatory hurdles which affect firm-level fixed costs of trade. The most appropriate variable, such as the "Cost of Doing Business" provided by the World Development Indicators dataset (World Bank, 2008), does not cover the entire period, so we have considered the Rule of Law indicator, also provided by the World Bank, as a good proxy for (the inverse) cost of doing business at the country level. More properly, we have built a time-variant country-pairs specific variable as the sum of the relative regulatory framework of both exporting and importing countries. From the first-stage equation we have calculated two variables explaining the role played by the extensive margins ($fhet_{ijt}$) and the intensive margins ($mills_{ijt}$) of trade[6].

We have also addressed dynamics by including lags of our dependent variable, and endogeneity of the technological innovation variable by instrumenting it with lags. The final equation for our gravity model is given by equation (3):

$$\begin{aligned} x^k_{ijt} = {} & \alpha_{it} + \delta_{jt} + \tau_{ijt} + \sum_{p=1}^{n} \lambda_p x^k_{ij,t-p} + \beta_1 COL_{ij} + \beta_2 CONT_{ij} + \beta_3 dist_{ij} + \beta_4 land_j \\ & + \beta_5 LOCK_j + \beta_6 mass_{ijt} + \beta_7 simil_{ijt} + \beta_8 endow_{ijt} + \beta_9 fhet^k_{ijt} \\ & + \beta_{10} mills^k_{ijt} + \beta_{11} ENL_{ij} + \beta_{12} innov^k_{i,t-q} + \beta_{13} innov^k_{j,t-q} + \varepsilon_{ijt} \end{aligned} \tag{3}$$

where lower case letters denote variables expressed in natural logarithms and upper case letters indicate dummy variables.

The country sample here considered is made up of 22 exporting countries (the *i*th countries), 14 old EU Members (all EU15 members where Belgium and Luxembourg are together) and eight new CEEC Member States (Czech Republic, Estonia, Hungary, Latvia, Lithuania, Poland, Slovak Republic, Slovenia)[7].

There are 145 *j*th importing countries, chosen on the basis of data availability, and considering that in all cases export flows from *i*th countries to the 145 *j*th partners constitute more than 95 per cent share of total *i*th country exports. A distinct equation has been estimated for total trade and for each specific *k*th economic sector, classified in terms of its technological content (Table I).

The time period analysed goes from 1996 to 2007[8], thus allowing us to include all the EU15 as already existing EU Member States, while considering only the CEECs as new members. The full sample therefore covers a total of 38,280 potential available observations, of which 24,360 refer to the EU15 and 13,920 to CEECs[9].

The standard gravity variables for geographic size are taken from CEPII, where COL_{ij} and $CONT_{ij}$ are dummy variables for the existence (value 1) or non-existence (value 0) of past colonial relationships and a common geographical border between

Macro sector	Sector	ISIC Rev. 3	NACE	Patent field
High-technology industries (SEC-1)	1. Aircraft and spacecraft	353	35.3	43
	2. Pharmaceuticals	2423	24.4	13
	3. Office, accounting and computing machinery	30	30	28
	4. Radio, TV and communications equipment	32	32	34-35-36
	5. Medical, precision and optical instruments	33	33	37-38-39-40-41
Medium-high-technology industries (SEC-2)	6. Electrical machinery and apparatus	31	31	29-30-31-32-33
	7. Motor vehicles, trailers and semi-trailers	34	34	42
	8. Chemicals excluding pharmaceuticals	24 excl. 2423	24 excl. 24.4	10-11-12-14-15-16
	9. Railroad equipment and transport equipment	352 + 359	35.2-35.4-35.5	44
	10. Machinery and equipment, others	29	29	21-22-23-24-25-26-27
Medium-low-technology industries (SEC-3)	11. Building and repairing of ships and boats	351	35.1	45
	12. Rubber and plastics products	25	25	17
	13. Coke, refined petroleum products and nuclear fuel	23	23	09
	14. Other non-metallic mineral products	26	26	18
	15. Basic metals and fabricated metal products	27-28	27-28	19-20
Low-technology industries (SEC-4)	16. Manufacturing, others; recycling	36	36	46
	17. Wood, pulp, paper, paper products, printing and publishing	20-21-22	20-21-22	06-07-08
	18. Food products, beverages and tobacco	15-16	15-16	01-02
	19. Textiles, textile products, leather and footwear	17-18-19	17-18-19	03-04-05

Notes: The figures reported in column "patent field" refer to the 46 fields where patents are classified by Schmoch *et al.* (2003) in order to provide a correspondence between IPC codes and ISIC Rev. 3 industrial sectors; the full list of IPC codes for each patent field is described in the Appendix of Schmoch *et al.* (2003)

Table I.
Classification of industrial sectors and concordance with patents fields

each country pair. The log of distance ($dist_{ij}$) is calculated as the great-circle formula (Mayer and Zignago, 2006), and $land_j$ represents the log of surface area of importing countries. We expect that coefficients for COL_{ij} and $CONT_{ij}$ should be positive, while those for $dist_{ij}$ and $land_{ij}$ should be negative. While distances are considered as a proxy of transport costs, the surface area of importing countries gives a dimension to the role of intra-national trade, and the larger the country, the higher its intra-national trade share with respect to total trade.

Considering our factors endowment approach, we have adopted some specific combinations of variables explaining the role of the economic size of the trading partners. We have included as a standard measure of relative country size the similarity index of the GDPs of two trading partners ($simil_{ijt}$) proposed by Egger (2000), calculated as:

$$simil_{ijt} = \ln\left[1 - \left|\left(\frac{GDP_{it}}{GDP_{it} + GDP_{jt}}\right)^2 - \left(\frac{GDP_{jt}}{GDP_{it} + GDP_{jt}}\right)^2\right|\right] \quad (4)$$

This index is bounded between 0 (equal country size) and $-\infty$ (absolute divergence in size). The larger this measure, the more similar the two countries are in terms of GDP, and the greater the share of intra-industry trade[10]. It is also clear that the total volume of trade should be greater, the larger the overall economic space. We have employed a synthetic measure of the impact of country-pair size as a proxy of the "mass" in gravity models, $mass_{ijt}$, calculated as the sum of value added at constant term for exporting and importing countries (De Benedictis and Vicarelli, 2005):

$$mass_{ijt} = \ln(GDP_{it} + GDP_{jt}) \quad (5)$$

We have also included a measure of the distance between domestic endowment, $endow_{ijt}$, approximated by the formula proposed by Breuss and Egger (1999), where, in the absence of capital stock and labour force data for all j countries, GDP per capita can be considered as a proxy for the capital-labour ratio of each country. This yields to:

$$endow_{ijt} = \left|\ln\left(\frac{GDP_{it}}{POP_{it}}\right) - \ln\left(\frac{GDP_{jt}}{POP_{jt}}\right)\right| \quad (6)$$

where an increase in the capital-labour ratio will increase GDP per capita. The importers' GDP per capita is usually interpreted as an indicator of the sophistication of demand in the importing country. The coefficient of the importer's per capita income is its income demand elasticity. If this value is greater than one, imported goods are classified as so-called luxury goods; if it is less than one they are so-called necessities. According to theory, the larger this difference, the higher is the volume of inter-industry trade, and the lower the share of intra-industry trade[11].

When we explore trade patterns for different sectors, there are other factors than pure border effects which affect bilateral trade flows. A type of distance rarely used is technological distance, which allows better shaping than what is normally attributed to undistinguished country fixed effects. Intuitively, assuming that the technological gap can be a check on trade, and remembering that similar countries have more intensive commercial relations (intra-industry trade), we expect a negative correlation between technological distance and bilateral export flows. In the contribution by Filippini and Molini (2003), technological distance is a general variable for each country pair, whereas we would like to investigate the role of such distances at the sector level. We suppose that the higher the technological content of the traded good, the greater the negative impact of a large technological distance for a country pair on their trade flows.

On the contrary, for low-tech sectors we expect a significant reduction in the importance of this element in explaining trade flows. In order to grasp the propensity of *j*th countries to import goods with different technological characteristics, we have computed a technological distance variable ($tecdis_{ijt}$) as the absolute difference of values assumed by a technological capabilities index.

Starting from the catching-up hypothesis by Abramovitz (1986), where level of education may be one way to measure social and technological capability, theoretical and empirical analyses have considered several ways to measure technological capabilities. One of the most complete proposals in this sense is the contribution by Archibugi and Coco (2004), with their ARCO index.

We have built the $tecdis_{ijt}$ index by using an ARCO with only two out of the four components proposed by Archibugi and Coco (2004), relying on World Development Indicators online database provided by The World Bank, since data coverage allows us taking information for the whole considered period 1996-2007. In order to represent the diffusion of technological infrastructures, we have accounted for internet and telephone penetration (number of internet, fixed and mobile telephone lines per 1,000 persons) and per capita electricity consumption. The second dimension, related to the creation of human capital resources, is the arithmetic mean of two components: domestic efforts in accumulating human capital, expressed as the secondary gross enrolment ratio, and the influence produced by foreign direct investments (FDI) inflows. This second dimension partially represents results provided by Eaton and Kortum (1996), which have estimated that a country's level of education significantly facilitates its capability to adopt technology. The final formulation of our ARCO index for each country i and j at time t is given by:

$$ARCO^t_{i,j} = \frac{1}{2}\left[\frac{1}{3}\left(\frac{\ln\left(TEL^t_{i,j}\right)}{\ln(TEL_{\max})} + \frac{\ln\left(INTERNET^t_{i,j}\right)}{\ln(INTERNET_{\max})} + \frac{\ln\left(ELECAP^t_{i,j}\right)}{\ln(ELECAP_{\max})}\right) + \frac{1}{2}\left(\frac{\ln\left(EDU^t_{i,j}\right)}{\ln(EDU_{\max})} + \frac{\ln\left(FDI^t_{i,j}\right)}{\ln(FDI_{\max})}\right)\right] \tag{7}$$

while the index for technological distance between each pair of ij countries at time t is computed as the logarithm of the absolute value of the difference between $ARCO_{it}$ and $ARCO_{jt}$ as[12]:

$$tecdis_{ijt} = \ln\left|ARCO_{it} - ARCO_{jt}\right| \tag{8}$$

This measure is reliable only if the dependent variable we investigate is built as the total amount of export flows, while it is less useful if a sector specification is taken. In order to grasp sector-specific features of exporting countries we have included technology in an original way, by computing a sector innovation capacity for country i.

The explanatory variable associated with the role of technological innovation for exporting countries $innov^k_{i,t-q}$ has been built as an adaptation of the stock of knowledge function based on patent count. The stock of knowledge is defined following the accumulation function proposed by Popp (2002), with the exclusion of the diffusion component[13]. Our data allow us to assign patents as four-digit codes of the

International Patents Classification (IPC) for inventing industries so that our stock of knowledge function is defined as:

$$KPAT_{it}^{k} = \sum_{s=0}^{t} PAT_{is}^{k} e^{[-\beta_1(t-s)]} \qquad (9)$$

where $KPAT_{it}^{k}$ represents the knowledge stock in industry k for each ith exporting country at time t. PAT_{is}^{k} represents the number of patents produced by industry k in country i in year s, and s represents an index of years up to and including year t. β_1 represents the rate of decay, and we have taken an average value of 0.3 as a standard value from the literature. The final variable $innov_{i,t-q}^{k}$ is calculated as the logarithm of the stock for each year.

The stocks allow us to estimate an overall knowledge production function, considering that in most cases the capacity to apply for a patent (and more importantly to an international patent office such as the European Patents Office (EPO)) largely depends on previous experience, so that the higher the number of patents granted to a certain firm, the greater the probability that this specific firm will apply for new patents. Moreover, the skills acquired during first applications can be considered as sunk costs, while the marginal cost of successive applications is somewhat lower than in the beginning. So far, we use a stock of knowledge function instead of a pure patents count approach, because there is convincing empirical evidence that cumulative domestic innovation efforts are an important determinant of productivity and competitiveness of trade flows (Coe and Helpman, 1995; Eaton and Kortum, 2002).

Moreover, using patents as a technology measure allows us to avoid some of the pitfalls encountered when using R&D expenditures. Unlike R&D expenditures and other data on inventive activity, patents data are available in highly disaggregated form for many countries, including CEECs, for which data on R&D by industry are not available prior to 2001.

As we are aware that R&D productivity, expressed as patent-to-R&D ratios, is decreasing over time, especially after the sector has become mature (or is well developed in a country), by taking the stock we are implicitly evaluating the accumulation of the stock of knowledge in the followers (CEECs) with a higher weight than that of the leaders (EU15). Considering that an R&D effort in a follower produces, *ceteris paribus*, a higher output (number of patents), by accounting for the accumulation of knowledge stock, we are considering increasing returns to scale for new EU Member States' investments in new technologies.

However, when working with patent data, it is important to be aware of their limitations. The existing literature on the benefits and drawbacks of using patent data is quite large. An important concern is that the quality of individual patents varies widely. Some inventions are extremely valuable, whereas others are of almost no commercial value. This is partly a result of the random nature of the inventive process. Accordingly, the results of this paper are best interpreted as the effect of an "average" patent, rather than any specific invention. However, there are other reasons for variation in the quality of patents which can be checked. For example, the propensity to patent varies widely by industry. In some industries, secrecy is a more important means of protection. In these industries, the cost of revealing an idea to competitors is often not worth the gains from patent protection. Moreover, not all inventions are patentable, and not all inventions are patented, because the magnitude of inventive output differs greatly due to specific sector and firm characteristics (Griliches, 1990). This specific point is strongly linked with the different propensity to export due to firms' heterogeneity. In this sense, the adoption of the HMR two-step procedure, especially with the inclusion of an *ad hoc* variable for firms' heterogeneity in the first selection estimation stage, allows us to reduce possible biases related to technological innovation.

Four economic sectors are considered in this paper, classified by OECD (2008) as high, medium-high, medium-low, and low technology industries. The sectors are classified by using the ISIC Rev. 3 classification as described in Table I, and the linkages between ISIC Rev. 3, NACE and IPC codes are also reported. In this way, it is possible to put together data from different sources, such as the STAN database, structural economic data from EUROSTAT and data for patents from PATSTAT. In particular, we have taken patent applications by year, due to their high correlation with R&D expenditures (Griliches, 1990)[14].

The classification of patents data is taken from Schmoch *et al.* (2003) and Verspagen *et al.* (2004)[15], referring to 46 industrial sectors, classified by using ISIC Rev. 3, which are related to the International Patents Classification codes issued by the World Intellectual Property Rights Organization (WIPO). We have condensed the original 46 sectors into the 19 sectors and four macro-sectors used for the Annual OECD Technology Scoreboard Report, thus obtaining a set of industrial sectors where data on trade flows, structural characteristics and patents are fully comparable.

In order to compute an innovation variable for importing countries as well, we have decided to proxy it with the value of *ARCOj*. A sector specific dimension would be somewhat better for representing this aspect, but available data is scarce for patents in several j countries. At the same time, including a specific structural variable related only to exporting countries as $innov^{k}_{i,t-q}$ without shaping the same dimension for the importing partners may produce a substantial overestimation of the impact of technological innovation, reducing the intrinsic characteristics of gravity models representing bilateral features. The best proxy of the stock of knowledge would be R&D efforts as percentage of GDP, but patents data are also missing for several importing countries.

Let us consider the knowledge production function modelled by patents as the model developed by Griliches (1990, p. 1672):

$$\begin{aligned} \dot{K} &= R + u \\ P &= a\dot{K} + v = aR + au + v \\ Z &= b\dot{K} + e = bR + bu + e \end{aligned} \tag{10}$$

where the first equation is the knowledge production function, with unobservable $\dot{K}$ measured in units of R (e.g. R&D efforts). The second equation shows how patents (P) relate to $\dot{K}$ and the third equation models the influence of $\dot{K}$ on subsequent variables of interest. In our case we can state that, *ceteris paribus*, given the strong correlation between technological capabilities and R&D efforts, we can use ARCOj as a proxy for R in explaining $\dot{K}$[16].

Finally, in order to investigate whether the enlargement process has produced some effects on the trade patterns of EU Member States, we have introduced a dummy variable for the "EU membership" effect. CEEC countries joining the EU should have benefited from the European trade integration process; thus the variable assumes value 0 up to the moment when the country entered the EU, and value 1 thereafter.

In particular, the variable ENL_{ijt} embodies the so-called "announcement effect" of the entrance of the eight new member countries into the EU (De Benedictis *et al.*, 2005; Paas, 2003), corresponding to the date of the European Council meeting of Laeken in December 2001. Hence, the dummy assumes the value of 1 as of 2002 for all EU country-pairs involved in the enlargement process[17].

5. Empirical results

The first estimations reported in Table II rely on the overall export flows from EU members (25 members excluding Cyprus and Malta and treating Belgium and Luxemburg as a single country) to 145 importing countries during the period 1996-2007. Results in Table II clearly show that that the best way to estimate a gravity equation in this analytical framework is to use a System GMM with a HMR two-step procedure. Very broadly we may notice that it is necessary to account for hysteresis in trade flows, since persistency is a concern.

When we estimate the gravity equation by including the lagged dependent variable and country fixed effects, and we instrument the technological variables considering them as endogenous, the χ^2 statistics for the Hausman test refuse the null hypothesis that OLS is a consistent and efficient estimator, confirming the endogeneity between export flows and technological innovation both for exporting and importing countries. Nonetheless, expected signs for knowledge stock as the cumulative of patents and as the ARCOj index are both confirmed only in the case of an instrumental variable estimator à la Hausman and Taylor (1981) when we also account for firms' heterogeneity in the HMR approach. Second, accounting for endogeneity of the technology-related variable is highly recommended. The endogeneous nature of technological innovation with respect to trade flows derives from the strong influence of openness to competition, which is heightened by the enlargement process. If we consider that technological innovation depends on a number of conditions, such as institutional capacities and the establishment and operation of new firms, it is quite obvious that technological capabilities are mutually correlated with export dynamics[18].

The last column reports the final specification that we will adopt in analysis at the sector level for the EU15 and CEECs separately. While both AR(n) and Hansen tests confirm the statistical validity of this estimation, it is also worth noting that in this case many of the variables we are interested in present statistically robust coefficients.

Third, consistent with the HMR approach, when we include the extensive margin of trade linked to firms' heterogeneity, the role of geographical distance as a proxy of trade costs is substantially reduced.

More generally, we can state that the impact of the enlargement process seems to be positive and statistically robust, and that the similarity between each pair of trading partners has a strong influence on volume of trade. On the contrary, the role of differences in capital-labour ratios given by relative endowment ($endow_{ijt}$ in equation (3)) is not statistically robust, reinforcing our research hypothesis that a pure HOV model without differences in technical progress among countries fails to fully explain trade dynamics.

We have established that a System GMM estimator with the two-step HMR procedure is the best way to deal with our panel dataset. We have also found that at the general level technological innovation does play a crucial role in explaining the export

Table II.
Estimation of the enlargement effect on EU25 on total export flows

	OLS	IV-BVK[a]	IV-HT-HMR[b]	IV-BVK-HMR[a]	Sys-GMM	Sys-GMM-HMR (1)[c]	Sys-GMM-HMR (2)[c]
$Export_{(t-1)}$		0.726***	0.332***	0.742***	0.616***	0.497***	0.519***
		(159.74)	(59.51)	(181.27)	(22.97)	(15.15)	(19.73)
$Export_{(t-2)}$					0.132***	0.167***	0.192***
					(5.55)	(6.16)	(8.74)
Colonial relationship	0.996***	0.246***	1.522**	−0.170	0.017	−10.802***	−0.791
	(10.08)	(8.88)	(2.22)	(−0.44)	(0.04)	(−4.35)***	(−0.39)
Common border	−0.723***	−0.165***	1.781***	0.818***	−0.062	−11.537	−5.417
	(−4.72)	(−3.91)	(6.03)	(8.25)	(−0.22)	(−0.88)	(−1.32)
Distance	−1.695***	−0.426***	0.829***	0.373***	−0.205	−0.368	−0.295**
	(−26.98)	(−22.48)	(8.47)	(11.43)	(−3.25)***	(−0.77)	(−1.99)
Surface area *j*th	−0.259***	0.697***	0.097	0.334***	−0.305	0.050	0.004
	(−4.02)	(5.72)	(1.15)	(3.12)	(−4.91)***	(0.35)	(0.06)
Landlocked *j*th	−3.060***	0.269	−1.299**	−1.276***	−0.276	2.869***	0.040
	(−9.40)	(1.60)	(−2.38)	(−4.42)	(−1.02)	(2.60)	(0.11)
Common language	0.914***	0.264***			1.333		
	(8.33)	(8.61)			(1.20)		
Regulatory framework	0.095***	−0.124***			−0.021		
	(2.85)	(−3.05)			(−0.21)		
Firms heterogeneity			−0.779***	−0.440***		−2.263***	−0.595***
			(−11.07)	(−8.54)		(−6.02)	(−2.73)
Inverse Mills ratio			0.003	−0.007		−0.133***	−0.023
			(0.37)	(−1.27)		(−7.80)	(−1.18)
Mass	3.688***	1.789***	2.902***	1.517***	0.492***	0.223	0.415***
	(42.50)	(9.48)	(16.46)	(4.33)	(7.14)	(1.11)	(4.43)
Similarity	1.658***	0.806***	1.353***	0.643***	−0.933	1.666	1.933*
	(18.14)	(8.28)	(7.03)	(3.53)	(−1.29)	(0.35)	(1.70)
Relative endowment	−0.072	−0.046**	0.317**	0.047	−1.381**	0.336	0.992
	(−1.12)	(−2.25)	(2.45)	(0.91)	(−2.14)	(0.09)	(1.10)
Enlargement	−0.141***	0.171***	−0.123***	0.218***	0.127***	0.014	0.110***
	(−8.53)	(6.83)	(−3.78)	(4.25)	(5.87)	(0.40)	(4.50)
Stock of knowledge *i*th	0.366***	−0.514***	0.407***	−0.341	0.251***		0.395***
	(13.57)	(−3.87)	(7.81)	(−1.38)	(6.82)		(5.54)

(continued)

Table II.

	OLS	IV-BVK[a]	IV-HT-HMR[b]	IV-BVK-HMR[a]	Sys-GMM	Sys-GMM-HMR (1)[c]	Sys-GMM-HMR (2)[c]
Stock of knowledge *j*th	−0.114***	−0.026**	−0.143***	−0.055***	0.002		−0.204***
	(−14.98)	(−2.57)	(−9.44)	(−3.01)	(0.08)		(−3.62)
Technological distance						−1.851***	
						(−3.97)	
Country *i* and *j* fixed effects		Yes	Yes	Yes	Yes	Yes	Yes
Country-pair trend		Yes	Yes	Yes	Yes	Yes	Yes
Year dummies		Yes	Yes	Yes	Yes	Yes	Yes
No obs.	26,969	24,048	28,143	25,281	23,718	25,405	25,405
Adj. R^2	0.89						
Wald test		446,813.73	32,849.15	236,869.17			
F-test					101,026.71	4,211.98	20,167.47
Woolridge AR (*F*-test) *p*-value in parenthesis	150.805						
	(0.00)						
Hausman (χ^2-test) *p*-value in parenthesis		2,648.14					
		(0.00)					
σu		0	1.67	0			
σe		0.68	1.49	1.49			
ρ		0	0.55	0			
AR (1) *p*-value in parenthesis					−10.44	−14.09	−13.9
					(0.00)	(0.00)	(0.00)
AR (2) *p*-value in parenthesis					0.11	0.02	−0.61
					(0.92)	(0.98)	(0.54)
Hansen overid. test					195.69	39.09	38.04
					(0.00)	(0.15)	(0.19)

Notes: Significant *p*-value at: *10, **5 and ***1 per cent; [a]instrumental variable estimator for panel data using the generalized two stage least square (G2SLS) by Balestra and Varadharajan-Krishnakumar (1987); [b]instrumental variable estimator for panel data by Hausman and Taylor (1981) for covariates correlated with the unobserved individual-level random effect; [c]robust standard errors are calculated for correcting heteroskedasticity of the error terms; twostep robust specification of XTABOND2 STATA command has been used; robust *t*-statistics in absolute value are reported in parenthesis; AR(1) and AR(2) are tests – with distribution *N*(0, 1) – on the serial correlation of residuals; Hansen χ^2 test for overidentification of restrictions (number of instruments) dynamics of EU Members, and that the enlargement process has had a positive effect on international competitiveness.

As we are also interested in understanding the effects of the enlargement process on the composition of the export dynamics of European countries, and more importantly whether these effects appear to favour the new Member States, we have computed five distinct estimations for two distinct country samples, the old and new members (the EU15 and CEECs, respectively), addressing total export flows and the four macro-sectors classified in Table I on the basis of the technological content of the production process.

Results for the EU15 and CEEC samples are quite different (Tables III and IV), allowing us to make some interesting comments on divergences between the two country groups, but more importantly on the impact of the enlargement process and the technological catching-up of the new Member States during the period 1996-2007.

The lag structure of the dependent variable with two lagged values still remains coherent, for both the country sample and for all the investigated macro-sectors, revealing a strong persistence in the dynamic of export flows toward a specific importing country. The evidence on the role of sunk and transactional costs, as crucial factors distinct from pure transport costs explaining export dynamics, is also reinforced by results for the impact of firms' heterogeneity. It is worth noting that for the EU15 this factor positively affects only mature sectors (low-medium-tech and low-tech, sectors 3 and 4 in Table III, respectively). To some extent, we can state that firms' heterogeneity plays a positive role in enhancing export capacity in mature sectors where product differentiation and demand-driven consumption are more evident, and that the existence of many (medium-small) firms leads to increasing competitiveness capacity on highly disaggregated consumption paths. On the contrary, the existence of many heterogeneous firms reduces export competitiveness within technologically advanced sectors. This is more evident in the CEEC sample where countries are much more differentiated in terms of industrial concentration. Where monopolistic competition is more relevant, countries with higher concentration can gain in technological competitiveness, especially when economic resources are more constrained.

It is also interesting to see that, by including firms' heterogeneity, the explanatory power of the standard capital-labour ratio (here expressed as the relative distance between each country pair) is lower, showing that the standard HOV model fails to consider specific production structures other than standard (capital and labour) endowments[19].

The coefficients for distance are lower for the EU15 than for CEECs at the general level, but the gap is much larger for high-tech sectors where distance is statistically significant only for new EU Members. This means that for CEECs trade barriers related to trade costs are still a significant constraint for exporting goods with high economic value.

For the EU15, the coefficients for *Mass* are positive and statistically significant for all sectors except high-tech, where the coefficient is not robust. Recalling that *Mass* represents the role of global bilateral demand, the higher the value the greater the influence of demand factors in export dynamics. As we can see from Table IV, results for CEECs are more homogeneous and robust, meaning that to some extent factors from the demand side have a greater influence on the capacity to export. In particular, we have to consider how this variable is composed, as the sum of GDP for each pair of exporting and importing countries. Typically, the EU15 have larger economic size, where domestic demand plays a crucial role in sustaining production capacity in the

Table III. Estimation for EU15 export flows for different macro-sectors (Sys-GMM-HMR-2)

	EXP-TOT	EXP-SEC 1	EXP-SEC 2	EXP-SEC 3	EXP-SEC 4
$Export_{(t-1)}$	0.541***	0.341***	0.359***	0.318***	0.427***
	(13.45)	(5.69)	(10.02)	(9.23)	(10.31)
$Export_{(t-2)}$	0.247***	0.102***	0.131***	0.082***	0.218***
	(6.31)	(2.34)	(4.49)	(2.72)	(5.41)
Colonial relationship	−6.172***	14.746*	0.471	43.622***	0.253
	(−5.09)	(1.76)	(0.18)	(3.84)	(0.13)
Common border	−4.562	−18.494	−24.062**	11.051	−18.844***
	(−1.48)	(−0.51)	(−2.25)	(1.54)	(−3.26)
Distance	−0.350***	−1.045	−0.829**	0.053	−0.743***
	(−2.12)	(−0.80)	(−2.28)	(0.17)	(−3.35)
Surface area *j*th	0.091**	−0.020	−0.203**	0.110	−0.222*
	(2.00)	(−0.08)	(−2.07)	(0.81)	(−1.59)
Landlocked *j*th	−0.029	1.294	0.354	−1.261*	0.425
	(−0.10)	(0.75)	(0.75)	(−1.73)	(0.86)
Mass	0.189**	0.043	0.402***	0.196*	0.653***
	(1.82)	(0.04)	(3.60)	(1.64)	(5.52)
Similarity	−0.616	6.526**	1.141	6.388***	1.573*
	(−1.24)	(2.24)	(1.58)	(3.23)	(1.73)
Relative endowment	−0.547	4.372*	0.204	3.991***	0.187
	(−1.35)	(1.74)	(0.33)	(2.49)	(0.25)
Enlargement	−1.113	−0.119	−0.066	0.009	0.042
	(−0.50)	(−1.11)	(−1.06)	(0.12)	(0.67)
Stock of knowl. *i*th	0.105***	1.027***	0.881***	0.994***	0.680***
	(2.26)	(10.30)	(5.25)	(12.78)	(9.12)

(*continued*)

Table III.

	EXP-TOT	EXP-SEC 1	EXP-SEC 2	EXP-SEC 3	EXP-SEC 4
Stock of knowl. *j*th	−0.055*	−0.146***	−0.237***	−0.181***	−0.035
	(1.76)	(−2.73)	(−5.06)	(−3.29)	(−1.06)
Firms heterogeneity	−0.782	0.746	−0.529	1.538***	3.276***
	(−1.13)	(1.12)	(−0.73)	(3.16)	(3.25)
Inverse Mills ratio	−0.087***	0.008	−0.047*	−0.105***	−0.082***
	(−3.66)	(0.32)	(−1.42)	(−3.62)	(−2.50)
Country fixed effects	Yes	Yes	Yes	Yes	Yes
Country-pair trend	Yes	Yes	Yes	Yes	Yes
Year dummies	Yes	Yes	Yes	Yes	Yes
No obs.	16,074	15,779	15,794	15,623	15,920
F-stat. *p*-value in parenthesis	47,242.49	771.57	14,576.28	3,825.91	8,703.51
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
AR(1) *p*-value in parenthesis	−5.6	−8.34	−8.48	−10.41	−6.98
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
AR(2) *p*-value in parenthesis	−0.2	−1.37	−0.72	−0.68	−0.9
	(0.84)	(0.17)	(0.47)	(0.49)	(0.37)
Hansen	46.64	62.72	47.41	50.83	86.22
	(0.11)	(0.10)	(0.10)	(0.05)	(0.00)

Notes: Significant *p*-value at: *10, **5 and ***1 per cent; twostep robust specification of XTABOND2 STATA command has been used; robust *t*-statistics in absolute value are reported in parenthesis; AR(1) and AR(2) are tests – with distribution $N(0, 1)$ – on the serial correlation of residuals; Hansen χ^2 test for overidentification of restrictions (number of instruments)

Table IV. Estimation for CEECs' export flows for different macro-sectors (Sys-GMM-HMR-2)

	EXP-TOT	EXP-SEC 1	EXP-SEC 2	EXP-SEC 3	EXP-SEC 4
$Export_{(t-1)}$	0.483***	0.441***	0.363***	0.432***	0.472***
	(16.40)	(15.33)	(11.06)	(12.30)	(16.43)
$Export_{(t-2)}$	0.229***	0.146***	0.154***	0.147***	0.185***
	(8.42)	(5.44)	(4.68)	(4.33)	(6.81)
Colonial relationship	−6.534	16.642	18.497	7.008	−4.899
	(−1.43)	(0.78)	(1.13)	(0.83)	(−0.56)
Common border	7.414	−1.265	−35.372	11.260	−11.298
	(1.03)	(−0.02)	(−0.39)	(0.63)	(−1.12)
Distance	−0.502***	−0.212***	−0.134**	−0.537**	−0.222
	(−2.52)	(−2.92)	(−2.46)	(−1.96)	(−1.42)
Surface area *j*th	0.438***	−0.061	−0.437	−0.033	−0.201
	(2.78)	(−0.26)	(−1.23)	(−0.13)	(−0.86)
Landlocked *j*th	−0.860	−1.146	0.563	−1.435	−0.213
	(−1.02)	(−0.94)	(0.46)	(−1.25)	(−0.24)
Mass	0.062	0.259***	0.825*	0.337***	0.271***
	(0.73)	(2.63)	(1.54)*	(3.06)	(2.59)
Similarity	3.454	0.583	3.255	4.134	1.009**
	(1.02)	(0.17)	(0.77)	(1.06)	(1.96)**
Relative endowment	2.537	−0.348	0.623	2.788	0.593
	(1.01)	(−0.14)	(0.20)	(0.94)	(1.52)
Enlargement	0.679***	0.531***	0.289***	0.180*	0.353***
	(8.81)	(4.61)	(2.92)	(1.67)	(3.81)
Stock of knowl. *i*th	0.029	0.194**	1.104***	0.429***	0.017
	(0.49)	(2.08)	(5.73)	(4.56)	(0.21)

(*continued*)

Table IV.

	EXP-TOT	EXP-SEC 1	EXP-SEC 2	EXP-SEC 3	EXP-SEC 4
Stock of knowl. *j*th	−0.157**	−0.063	−0.247***	−0.076	0.001
	(−2.08)	(−0.54)	(−2.72)	(−0.71)	(0.01)
Firms heterogeneity	−0.812**	−0.431***	−0.397*	−1.019***	−0.225
	(−2.41)	(−2.82)	(−1.91)	(−3.71)	(−1.28)
Inverse Mills ratio	−0.038	−0.095	−0.072	0.018	−0.161***
	(−0.96)	(−1.64)*	(−0.62)	(0.29)	(−3.47)
Country fixed effects	Yes	Yes	Yes	Yes	Yes
Country-pair trend	Yes	Yes	Yes	Yes	Yes
Year dummies	Yes	Yes	Yes	Yes	Yes
No obs.	9,131	7,769	8,183	7,396	8,500
F-stat. *p*-value in parenthesis	3,032.66	1,092.35	795.37	900.80	1,575.12
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
AR(1) *p*-value in parenthesis	−11.62	−12.66	−11.52	−10.69	−11.99
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
AR(2) *p*-value in parenthesis	−1.81	−1.47	−1.5	−1.19	−0.78
	(0.11)	(0.14)	(0.13)	(0.24)	(0.44)
Hansen	44.26	40.44	16.19	29.2	73.22
	(0.12)	(0.11)	(0.85)	(0.45)	(0.07)

Notes: Significant *p*-value at: *10, **5 and ***1 per cent; twostep robust specification of XTABOND2 STATA command has been used; robust *t*-statistics in absolute value are reported in parenthesis; AR(1) and AR(2) are tests – with distribution $N(0, 1)$ – on the serial correlation of residuals; Hansen χ^2 test for overidentification of restrictions (number of instruments) earlier stages of development for a certain industry. On the contrary, for CEECs domestic demand may be somewhat smaller so that exports are better explained by external demand. The composition of CEECs' export flows in terms of geographical destinations can shed some light on this result, if we consider that most exports from CEECs go to the European market. In this case, the size of demand from importing countries dominates the effect represented by the variable *Mass*, and it is not surprising to see a higher coefficient for the medium-high-tech sector, where most of the increasing export flows in the period 1996-2007 have gone to the EU15.

Another difference is the role of the similarity in the economic size of each country pair (*similarity*) and the relative endowment between exporting and importing countries (*relative endowment*). The higher the similarity between two countries and, thus, the more similar two countries are in terms of GDP, the higher the share of intra-industry trade. For the EU15, coefficients are always positive and statistically robust, with the exception of the medium-high-tech sector, where we find a positive but not statistically robust coefficient. For relative endowment, we find positive coefficients corresponding to the same sectors where similarity is robust, except for low-tech. Combining these two indications, our results can be interpreted as a clear sign of the greater importance of intra-industry trade in the high-tech and medium-low-tech sectors, typically occurring between countries with similar endowment factors, as in early explanations by Linder (1961) and Grubel and Lloyd (1975). In the case of Sector 3, the prevalence of intra-industry trade for the EU15 can be partially explained by the relevance of internal protection guaranteed by European countries to energy-intensive industries, which make up the greater part of this macro-sector.

On the contrary, for the CEEC sample coefficients for Relative endowment are consistently not statistically robust for all sectors. Also in this case, we can interpret our results considering the great importance of the EU as a privileged destination market for new EU Members.

Our results appear to be confirmed both by the absence of a clear impact associated with similarity in economic size, and more importantly by the large difference between the coefficients of *Enlargement* for the EU15 and CEECs. The impact of the enlargement process is clearly stronger for the new accession countries than for the older EU Member States. The coefficients for the EU15 are not statistically robust, with mixed signs. On the contrary, for the CEEC sample, the enlargement process has a large, positive and statistically significant impact.

It is also interesting to note that the highest coefficient for CEECs is in the high-tech sector, meaning that the more stable institutional setting, combined with a larger flow of FDI inflows from European firms, has produced a substantial increase in export capacity in this sector. More importantly, in this specific case a trade diversion phenomenon has not occurred, because most of this increase has gone to destinations other than the European market. Hence, we can interpret this specific result as a clear sign of a technological catching-up process for CEECs, which have encountered incremental productivity gains and competitiveness in international markets.

An additional explanation to this specific evidence is related to the great role played by intra EU exchange of intermediate goods, especially for those sectors characterized by market power concentration as in the automotive sector. The enlargement process has brought to a decentralization of large portions of the production process from EU15 toward CEECs (and the statistics on FDI flows shown in Figure 5(a) and (b) reinforce this interpretation), thus explaining the smaller evidence on intra-industry trade for CEECs. This point seems to be a crucial one and further investigation at a more disaggregated level (both at sector and country dimension) is necessary, where aggregated trade flows models should replace a bilateral gravity approach, but this is beyond the scope of our analysis.

It is worth noting that the domestic stock of knowledge in CEECs plays a crucial role in explaining export dynamics, especially in the medium-high and medium-low-tech sectors, while for the EU15 the explanatory capacity of the domestic stock of knowledge is rather higher at the general level, and more specifically for the high-tech sector. The lower impact of the existing stock of knowledge for CEECs can also be explained in a Vernon context, where product differentiation is primarily demand-determined: high levels of income and sophisticated demand patterns induce innovative responses from domestic firms. Considering that per capita income levels in CEECs are still much lower than in the EU15, domestic demand is not sufficient to drive technological innovation and production specialization in highly sophisticated goods. In this sense, the enlargement process should act as an external demand factor by widening the destination market.

To some extent, we can state that the enlargement process has fostered the technological upgrading process of CEECs, and more importantly that the impact of the stock of knowledge on export dynamics is clearly positive and favours sectors with greater technological content, thus helping new Member States to reduce the technological gap, converging to a higher economic development level by increasing growth rates. As we can see from the results obtained for the EU15, the accumulation of a stock of knowledge has a strong positive impact on export capacity, especially in the high-tech sector. This result confirms the importance of the enlargement process in inducing technological upgrading of the whole economy as a major potential source of economic growth, even for new accession countries[20].

This specific result has some important policy implications, since policies pointing to a better technological performance in the new Member States may also produce some negative externalities to old EU countries, shifting international competitiveness towards a more relevant role of CEECs, while reducing export relative comparative advantages of EU15. This effect should be taken into account carefully, as it may bring to potential negative impacts on employment rates. If export competitiveness of CEECs will grow thanks to a technological catch-up process, while labour cost remains at lower levels with respect to EU15, it could be a medium-term effect fostering employment rates in CEECs while reducing demand on the EU15 labour market even in high value-added sectors. As a final interesting piece of evidence, in the low-tech sector the enlargement process has produced a strong stimulus to export flows, while technological innovation appears to be neutral. In this specific case, trade policies and quality standards imposed by the EU on the food industry play a crucial role in explaining this evidence. The enlargement process in this case has led to a rapid convergence in production standards of CEECs in the agri-food sector while eliminating all trade barriers, allowing new Member States to enter a highly protected sector, characterised by higher market prices than in the rest of the world.

6. Conclusions

In this paper we have evaluated the export performances of the EU during the enlargement process by using a disaggregated analysis based on four macro-sectors classified by technological content in a gravity model framework.

We have developed a new empirical estimation of the gravity equation for export flows by specifically including the role of technological innovation as a source of international competitiveness. Hence, we have classified IPC patent codes by aggregating them on the basis of the OECD Technology Concordance in order to compute the specific stock of knowledge for each manufacturing sector. Next, we have aggregated data for distinct industrial sectors into four macro-sectors, such as those analysed by the OECD Technology Scoreboard.

We have shown that a dynamic panel estimator as a System GMM is the most efficient econometric solution in order to consider both autocorrelation of the residuals and endogeneity of some regressors, while maintaining time invariant covariates which are necessary for a proper estimation of a theoretically-based gravity equation. We have also adopted a two stage procedure by considering a first stage probit selection equation in order to reduce bias coming from zero values in export flows. We have developed a slightly different specification in the first stage probit selection equation in order to consider time variant country pair variables explaining the probability to export for heterogeneous firms.

Our main findings are that the economic integration induced by the enlargement process has produced an overall positive impact on the export dynamics of the EU. This impact seems to be much greater for new EU Member States, and is much more evident for high-tech sectors than for low-tech sectors. On the contrary, the impact of the enlargement of the EU seems not to have any impact on the export dynamics of the EU15. This specific result, combined with the evidence that CEECs' high-tech sectors have benefited the most from EU enlargement, allows us to state that economic integration into the EU has given CEECs more than a larger market to sell low value added goods.

This result may be partially explained also by the general recover in economic growth paths occurred to all transition economies after the early 1990s crisis. Nonetheless, growth rates for CEECs were rather more constant during the whole period analysed compared to the other transition economies which have shown a greater economic instability. To some extent this evidence allows reinforcing our empirical results that the enlargement process brought some advantages to CEECs compared to the other transition economies, and to the old EU Member States.

Moreover, including technological innovation as a specific factor on the supply side of a gravity model provides a better understanding of export dynamics, especially in a disaggregated context. Differently from previous works, what we are interested in is to investigate the relevance of some variables not on the total export flows but on disaggregated sectors on the basis of their technological content.

From our results we can argue that technological innovation plays a crucial role in fostering the export performance of EU, both for EU15 and CEECs.

The policy implication we derive is that if an economic integration process occurs between two regions with different economic development levels, the follower will benefit the more from the integration process, the higher will be the influence of the leading area in enhancing in the follower a proper institutional setting, a greater transparency in market rules, all factors able to attract foreign capitals as well as facilitating knowledge spillovers. As we have seen, a technological catch-up process has occurred into the enlarged Europe, influencing the competitiveness of the followers especially into sectors with the highest impact in terms of a long run economic development path.

Notes

1. We thank an anonymous referee for addressing this point.
2. For a more punctual description of sector classification see Section 4.
3. The log-linear transformation is usually adopted for interpreting the coefficient values as elasticities.
4. A common application of the inverse Mills ratio (sometimes also called "selection hazard") arises in regression analysis to take account of a possible selection bias. If a dependent variable is censored (i.e. a positive outcome is not observed for all observations), it causes a concentration of observations at zero values. The inverse Mills ratio is the ratio of the probability density function of predicted values from probit estimation to the cumulative distribution function of predicted values.
5. It is true that increasing investments in innovation leads to improvement in production capacity and, in the medium-term, in export competitiveness. But it is also true that those sectors which are characterized by a greater degree of openness can benefit from international knowledge spillovers resulting, in an increased innovation capacity. Considering that the enlargement process has led to a relatively rapid opening process for the accession countries, the increase in trade flows could have reasonably influenced the technological capabilities of industrial sectors.
6. It is worth noting that Rule of Law indicator is available every two years.
7. We have not included Belgium and Luxemburg separately because data on trade flows from COMTRADE are available only for the aggregate Belgium plus Luxemburg up to 2001. We have not considered Cyprus and Malta and countries of the new enlargement wave and potential candidates (i.e. Bulgaria, Romania, Croatia and Turkey) because of lack of data at disaggregated level.
8. This choice is quite necessary considering the lack of available patents data for CEECS before 1996. Finally, structural data on specific economic sectors are rather difficult to obtain in a long time series, and this is particularly true for CEECs.
9. Trade data on export flows are taken from the UNCTAD-COMTRADE database, based on the Harmonised Commodity Description and Coding System (HS 1996), expressed as annual unilateral export flows in current value (US$) from country ith to country jth. Trade flows are expressed as current US$ as given by COMTRADE database, and they are not converted into constant price values because in the Anderson and van Wincoop (2003) version of the gravity model all price effects (including exchange rates) are caught by country fixed effects.
10. For the sake of simplicity, we have changed the original formulation slightly in order to have the upper bound equal to 0 rather than equal to log(0.5). The lower bound remains unchanged.
11. Data on GDP and population are from the World Development Indicators online database (WDI, 2008).
12. As we can see, the formulation of the ARCO index is based on the same methodology adopted for the Human Development Index (HDI), where the observed values are normalised by a minimum and maximum value. In this case the minimum value is always equal to zero, whereas the maximum value has been taken in the whole time period/countries sample considered in this work. This formulation gives us the possibility of accounting for temporal changes at country level as well as the methodology adopted by UNDP for the HDI. Following the UNDP methodology, all components have been considered in a logarithm form, creating a threshold above which the technological capacity of a country is no longer enriched by the increase of single components.

13. This choice is related to the fact that Popp (2002) accounts for the diffusion of technologies by assigning patents to the end-user sectors, rather than to the innovation producer alone. In our case, we are interested in investigating the knowledge production process, whereas addressing technology diffusion within and among sectors in a gravity setting is somewhat more complicated.
14. We have considered only EPO applications, because as we consider only patents applied to the European Patents Office, which is generally more expensive than patenting in domestic patents offices, we assume that the marginal benefits from patenting are at least equal to marginal cost, so that firms apply to EPO only for economically valuable inventions.
15. There are many contributions on concordance techniques for the assignment of patent data by field of technology to a classification by economic sector, mapping patent product or process categories into the economic sectors responsible for their creation and subsequent use. The OECD Technology Concordance (OTC) described in Johnson (2002), like its predecessor the Yale Technology Concordance as originally presented by Kortum and Putnam (1997), is a tool that bridges definitions, allowing researchers to transform IPC-based patent data into patent counts by sector of the economy (for an extensive review of concordance classifications see Kaplinsky and Santos-Paulino, 2006). In our paper we have adopted the version proposed by MERIT (Verspagen *et al.*, 2004), and SPRU (Schmoch *et al.*, 2003), specifically oriented to EPO patents, considering that we work with EU countries and with EPO patents statistics.
16. We are aware that in this case we use an input variable for innovative capacity in country j and an output variable for country i, but we find the approximation, especially for less developed economies, is rather good.
17. We have also computed two control variables for the accession process as a standard procedure in literature, namely a dummy for the Central European Free Trade Agreement (CEFTA) and one for the Baltic Free Trade Area (BAFTA), but neither is statistically significant.
18. We have modelled the stock of knowledge instrumenting it with its two-periods-back value. This choice in the regression is based on several estimations showing that coefficient values do not change in sign for different lag structures.
19. The statistical robustness of coefficients for firms' heterogeneity (extensive margins of trade) compared to non-robust results for intensive margins given by the inverse Mills ratio is fully consistent with Helpman *et al.* (2008).
20. In order to check for sectors' heterogeneity, we have run a second estimation by using a stock of knowledge weighted by the number of employees, or alternatively by sector production value. In both cases, results remain robust and coherent.

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Appendix. Robustness check for the choice of system GMM estimator

Results in Table II clearly show that estimating a gravity model by using standard OLS produces results that are not statistically robust. The first issue that arises is the presence of autocorrelation of residuals, as the Woolridge AR test rejects the null hypothesis of absence of autocorrelation. If we introduce a lagged dependent variable, its coefficient is always positive and statistically robust, meaning that it is necessary to account for hysteresis in trade flows, but in this way autocorrelation of residuals is still not appropriately addressed.

Moreover, the high coefficient found for bilateral distance reveals that a theoretically based gravity model à la Anderson and van Wincoop (2003) with country *i*th and *j*th fixed effects is necessary for better modelling of the multilateral resistance term.

When we estimate the gravity equation by including the lagged dependent variable and country fixed effects, and we instrument the technological variables considering them as endogenous, the (two-statistics for the Hausman test refuse the null hypothesis that OLS is a consistent and efficient estimator, confirming the endogeneity between export flows and technological innovation both for exporting and importing countries.

Nonetheless, expected signs for knowledge stock as the cumulative of patents and as the ARCOj index are both confirmed only in the case of an instrumental variable estimator à la Hausman and Taylor (1981) when we also account for firms' heterogeneity in the HMR approach.

As these results are not sufficiently robust, we have performed a System GMM estimator in three different versions. The first (Column Sys-GMM) does not account for firms' heterogeneity, while the second (Sys-GMM-HMR-1) and third (Sys-GMM-HMR-2) both consider the HMR approach, also giving robustness to the choice of separate modelling of technological innovation for exporting and importing countries. As we can see in the estimation by Sys-GMM-HMR-1, AR tests confirm that autocorrelation exists and it is appropriately addressed by differencing, and the inclusion of firms' heterogeneity and selection bias from the first-stage probit equation gives better performance in terms of robustness of instruments (Hansen test).

Estimations with HMR methodology could be affected by high heteroskedasticity in the error terms as stressed by Santos-Silva and Tenreyro (2006). While they propose a PPML for a single gravity equation without endogeneity problems, in our model we must consider a log-linear version of the gravity equation for instrumenting endogenous variables. In order to account for potential heteroskedasticity, we have computed robust standard errors in our System GMM estimator.

The last Column reports the final specification that we will adopt in analysis at the sector level for the EU15 and CEECs separately. While both AR(n) and Hansen tests confirm the statistical validity of this estimation, it is also worth noting that in this case many of the variables we are interested in present statistically robust coefficients.

Consistent with the HMR approach, when we include the extensive margin of trade linked to firms' heterogeneity, the role of geographical distance as a proxy of trade costs is substantially reduced. The impact of differences in firms' capacity to export, together with the strong hysteresis in export flows, reveals the great importance of sunk and transactional cost in trade decisions which are not properly shaped by transport costs. It is also important to stress that the proper lags structure of the dependent variable includes a second-order temporal lag, as suggested by Bun and Klaassen (2002). While the variable related to the regulatory framework presents a coefficient not always consistent and robust when included in single equation estimation, in the first-stage probit equation this variable is much more stable and suitable for checking the propensity to trade in a time-variant setting.

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