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The Impact of Technology and Structural Change on Export Performance in Nine Developing Countries

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Summary. — This paper focuses on nine large developing countries. Structural decomposition analysis shows that they tend to concentrate innovative activities in industries stagnating at the world level; international trends partly offset national improvements in patent shares. The same occurs for world export shares, although countries display greater adaptation to world demand. Econometric analysis suggests that technological activity is related to export gains in high technology sectors if a country expands in industries with increasing technological opportunities, in medium technology sectors if it moves away from low opportunity sectors, in low technology sectors if it is initially specialized in growing sectors. In high-tech and low-tech sectors, export performance is also affected by the growth of technical capabilities, foreign direct investments, productivity, and the initial level of technical skills and in medium tech by the growth rates of foreign direct investments.

Key words — innovation, technical change, export performance, development, Asia and Latin America

1. INTRODUCTION

The past two decades have witnessed a remarkable degree of structural change [1] of technological activities and export in manufacturing and primary industries at the world level. There has been a dramatic increase of both international trade and innovative activities in sectors related to electronics, physics, and pharmaceuticals (see Table 1). Sectors such as electronics, computing and data processing, drugs and biochemistry, communication and networking have shown above average growth rates in terms of patenting activity and export. In particular, stylized evidence, as displayed in Table 1, suggests that industries offering higher technological opportunities—those leading technical change in the whole economy—show the largest improvements in export world shares. [2]

Similarly, there seems to be an association between technological performance and export growth at the country level. Table 2 shows that countries such as China, Malaysia, Singapore, and Thailand display a relatively higher degree of innovativeness and technological intensity of trade (in 1998) and, at the same time, improve more significantly their overall importance in world export (relatively to the United States, the largest exporter in the world). Such

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Table 1. *Annual rate of growth for world shares of patents and exports, by industry*

Industry	Annual growth 1985–98	
	Patents	Exports
Computing and data processing	108.96%	33.80%
Electricity and electric power	2.77%	24.77%
Electronics and components classes	94.15%	62.38%
Optics–radiant energy–photography	30.36%	−7.37%
Communications and networking	94.98%	14.77%
Other science and engineering, measurement, nuclear	16.00%	17.09%
Music–education–games	−12.12%	8.84%
Electronics, Physics	*42.93%*	*25.19%*
Biochemistry (pharmaceuticals)	34.19%	38.14%
Chemical engineering	−38.34%	−28.46%
Organic chemistry	−25.50%	−2.95%
Surgery–body care–cosmetics	62.60%	8.27%
Materials–compositions–explosives	−15.92%	1.37%
Agriculture and farming	−39.89%	−1.49%
Chemistry, Biology	*−12.46%*	*−9.35%*
Material or article handling	−35.17%	10.25%
Heating–cooling–buildings–fluid/gas handling	−26.95%	5.67%
Earth working and civil engineering	−32.38%	−14.62%
Vehicles and transportation	−30.19%	1.48%
Office devices–paper handling–coatings	−5.95%	0.19%
Textiles and apparel	−48.59%	−1.46%
Engineering, Transportation	*−30.99%*	*0.86%*
Tools–hardware–pipes–joints	−28.92%	−5.96%
Receptacles–containers–supports–furniture	−2.72%	18.97%
Manufacturing assembling–metal working	−19.40%	−2.50%
Motors–engines–pumps	−43.59%	11.81%
Rotary machines and mechanical power	−21.19%	10.41%
Machining and cutting	−24.58%	1.54%
Mechanics	*−26.56%*	*2.00%*

Note: the percentage change is relative to the overall average annual rate of growth.
Source: Authors' calculation on COMTRADE and USPTO data (see Appendix A for data description and sectoral definitions and concordance).

advancements in technological and export performance go along with a significant structural change in the economy. In China, Malaysia, Singapore, and Thailand, the share of medium- and high-tech products on total exports improved substantially.

A comparison of export structure in South America and East Asia suggests that specializing in medium and high-tech products translates into large gains on international markets. South American countries experience small shifts in the sectoral composition of export and stagnant export performance; East Asian countries reverse the relative importance of technologically complex sectors over mature ones and establish themselves as the most dynamic region in world trade.

Moreover, the stylized evidence displayed in Table 2 on country technological and export performance and structural change seems to confirm the importance of the quality of specialization for economic success. The quality of export specialization of countries may be evaluated through the analysis of export elasticities to trade partners' income. [3] Recent evidence suggests that faster growing economies (in particular within the developing countries) have high-income elasticities of demand for their exports but lower import elasticities. [4] Asian countries seem to have higher income elasticities for their exports than the rest of the developing countries, corroborating the idea that export specialization and trade play a key role in the rates of growth of these econ-

Table 2. *Descriptive statistics on technological and export performance and structural change*

	Country								
	Argentina	Brazil	China	Colombia	India	Malaysia	Mexico	Singapore	Thailand
Total export value in 1985 (US = 100)	3.84	11.72	12.50	1.62	4.18	7.00	13.30	10.43	3.25
Total export value in 1998 (US = 100)	3.88	7.50	26.91	1.59	4.90	10.75	17.22	16.11	7.98
Low-tech and resource-based exports (as percentage of total exports, 1985)[a]	33.8%	44.9%	19.5%	24.6%	59.6%	34.0%	13.1%	43.4%	38.0%
Low-tech and resource-based exports (as percentage of total exports, 1998)	32.4%	41.7%	54.6%	30.2%	61.7%	24.9%	22.9%	19.9%	36.3%
Medium- and high-tech exports (as percentage of total exports, 1985)[a]	10.3%	23.9%	4.1%	5.6%	9.8%	21.1%	25.1%	39.9%	13.8%
Medium- and high-tech exports (as percentage of total exports, 1998)	23.3%	34.3%	36.6%	8.9%	16.6%	65.1%	65.5%	74.3%	44.9%
Patents growth 1985–98[b]	1.0%	1.8%	63.3%	0.4%	4.4%	6.9%	0.3%	16.9%	8.8%

Source: Authors' calculation on COMTRADE and USPTO data (see Appendix A for data description).
[a] The technological classification of SITCrev2 exports is from the UNIDO Scoreboard Database.
[b] The percentage change is relative to the overall world rate of growth.

omies (Caporale & Chui, 1999; Senhadji, 1998; Senhadji & Montenegro, 1999).

Different theoretical contributions and various empirical studies have led to the accepted view that the sectoral composition of technological activities and trade affects growth opportunities and, in turn, the process of technological and trade specialization. Similarly, it is claimed that technology plays a significant role in shaping the trade patterns of advanced and developing economies (Dosi, Pavitt, & Soete, 1990; Grossman & Helpman, 1991; Krugman, 1995; Lall, 1992, 2000). This is because specific characteristics of the process of knowledge creation and technological accumulation may lead to specific developments of capabilities that make export structures difficult to change (Lall, 1992, 2001).

The empirical literature supports the idea of a significant relationship between technology and trade (Amable & Verspagen, 1995; Amendola, Dosi, & Papagni, 1993; Dosi *et al.*, 1990; Fagerberg, 1988; Greenhalg, 1990; Laursen, 1999; Laursen & Meliciani, 2000; Magnier & Toujas-Bernate, 1994; Montobbio, 2003; Soete, 1981). However, consistent cross-country and cross-sector evidence is available almost exclusively for manufacturing sectors in the OECD countries. This paper extends the empirical analysis to developing countries. Its purpose is to evaluate the relationship between technology and trade and, in particular, to study the impact of processes of structural change—driven by technological advancements—upon the sectoral distribution of export activities and market shares. This analysis sheds some light on the type of technological improvements that may be related to export performance at the country level. Export performance may depend upon a diffused relative technological improvement in every sector, upon the type of technological specialization (which can be oriented toward classes with high or low technological opportunities), or finally, upon the ability to adapt, upgrade, and enter innovative sectors.

Moreover, the analysis is conducted for those developing countries which have large enough industrial and primary sectors and examines whether foreign direct investment, skill upgrading, and productivity, along with domestic technological effort, can account for the dynamics of export market shares. The analysis considers 25 manufacturing and primary sectors for nine developing countries in the period 1985–98: Argentina, Brazil, China, Colombia, India, Malaysia, Mexico, Singapore, and Thailand. In Section 2, the theoretical and empirical background is briefly reviewed. In Section 3, the hypotheses are specified. Section 4 describes the data and methodology. Results are discussed in Section 5, and Section 6 concludes.

2. BACKGROUND

A great number of models emphasize the importance of scale economies, product differentiation, endowments of skilled labor and R&D resources, technological learning and spillovers, as determinants of the international patterns of exports. [5] The first contributions, as in Krugman (1979), showed that countries and products can be ranked by technological level and that economies ahead in this scale specialize in the technological intensive goods. Increasing returns to scale and product innovations generate trade specialization and first mover advantages. But in equilibrium, imitation reduces technological gaps between countries, and the monopolistic power of leaders is temporary.

Various authors expanded this kind of analysis in the endogenous growth framework. This approach, usually referred to as the "new trade theory," [6] models technology as an economic product, resulting from either investment in R&D activities or learning by doing mechanisms. In Grossman and Helpman (1991, 1995), conclusions rely crucially on the assumption about the nature of technological spillovers. If knowledge can spread instantaneously and for free, there is an international common stock of scientific and technical information (function of the amount of differentiated products in the world economy). In this case, a comparative advantage in innovation activities depends only on differences in the cost of input, namely human capital. Therefore, a relative abundance of this factor leads to competitive advantage in the technology intensive sector because of higher R&D performance. Countries relatively endowed with human capital specialize in research and export hi-tech goods, whereas labor abundant economies export traditional products.

If spillovers are only local in scope, each country accumulates a stock of knowledge proportional to national R&D activities. As a consequence, economies with a larger initial stock of technology have an initial advantage, independently of the relative endowment of inputs. Previous experience, more than human capital costs, determines international allocation of R&D resources. The model shows equilibria with geographical agglomeration of innovative activities, as countries with even a small historical advantage in technological sectors become, through higher rates of innovation, world leaders in these markets. The other countries follow a path of increasing imports of those goods. Here initial conditions of technological capabilities are crucial, while in the case of global spillovers, historical differences between countries have no relevance for dynamic comparative advantages. Importantly, in this theoretical framework, the government of a follower country can establish a subsidy to improve national R&D performance. If the policy is sufficiently strong, the economy could catch up the initial technological disadvantage.

The new trade theory approach suggests that developing countries are technological followers, being typically relatively scarce of human capital and historically poor in scientific and technical knowledge. So, whatever the nature of technological spillovers, they specialize in traditional products, with labor-intensive and mature techniques, and they import innovations from developed economies. In our perspective, it is particularly relevant that over time, technological activities tend to lose relevance for developing countries' exports, unless governments can design effective policies to improve endowments of human capital and R&D capabilities.

Other authors, drawing on the product cycle and technological gap traditions (Dosi *et al.*, 1990; Posner, 1961; Vernon, 1966), have emphasized that the sectoral distribution of technological activities and exports depends upon specific and cumulative national trajectories which might lead to productivity advantages in many sectors in a specific country (Amendola *et al.*, 1993; Dosi *et al.*, 1990). As a result, it is less important to assess the relative adjustments between sectors within countries based on relative factor prices and quantities. The process of technological competition implies, at least in a first approximation, trajectories along fixed coefficients and irreversibilities. Therefore, it is the outcome in terms of sectoral world market share dynamics, [7] together with the sectoral composition of demand, which guides the pace of structural changes within countries (Amendola *et al.*, 1993; Dosi *et al.*, 1990; Lall, 2001; Montobbio, 2003). In order to understand the process of economic growth and transformation, the analysis should focus upon the relation between national technological effort in specific sectors and outcomes in terms of competitiveness. This can be expressed in terms of *changes* of world market shares within the same industry.

Empirical evidence generally supports the claim that the variance in terms of changes of world export shares can be explained by a set of technological variables at country and sectoral level (Amable & Verspagen, 1995; Amendola *et al.*, 1993; Dosi *et al.*, 1990; Fagerberg, 1988; Greenhalg, 1990; Magnier & Toujas-Bernate, 1994; Montobbio, 2003; Soete, 1981). Statistically significant relationships between technological and export variables are also shown in terms of patterns of technology and trade specialization (Amendola, Guerrieri, & Padoan, 1998, chap. 7; Malerba & Montobbio, 2000) and in terms of a country's ability to actively move into industries offering above average technological opportunity (Laursen, 1999).

However, this empirical literature focuses almost exclusively on OECD countries and mainly considers R&D expenditure, gross fixed capital formation, and labor costs as determinants of export market shares. This neglects important variables which are particularly important when the analysis addresses the relationship between technology and trade in developing countries. Access to capital goods in many core technologies, skill upgrading, and infrastructures significantly affect technological transfer and adoption in developing countries where these processes are more difficult and costly, with risky and prolonged learning (Lall, 1992, 2000, 2001).

In particular, in developing countries, not only explicit technological effort (as in technological gap analyses of OECD countries), but also the characteristics of distribution of skills in the labor force, foreign direct investments (FDIs) by transnational corporations (TNCs), and targeted government policies are expected to drive and constrain the process of technological advancement and diffusion and the relationship between technology and export performances.

Schools and universities are among the crucial institutions affecting innovative behavior. Historically, developing a wide and diversified educational system is a key factor to generate the capabilities required for the successive stages of the industrialization process. This is even more the case for the diffusion than for the creation of innovations and technical skills. Hence, such an element is particularly important for developing countries, and lack of targeting toward the generation of technological capabilities on a large scale, poor financial resources, weak linkages between schools, universities, and the productive system, help in explaining why these economies are often stagnating from the technological point of view (Bell & Albu, 1999; Kuruvilla, Erickson, & Hwang, 2002; Psacharopoulos & Ng, 1992).

The role of TNCs and their FDIs in less advanced contexts is also relevant. The contribution of TNCs to the technological progress in host countries varies with the level of industrialization in the economy, since this affects corporate strategies of investment and R&D and the ability of local producers to benefit from the activities of multinationals. Evidence of the historical importance of TNCs for developing countries' exports and of their superiority in technological skills and in international market access suggests that TNCs offer big opportunities in terms of capability building and commercial growth (Borensztein, De Gregorio, & Lee, 1998; Buckley & Clegg, 1991; De Mello, 1999; UNCTAD, 1999).

Moreover, in less industrialized contexts, the R&D expenditure is low both in absolute terms and relative to GDP, and is concentrated in university or government laboratories. This fact, together with a major targeting toward sectors of national interest, usually causes a centralized management of research efforts and leads to weakness of technological transfer and incentive mechanisms. Improvements in research activities are without doubts one of the change needed for a general progress in technological capabilities of developing economies. What is particularly important for them is private R&D effort devoted to imitation and adaptation, and directed toward the absorption of knowledge coming from external sources such as public institutions or TNCs (Bell & Pavitt, 1993; Hobday, 1995; Kim, 1999).

Strong inputs of technological activities, though, are not enough to ensure that technical progress translates into productive efficiency and export success. Skills, FDI, R&D do not necessarily give good results in the case of poor coordination and ineffective interactions between the agents involved (Katz, 2000; Lundvall, 1988). Therefore, when assessing the role of technology for competitiveness, it is important to control for the actual efficiency of the productive system. Value added, as the ultimate outcome produced by an economy, reflects productivity trends and is expected to have a strong positive impact on market share dynamics.

These qualifications about the relationship between technology and trade in developing countries bring about relevant policy implications. Failures affecting technology markets and learning processes stress the importance of creating technical skills to improve export competitiveness in less advanced contexts and hence the need to overcome the difficulties domestic firms face in building capabilities. [8] There is more room for government intervention and FDI in the case of developing countries relative to developed ones. Appropriate policies could directly solve failures in the learning of local producers in order to upgrade national technological capabilities. Targeted FDI bringing in new technologies, higher levels of technical skills, and enhanced international market access would strengthen the competitive position of firms, especially alongside domestic ability to interact with TNCs and to absorb part of their knowledge and organizational competences (Ernst, Ganiatsos, & Mytelka, 1998; Lall, 1998; UNCTAD, 1999).

3. THE HYPOTHESES TO BE TESTED

The arguments presented so far suggest that the technological level of firms' activities significantly affects their ability to compete on world markets. This paper—in line with the empirical and theoretical frameworks outlined above—analyzes the relationship between changes in national technological efforts and outcomes in terms of competitiveness expressed as changes of world market shares.

(1) The first, and more general, hypothesis is that technological activity affects export performance. As shown in Section 2, this is widely recognized for developed countries, but not for developing ones. The variables chosen to describe such a relationship are export and patent world shares. Patent counts reflect technological and innovation opportunities and measure the propensity of a country to undertake innovative activities in each sector.

Moreover, this paper claims that important country and industry specificities exist in the relation between technology and trade. Competitiveness is affected both by general economic conditions of a country (education system, investment climate, competition rules, macroeconomic stance, etc.) and by core technologies and productive characteristics peculiar of a single industry (knowledge flows, modes of financing, informational networks, targeted policy interventions, etc.). Heterogeneity across sectors and across countries is detected by using econometric models with dummy variables.

(2) In particular, we expect that export market share dynamics and countries' ability to adapt their export sectoral composition to the change in sectoral composition of exports worldwide are affected by the patterns of technological specialization. Therefore, the second hypothesis is that the change in export world share can be in part ascribed to four different components of the change in countries' world share of technological (patent) activity (diffused relative improvement of the patent shares in all sectors, change of the technological opportunities in the sectors in which the country is technologically specialized, ability to enter innovative sectors with high technological opportunities, ability to move out of low opportunity sectors). This paper tests the statistical significance of such an impact and assesses for each country the relative weight of the four components.

(3) The third hypothesis is that, as discussed in Section 2, export market shares are significantly affected by levels and changes of the skill base, R&D activities, productivity, and foreign direct investments by TNCs. Some proxies for R&D effort, level of technological capabilities provided by educational institutions, role of TNCs, and productivity trends are therefore included in the regression analysis alongside patents.

(4) Finally, we expect that the characteristics of the specific technological and learning processes affect patterns of innovation activity and, in turn, the industrial rules which translate technological investments into market share gains (Lall, 1992). Evidence suggests that the specific features of the relationship between technological activities and export performance are different in *low*-, *medium*-, and *high-tech*

industries, as they vary in terms of learning potential, scope for upgrading, spillovers to the rest of the economy, and growth opportunities (Amable & Verspagen, 1995; Lall, 2000; Malerba & Montobbio, 2003, 2004; Montobbio, 2003). Therefore, the last hypothesis is that sectors differ in the relation between technology and market share dynamics. We expect variables representing technology to have different relative importance for competitiveness dynamics in different groups of sectors distinguished by technological intensity. With respect to these industry-specific effects, the empirical exercise is then performed separately for groups of sectors with different research intensities.

4. DATA AND METHODOLOGY

The analysis considers nine developing countries in the period 1985–98: Argentina, Brazil, China, Colombia, India, Malaysia, Mexico, [9] Singapore, and Thailand. These economies cover a wide range of demographical and geographical conditions, GDP per capita, industrial development, endowment of natural resources, and growth rate of exports.

Data on exports are from the United Nations "COMTRADE" database. The measure for technological opportunities is the number of patents granted to firms of the selected countries by the "United States Patent and Trademark Office" (USPTO). Since statistical robustness requires a large sample and patent counts at the sectoral level for a single year are small, data are aggregated adding up the numbers for the reference years with those of the three preceding years. So the observations on trade relate to 1985 and 1998, whereas those on technology to 1982–83–84–85 and 1995–96–97–98. This operation is quite usual in the literature, and, to some extent, allows temporal lags between innovations and their actual commercial exploitation to be taken into account (Griliches, 1987).

Innovation as such is not crucial for the technological upgrading of developing countries. Imitation activities, adaptation to the local context of imported technologies, small incremental improvements, and learning-by-doing are more important. The priority for firms competing on international markets is the diffusion and mastering of existing technology, not the creation of new ones. However, as emphasized by Pavitt (1988), patents tend to reflect incremental innovation as well and this may legitimate the use of patents also for developing countries. Moreover, patents offer two advantages: First, these legal documents are officially registered, and are not subject to uncertainty, measurement errors, and arbitrariness of the survey collecting the data. Second, when patents are granted by one institution, in this case, the US Patent and Trademark Office (USPTO), standard criteria of quality assessment of the innovation and common procedure of approval generate consistent time series that are uniform and comparable even if firms are from different countries. Moreover, the choice of the American office is particularly relevant, as the United States is the largest and most important technology market in the world, and the largest market for exports. Hence, a producer facing international competition is more likely to register its innovations there rather than in any other office.

Exports and patents are the only variables for which data from the selected countries exist at the fine sectoral level we need. The 25 industries considered correspond to a particular level of aggregation of the 410 technological classes of the "United States Patent Classification" (USPC). To analyze the impact of technological activities on competitiveness at the sectoral level, it is necessary to match the classifications of trade and patent data. The 25 industries are also ordered into three groups of different technological intensities, according to the OECD methodology: a sector is defined high, medium or low tech if its ratio of R&D expenditure to production is, respectively, greater than four, between one and four, or less than 1% (OECD, 1986).

The other variables, constant across industries (this is due to the poor availability of disaggregated data), are manufacturing value added (data for 1985 and 1998), FDI inflows (aggregations from 1981 to 1985 and from 1993 to 1997), productive enterprise financed R&D (1985 and 1998), and tertiary enrolments in technical subjects (1985 and 1995); these observations were provided by UNIDO (UNIDO Scoreboard Database). We have also calculated unit labor costs for high-tech, medium-tech, and low-tech aggregates form the UNIDO Industrial Statistic Database. Appendix A provides further details on the data and on the correspondence between the different classifications involved.

5. THE EMPIRICAL ANALYSIS

(a) *The structure of technological and export activities*

The empirical analysis uses the "structural decomposition" methodology to describe the different components of improvements or declines of a country in terms of world patent and export shares. This is a common tool of empirical studies of international trade, often referred to as "constant market share analysis." We follow Fagerberg and Sollie (1987), who develop a new version of the methodology, and Laursen (1999), who applies it for the first time to patenting activities of OECD countries. The following symbols are used:

i = subscript referring to sectors;
j = subscript referring to countries;
$t-1, t$ = superscripts referring to the initial year—1985—and to the final year—1998—of comparison, respectively;
P_{ij} = amount of patents granted to country j in sector i;
$p_{ij} = P_{ij}/\sum_j P_{ij}$ = share of world patents of country j in sector i;
$p_j = \sum_i P_{ij}/\sum_i\sum_j P_{ij}$ = the aggregate share of world patents of country j;
$o_i = \sum_j P_{ij}/\sum_i\sum_j P_{ij}$ = share of world pat ents of sector i.

The change of country j's aggregate share of world patents can be written as

$$\Delta p_j = p_j^t - p_j^{t-1} = SH_j + ST_j + AD_j. \qquad (1)$$

$SH_j = \sum_i\left(\Delta p_{ij} o_i^{t-1}\right)$ measures the *technology share effect* which is the gain/loss of world shares of country j, assuming that the world sectoral structure of patenting activities is fixed across time. This shows country j's innovative performance assuming out structural change: The national position with respect to changes in technological opportunities worldwide is not considered.

$ST_j = \sum_i\left(p_{ij}^{t-1}\Delta o_i\right)$ measures the *structural technology effect* which indicates what the change in country j's share of world patent would be, if its shares on individual sectors remained constant. ST_j shows whether a country increases (decreases) its share as a consequence of a "right" ("wrong") initial technological specialization. Since p_{ij} is fixed, changes are guided by Δo_i which indicates the growth in terms of technological opportunities of sector i at the world level.

$AD_j = \sum_i\left(\Delta p_{ij}\Delta o_i\right)$ measures to what extent country j is successful in transforming the sectoral composition of its technological activities according to structural changes in world patterns of technological opportunities. Fagerberg and Sollie (1987) shows that AD_j is directly proportional to the correlation coefficient across i between Δp_{ij} and Δo_i. So AD_j is positive (negative) if country j's share increases in those sectors which increase (decrease) their weight in terms of world patents.

Since we are interested in understanding the effect of an increase (or decrease) of shares both in *expanding* sectors and in *declining* sectors, we need to use a further decomposition of AD_j (Laursen, 1999).

$$AD_j = GR_j + SG_j. \qquad (2)$$

$GR_j = \sum_i \Delta p_{ij}(\Delta o_i + |\Delta o_i|)/2$ is called *technology growth adaptation* effect and measures the ability of countries to enter sectors where technological opportunities are increasing above average. Accordingly, GR_j is positive (negative) if Δp_{ij} is positive (negative) for these sectors.

$SG_j = \sum_i \Delta p_{ij}(\Delta o_i - |\Delta o_i|)/2$ is called *technology stagnation adaptation* effect and singles out industries which display a relative decline. Therefore, SG_j is positive (negative) if Δp_{ij} is negative (positive) for these sectors. This measures the ability of countries to exit sectors with declining technological opportunities.

Table 3 presents the results for the nine countries analyzed in this study.[10]

All nine countries have very low initial shares of world patenting activity. In 1998, the highest proportion, belonging to Singapore, still did not count for more than 0.17%.

China and Singapore are by far the most successful stories. Singapore builds upon continuous improvements in technological competitiveness and is today a major player in dynamic high-tech sectors (electronics and components, communications and networking), as confirmed by the relatively high value of GR_j. China is catching up, and the remarkably high value of SH_j shows the country experienced a dramatic improvement of patent shares in every sector.

The other Asian countries, in order Thailand, Malaysia, and India, display a lower level of innovative performance and rate of growth. For these three countries, the value of SH_j is

Table 3. *Structural decomposition analysis for world shares of patents*

Country	Share of world patents 1985	Share of world patents 1998	Total rate of change	Technology share effect	Structural technology effect	Technology growth adaptation effect	Technology stagnation adaptation effect
Argentina	0.064%	0.07%	2.17%	3.07%	−0.95%	−1.19%	1.23%
Brazil	0.088%	0.12%	40.42%	64.99%	−18.01%	8.65%	−15.21%
China	0.004%	0.11%	3012.77%	3202.33%	−21.68%	412.63%	−580.51%
Colombia	0.016%	0.01%	−30.39%	−28.74%	−4.98%	−1.76%	5.10%
India	0.037%	0.10%	162.40%	176.46%	−16.06%	26.76%	−24.75%
Malaysia	0.007%	0.03%	285.88%	319.37%	−28.84%	41.37%	−46.03%
Mexico	0.129%	0.09%	−33.95%	−21.28%	−8.54%	−4.24%	0.11%
Singapore	0.019%	0.17%	769.76%	630.32%	−0.51%	215.17%	−75.22%
Thailand	0.004%	0.02%	375.92%	429.01%	62.02%	−22.67%	−92.45%

Source: Authors' calculation on USPTO data.

particularly high, testifying a generalized improvement in their technological performance. However, Malaysia and India seem to have been penalized by their initial sectoral composition of innovative activities (negative ST_j and $GR_j + SG_j$ close to zero); conversely, Thailand started from a favorable structural position (positive ST_j), but showed a perverse pattern of adaptation losing shares in expanding sectors and gaining shares in declining sectors (negative GR_j *and* SG_j).

Latin American countries performed less well. Brazil and, above all, Argentina have weak patent share growth rates, with positive SH_j. While Brazil manages to partially compensate the adverse effect of its sectoral composition of technological activities (negative ST_j and SG_j) with a moderate shift toward dynamic sectors (positive GR_j), Argentina displays no sizeable structural transformations (AD_j close to zero). Mexico and Colombia experienced a negative rate of change mainly due to a diffused loss of patent shares (negative SH_j). This has not been compensated by a favorable transformation of the structure of their activities.

This analysis of patenting activity in the United States captures some stylized facts. First, for every country, the highest component of Δp_j is SH_j. All the nine countries considered undergo large changes in the *level* of innovative activities independently of world sectoral trends, and these movements largely determine the sign of Δp_j.

It should be underlined that without structural change ($\Delta o_i = 0$), technological performances would have been better for all countries (with the exception of Singapore which considerably improved its patent shares in expanding sectors). In particular, the negative signs of the "structural technology" component indicate that the historical specialization of developing countries in 1985 was in industries that were relatively stagnant throughout the period considered (with the exception of Thailand), and these international trends partly offset generalized national improvements in terms of patenting activities. The negative impact of historical technological specialization is smaller for economies that in the initial year were at an advanced stage in their industrial development path, such as Singapore, for which this value is nearly zero.

The "technology stagnation adaptation" effects are either negative and large or positive and negligible, and reveal the difficulties faced by developing economies in shifting out from activities offering poor technological opportunities. Finally, notice that the "growth adaptation" effect is positive and higher for Asian countries, with China and Singapore on top, and small, often negative, for Latin America.

These findings about the negative impact of the "structural technology" and "stagnation adaptation" effects confirm that, in developing countries, the significant role of mature sectors with slow technical upgrading tends to perpetuate itself. On the other hand, as emphasized by various authors, it seems that targeted policy interventions can overcome these historical disadvantages (Ernst *et al.*, 1998; Kim, 1999; Lall, 1998). In the case of our evidence, the dichotomy between Latin America and Asia is clear. *De facto*, differences in governments' ability to shape industrial development partly explain why China and East Asian Tigers are referred to as "miracles" and recent South-American experiences as "lost decades."

In order to describe the impact of export structures on market share dynamics, we also apply the "structural decomposition analysis" to trade data. Accordingly, the following variables are defined:

X_{ij} = country *j*'s export in sector *i*;

$x_{ij} = X_{ij}/\sum_j X_{ij}$ = export share of country *j* in sector *i*;

$x_j = \sum_i X_{ij}/\sum_i \sum_j X_{ij}$ = aggregate export share of country *j*;

$y_i = \sum_j X_{ij}/\sum_i \sum_j X_{ij}$ = share of sector *i* on the world total of exports.

The change of the aggregate export share of country *j* can be written as

$$\Delta x_j = x_j^t - x_j^{t-1} = MSH_j + MST_j + MGR_j + MSG_j; \quad (3)$$

$MSH_j = \sum_i (\Delta x_{ij} y_i^{t-1})$ is the *market share effect*;

$MST_j = \sum_i (x_{ij}^{t-1} \Delta y_i)$ is the *structural market effect*;

$MGR_j = \sum_i \Delta x_{ij}(\Delta y_i + |\Delta y_i|)/2$ is the *market growth adaptation effect*;

$MSG_j = \sum_i \Delta x_{ij}(\Delta y_i - |\Delta y_i|)/2$ is the *market stagnation adaptation effect.*

As thoroughly explained above, these effects represent, respectively, the change of export shares assuming out changes in the structure of world export (MSH_j); the impact of trade specialization assuming it constant throughout the period (MST_j); the move toward sectors growing above average or out of those that are stagnating at the international level (respectively MGR_j and MSG_j).

Table 4 summarizes the results of this decomposition.

All sample countries, apart from Brazil, increase their share of world trade. However, there are differences in the rates of change, and they are similar to those for patenting activity. In the period 1985–98 South America's performance was poor: Argentina and Colombia stagnated, whereas Brazil's share fell by 34%. China, by contrast improved dramatically, with a growth of nearly 200%. Significant progress was also registered by Thailand, Singapore, Malaysia and Mexico, and, to a smaller extent, India.

As for patents, the largest component is the quantitative increase in market shares, computed by assuming a fixed international sectoral distribution of exports at the initial year. The "structural market" effect shows that historical structures negatively affected performance; where positive, as in Thailand and Singapore, the impact of MST_j is negligible. The "market growth" effects capture a trend toward industries with above average trade potential in East Asia, China, and Mexico. Conversely, MGR_j is close to zero for South America. The negative signs of "market stagnation" indicate some movements into the "wrong" sectors. Finally, the predominance of the "growth" over the "stagnation" component confirms that developing countries increase the differentiation of their exports, reinforcing their specialization in mature industries but more significantly entering dynamic ones.

To conclude, the structural decomposition analysis provides preliminary evidence in favor of the existence of a positive relationship between technological activities and competitiveness. There is a remarkable similarity between the evolution of patent and export shares: China is far ahead in the two rankings, followed by East-Asian economies. Brazil, Argentina, and Colombia lag behind. Moreover, rates of growth in both patent and export shares are

Table 4. *Structural decomposition analysis for world shares of exports*

Country	World export market shares 1985	World export market shares 1998	Total rate of change	Market share effect	Structural market effect	Market growth adaptation effect	Market stagnation adaptation effect
Argentina	0.51%	0.53%	2.86%	19.51%	−6.18%	0.41%	−10.88%
Brazil	1.54%	1.01%	−34.86%	−33.23%	−2.97%	−1.88%	3.23%
China	1.25%	3.63%	190.72%	178.96%	−19.97%	34.59%	−2.86%
Colombia	0.21%	0.22%	1.71%	53.97%	−10.77%	0.59%	−42.07%
India	0.54%	0.65%	19.21%	19.56%	−0.20%	0.94%	−1.09%
Malaysia	0.95%	1.46%	53.43%	33.29%	−2.56%	19.56%	3.15%
Mexico	1.60%	2.35%	47.00%	40.43%	−18.24%	16.65%	8.16%
Singapore	1.29%	2.15%	66.65%	42.13%	2.37%	26.16%	−4.01%
Thailand	0.42%	1.05%	146.63%	117.13%	3.12%	35.23%	−8.85%

Source: Authors' calculation on COMTRADE data.

mostly due to SH_j and MSH_j. In the case of export market shares, although structural effects are negative, which means these countries are penalized by their initial sectoral composition with respect to world developments, countries show a greater ability to transform their economies according to world demand. This is the case in particular for the five Asian countries and Mexico. Since these are also the countries with higher absolute increases in export shares, this raises the issue of the relevance for countries to undergo structural transformations and to what extent technology is a constraining factor.

(b) *The determinants of export market share dynamics*

This section further investigates the relation between technology and trade performance, and regression analysis is used to test for the hypotheses discussed in Section 3. Different econometric models of the determinants of export market shares dynamics are therefore specified to evaluate: the statistical significance of innovative activities and other technological indicators, such as R&D, FDI, technical skills, and productivity trends; the relative importance of the four different technological effects; the differences existing between groups of sectors distinguished by technological intensity.

The dependent variable in our exercises, ΔE_{ij}, represents the contribution of a sector to the overall export performance of country j.[11] From Eqn. (3), we have

$$\Delta x_j = x_j^t - x_j^{t-1} = \sum_i (\Delta E_{ij})$$

with

$$\Delta E_{ij} = \Delta x_{ij} y_i^{t-1} + x_{ij}^{t-1} \Delta y_i + \Delta x_{ij} \Delta y_i.$$

The formulation of this variable allows us to describe the evolution of market shares by taking into account structural change and historical specialization alongside national dynamics. Thus, our meaning of "export performance" is wider than the simple change of shares held by a country (Δx_{ij}). ΔE_{ij} captures the underlying causes of the contribution of sector i to the overall trade results of country j: national and international trends ($\Delta x_{ij}, \Delta y_i$) and historical conditions (y_i^{t-1}, x_{ij}^{t-1}) for each sector.

Similarly,

$$\Delta p_j = p_j^t - p_j^{t-1} = \sum_i (\Delta T_{ij}),$$

where ΔT_{ij} indicates the contribution of sector i to the overall patent share variation of country j. Accordingly, the relationship between technology and trade is captured at the industry level. Since disaggregated sectoral data for the nine countries are available only for patents and exports, the following specification 1 is proposed:

$$\Delta E_{ij} = \alpha + \sum_i \mu_i D_i + \sum_j \sigma_j M_j + \beta \Delta T_{ij} + \varepsilon_{ij}. \tag{S1}$$

with $i = 1, \ldots, 25$ and $j = 1, \ldots, 9$ (225 observations).

D_i and M_j are dummy variables, which control for sectoral and national fixed effects and, in particular, for sectoral and national size effects.

Moreover, we also eliminate the restriction of constant slopes across different groups of sectors. In Sections 2 and 3, we stressed that the characteristics of the specific technological and learning processes affect the relationship between technological investments, innovation, and export market gains according to the technological intensity of sectors. Therefore, we expect variables representing technology to have different relative importance for competitiveness dynamics in different groups of sectors. In particular, following OECD (1986), we distinguish between high-, medium-, and low-tech sectors (HT, MT, LT) and test S1 for high, medium, and low R&D intensity groups of industries.

As shown in Table 5, *Least Squares Dummy Variable* (LSDV) estimated coefficients do not reject the hypothesis that changes in technological activity affect export competitiveness. Moreover, differences in the technological content of sectors affect the relation between the technological variable and export dynamics. In particular, in the high technology sample, the coefficient for patents is significantly different from zero. The opposite occurs in the medium and low technology case, where the estimated β is not significantly different from zero. Specification 1 suggests that if technology has a role to play in enhancing export performance, this is confined to the high-tech sectors. However, we can use the structural decomposition analysis to assess the relative importance of the four different technological effects upon export dynamics.

ΔT_{ij} can be decomposed into the usual four effects at a sectoral level:[12]

Table 5. *Regression results for specification 1: technological activities on export performance (for 25 sectors and nine countries)*

Indep. var.	All sectors	High tech	Medium tech	Low tech
ΔT	3.02*	4.89***	−1	0.45
	(1.65)	(5.49)	(−0.77)	(0.14)
N	225	54	99	72
F	3.18***	7.95***	2.07**	2.8***
R_{sq}	0.40	0.62	0.42	0.54
$F(\mu_i = 0)$	3.01***	5.4***	2.27**	3.43***
$F(\sigma_j = 0)$	4.41***	4.13***	0.78	2.69**

Notes: Test-*t* in parentheses. Heteroskedasticity consistent estimator are used (White estimator), $F(\mu_i = 0)$ and $F(\sigma_j = 0)$ test the hypothesis of joint insignificance of sector and country-specific dummies.
* Significant at the 90% level.
** Significant at the 95% level.
*** Significant at the 99% level.

$$\Delta T_{ij} = SH_{ij} + ST_{ij} + GR_{ij} + SG_{ij};$$

where

$SH_{ij} = \Delta p_{ij} o_i^{t-1}$ technology share effect of sector i;

$ST_{ij} = p_{ij}^{t-1} \Delta o_i$ structural technology effect of sector i;

$GR_{ij} = \Delta p_{ij}(\Delta o_i + |\Delta o_i|)/2$ growth adaptation effect of sector i;

$SG_{ij} = \Delta p_{ij}(\Delta o_i - |\Delta o_i|)/2$ stagnation adaptation effect of sector i.

A second specification which includes the four effects is then put forward.

$$\Delta E_{ij} = \alpha + \sum_i \mu_i D_i + \sum_j \sigma_j M_j + \beta SH_{ij} + \gamma ST_{ij} + \tau GR_{ij} + \delta SG_{ij} + \varepsilon_{ij}. \quad \text{(S2)}$$

The first column of Table 6 presents the *LSDV* estimates. Results are not reported for those regressors that are statistically insignificant in specifications S2 and S3 (see below). Again the estimated coefficients do not reject the hypothesis that improvements in technological activities positively affect trade performance; but this happens only through the "technology growth adaptation" effect. This means that technology is particularly important and generates export gains when a country is able to express innovative improvements in sectors with high levels of technological opportunities. Conversely, whenever a developing country is not able to increase its innovative activity in these sectors, export performance deteriorates.

Table 6 reports estimation results of specification S2 for high-, medium-, and low-tech industries. In each of the three subsamples a distinct measure of patents dynamics is significant to explain trade performance: the "growth," "stagnation," and "structural" components are, respectively, the single important effect for high-, medium-, and low-tech sectors. In high technology industries, the movement into activities offering above average technological opportunity is crucial, not the exit from stagnating ones or the initial patterns of specialization. For the medium-tech subsample, by contrast, the ability to move out of industries losing in terms of relative innovativeness is vital, as this group is mature from a technological point of view, and it is less likely to gain competitive positions by exploiting "frontier" activities with above average growth potential. Finally, in low tech, export competitiveness is due only to minor innovations in traditional sectors, as it is difficult to observe large changes in relative innovative opportunities within this group.

Two additional features of these econometric models have to be emphasized: their explanatory power and the statistical significance of the dummy variables. Even with a simple characterization of technological activities and without the inclusion yet of other possible determinants of competitiveness, our models can account for around half of the variance of export market shares. For the whole sample, the explanatory power is higher when the four technological effects are considered separately. If sectors are divided according to their R&D intensity, strong differences arise. In the case of high-tech industries, the model accounts for nearly two-thirds of the variance of the dependent variable. Dummy variables are included in specifications S1 and S2 to control for sectoral and national fixed effects. The estimation results confirm the existence of important

Table 6. *Regression results for specifications 2 and 3: the determinants of export*

Indep. var.	All sectors S2	All sectors S3	HT S2	HT S3	HT expanded S3	MT S2	MT S3	LT S2	LT S3
ST	9.59	–	−6.4	–	–	17.17	–	52.63***	25.83
	(1.42)	–	(−0.58)	–	–	(1.47)	–	(2.91)	(1.31)
GR	13.38***	12.07***	12.17***	10.99***	12.11***	−9.73	–	102.06	–
	(3.85)	(3.38)	(5.57)	(3.76)	(3.64)	(−1.07)	–	(0.48)	–
SG	9.41	–	12.11	–	–	16**	18.75**	2.6	–
	(1.16)	–	(0.17)	–	–	(2.08)	(2.15)	(0.31)	–
MVA'		0.00021***		0.00038***	0.0002***		−0.00009		0.0002*
		(3.49)		(2.90)	(3.66)		(1.19)		(1.74)
FDI'		0.00005***		0.000032*	0.00003***		0.0002*		0.00009**
		(3.31)		(1.93)	(3.66)		(1.72)		(2.06)
TTE'		0.00082***		0.1**	0.0007**		0.00013		0.0011*
		(3.09)		(2.19)	(2.62)		(0.49)		(1.67)
TTE^{t-1}		0.099***		0.138*	0.1**		−0.0003		0.136*
		(2.80)		(1.94)	(2.33)		(−0.08)		(1.72)
N	225	225	54	54	99	99	99	72	72
F	4.27***	3.29***	7.66***	5.78***	4.58***	4.34**	3.22**	8.47***	2.10*
R_{sq}	0.48	0.45	0.64	0.56	0.56	0.09	0.13	0.11	0.13
$F(\mu_i = 0)$	2.7***	2.45***	4.47***	5.81***	2.20**	1.66	2.17	2.35**	1.93
$F(\sigma_i = 0)$	3.27***		4.02***			1.24		2.36**	

Notes: Test-*t* in parentheses. Heteroskedasticity consistent estimator are used (White estimator). $F(\mu_i = 0)$ and $F(\sigma_i = 0)$ test the hypothesis of joint significance of sectoral and country dummies.

* Significant at the 90% level.

** Significant at the 95% level.

*** Significant at the 99% level.

country and industry specificities in the dynamic relationship between technology and export performance.[13]

As emphasized in Sections 2 and 3, in the case of developing countries, it is important to test whether export dynamics is significantly affected by another set of relevant variables. Firstly, production efficiency and productivity are important factors which affect unit costs and quality. Secondly, variables such as the quality of the skill base, R&D activities, and foreign direct investments by TNCs, enhance technological transfer and sustain the construction of technological expertise and absorptive capacity.

A third model is then proposed which brings in the different components of the technological effect and extends the analysis of the determinants of export dynamics including the set of variables discussed above. These variables are only available aggregated at the country level:

MVA_j = manufacturing value added in real terms per capita;
FDI_j = FDI inflows divided by GDP_j;
$R\&D_j$ = private R&D expenditure divided by GDP_j;
TTE_j = tertiary enrolments in technical sub jects per capita.

National indicators also replace national dummy variables and control for fixed effects.[14] Specification 3 is then the following:

$$\begin{aligned}\Delta E_{ij} =& \alpha + \sum_i \mu_i D_i + \beta SH_{ij} + \gamma ST_{ij} + \tau GR_{ij} \\ &+ \delta SG_{ij} + \phi MVA'_j + \eta FDI'_j + \varphi R\&D'_j \\ &+ \chi TTE'_j + \lambda MVA_j^{t-1} + \nu FDI_j^{t-1} \\ &+ \theta R\&D_j^{t-1} + \rho TTE_j^{t-1} + \varepsilon_{ij}. \qquad \text{(S3)}\end{aligned}$$

Since the focus here is on the dynamic relationship between technology and competitiveness, the growth rates of the four variables are computed (indexed with a "′"). In addition, also their values at the beginning of the period of interest ($t-1$) are included in the analysis, to control for the assumption that export performance is also affected by the absolute levels of technical capabilities, FDI, R&D intensity, and productivity.[15] Moreover, a descriptive analysis of the variables shows that $R\&D'$ has got two outliers for Argentina and China and that for the other countries is highly correlated with TTE' (0.8). Therefore, we decided to drop the $R\&D'$ variable from the regressions. Moreover, it can be claimed that at this level of aggregation, part of the effect of R&D is caught by the technological variables and that, as the collinearity shows, the research intensity may also be proxied by the change in skill intensity that is the tertiary enrolments in technical subjects per capita.[16]

The second column of Table 6 shows that the previous result is robust with respect to the new specification. The "technology growth adaptation" effect is the only component of the overall process of technological change affecting trade dynamics.[17] Moreover, the other variables included in the analysis have the expected positive impact on export market shares. The estimated coefficients for the rate of growth of *MVA*, *FDI*, and *TTE* and the initial value of *TTE* are significantly different from zero. Altogether, this accounts for almost half of the total variation in the dependent variable.

A larger role of TNCs can enhance technology transfer, knowledge diffusion, and access to international markets. Similarly, a progress in capabilities can increase the ability of firms to export successfully. *TTE* is the only variable for which the initial level has full and independent explanatory power. But strong inputs of technological activities, such as skills or FDI, do not necessarily give good results in the case of poor coordination and ineffective interactions between the agents involved. Therefore, manufacturing value added, as the ultimate outcome produced by an economy, controls for its actual efficiency and has a positive impact on competitiveness.

The final step of the analysis is to relax the restriction that coefficients are the same across sectors and to estimate S3 for high, medium, and low R&D intensity groups of industries (HT, MT, LT). Our results confirm that the technological intensity of sectors affects the relevance of different variables for export dynamics. In two out of the three subsamples, we confirm the results of specification 2. In high technology industries, the movement into activities offering above average technological opportunity is the key factor to achieve market share gains. For the medium-tech sample, by contrast, only the stagnation adaptation effect is important, that is the ability to move out of industries losing in terms of relative innovativeness. In the low-tech group, the growth of technological opportunities in sectors that are traditionally relevant for the economy maintains a positive sign but cannot be considered significantly different from zero. With respect to the other variables, the estimates for high-tech and low-tech industries are similar to those reported for the full sample. Value added, skill base, and FDI appear to have a statistically significant impact on export share changes. Finally, in the medium-tech group, only the rate of growth of FDI' appears to have an impact significantly different from zero.

The OECD classification in terms of Low Tech, Medium Tech, and High Tech has been criticized because it is based only on formal R&D. However, there are other sectors where the formal R&D is not high, in particular in the developing countries, but nevertheless there are high levels of technological opportunities. [18] These sectors include a great portion of Machine tools and Mechanicals. Therefore, we create a new aggregate (*HT expanded*) including the following high opportunity sectors: Manufacturing, assembling, metal working–Motors, engines, pumps–Rotary machines and mechanical power–Machining and cutting. The results of the regression, displayed in Table 6, confirm the previous results. Therefore, in all high opportunity sectors with both formal and informal R&D, there is a significant role of the technology growth effect. Only the size of the estimated coefficient of the change in the skill structure is lower, as expected.

Two other important differences between the three groups have to be emphasized. The level of the "R^2" is particularly high in the case of high-tech and low for medium-tech industries. The statistical significance of the sectoral dummies indicates that if we consider specification S3, technological advanced sectors display individual heterogeneity even within themselves, whereas medium- and low-tech sectors are more homogeneous in terms of factors affecting market share dynamics.

6. CONCLUSIONS

This paper addresses the issue of the relationship between technological performance and export growth at the country and sectoral level. It shows that structural change (i.e., a modification of the sectoral composition of the economy in technological and trade activities) is an important characteristic of modern economies and importantly affects the trajectories of growth of developing countries. In particular, Asian countries such as China, Malaysia, Singapore, and Thailand display a high level of innovativeness and technological complexity and, at the same time, improve significantly their overall importance in world export. Such advancements in technological and export performance go along with a significant structural change in the economy. Conversely, South American countries experience small shifts in the sectoral composition of export and stagnant export performance.

Taking these stylized facts as a point of departure, this paper explores the relationship between technological activity and export performance during 1985–98 for nine large developing countries and 25 primary and secondary sectors. Our results support the idea that there are different specific ways in which technological activity can enhance or constrain export performance. In particular, we jointly explore whether inherited technological specialization, national and international structural changes, foreign direct investments, skills, R&D, and productivity gains affect world shares in export markets.

Structural decomposition analysis shows that developing countries tend to concentrate their innovative activities in industries which are technologically stagnant at the world level throughout the period considered. These international trends partly offset generalized national improvements in terms of patent shares. This negative impact acts through different channels: the inherited patterns of technological specialization, the difficulties of shifting out from activities offering poor technological opportunities and of entering dynamic sectors. The experience of Asian countries though, with China and Singapore on top, shows that a shift toward industries where technological opportunities are increasing can overcome historical disadvantages.

A similar picture emerges for world export shares, although countries display a greater adaptation to world demand. There is a remarkable correspondence between the evolution of patent and export shares: China is far ahead in the two rankings, followed by East-Asian economies. Brazil, Argentina, and Colombia lag behind. Also, in the case of export market shares, we observe negative structural effects (with the exception of Thailand and Singapore).

The econometric analysis, through different specifications, confirms that technological advancements partly explain export performance. We show that the characteristics of the specific technological and learning processes affect the relationship between technological investments, innovation, and export market gains according to the technological intensity of sectors. In particular, technological activity generates export gains, in high technology sectors if a country expands its innovative activities in industries with increasing levels of technological opportunities; in medium technology moving out of low opportunity sectors; in low technology if it is specialized, in the initial year, in sectors with a greater growth of their world share.

Finally, we test these structural effects in a more general reduced form which includes R&D effort, level of technological capabilities provided by educational institutions, role of TNCs, and productivity trends. Previous results hold and our evidence suggests that in high-tech and low-tech sectors, export performance is also affected by the growth of technical capabilities, foreign direct investments, productivity, and the initial level of technical skills; in medium tech by the growth rates of foreign direct investments.

Altogether, the empirical findings of this paper suggest that low levels of competitiveness can be overcome in developing countries and that technological upgrading of firms can play a crucial role, especially when targeted toward industries growing above average worldwide. Policy reforms directed at solving the shortcomings in educational and technical training institutions and in productive efficiency, and a commitment to enhance the beneficial effects of TNCs would improve the level of technological capabilities and, consequently, the competitive position of exports. This paper also suggests that structural changes in terms of innovative activity—both in terms of entry in expanding sector and exit from low opportunity ones—are a major channel through which technological capabilities are translated into export performance.

NOTES

1. Structural change is defined as a modification of the sectoral composition of the economy. In particular, in this paper, we consider structural changes in technological and trade activities.

2. Growth rates of sectoral export and patent shares in Table 1 have a correlation of 0.7 at the 99% significance level.

3. This is a highly debated issue both on the theoretical ground and empirical estimation strategies (e.g., Krugman, 1989; Marquez & McNeilly, 1988).

4. Stringent data constraints limit the analysis in terms of level of sectoral aggregation and amount of countries considered; however, the commodity composition of the economies is one of the main determinants of export and import elasticities.

5. Krugman (1995) and Chui, Levine, Mansoob Murshed, and Pearlman (2002) survey this literature.

6. This approach belongs nowadays to the endogenous growth framework. However, before the development of the literature on endogenous growth, "new trade theory" was used to indicate models of international trade allowing for imperfect competition.

7. The term "Sectoral world market share dynamics" refers to the changes within each sector of countries' shares of world export.

8. The analysis of the processes of technology choice and transfer in developing countries received new impetus from the "capability approach" which emphasizes the role of incremental learning and mastering of tacit knowledge for technological upgrading (Lall, 1992).

9. The first year of trade data for Mexico is 1986.

10. Our table highlights the rate of change instead of the simple change of shares. Therefore, values reported for the four technological effects are obtained by dividing SH_j, ST_j, GR_j, and SG_j by p_j^{t-1}. The same holds for exports in Table 4.

11. The design of this variable is analogous to another measure often used in the literature on the dynamics of international trade (see Amendola *et al.*, 1998, chap. 7), the "contribution to the trade balance":

$$CBT_{ij} = \frac{X_{ij} - M_{ij}}{\left(\sum_i X_{ij} + \sum_i M_{ij}\right)/2} \times 100 - \frac{\sum_i X_{ij} - \sum_i M_{ij}}{\left(\sum_i X_{ij} + \sum_i M_{ij}\right)/2} \times \frac{X_{ij} + M_{ij}}{\left(\sum_i X_{ij} + \sum_i M_{ij}\right)} \times 100.$$

12. Such technological effects when added up across sectors correspond to the aggregate technological effects at the country level described in Sections 4 and 5(a).

13. This is true for every regression, with the exception of the sample of medium technology sectors: The hypothesis of heterogeneity across industries is accepted in specification S1 and rejected in specification S2, whereas heterogeneity across countries is always rejected. Tables 5 and 6 present the F test on statistical significance of the dummies. Estimated coefficients are not reported.

14. The inclusion of both sectorally invariant variables and national dummies would bias the estimates because of the problem of multicollinearity between these two set of regressors.

15. Following the suggestion of a referee we have also calculated the rate of growth of the productivity levels relative to the United States values (see Appendix A for details). In all the specifications, the estimated coefficient was never significantly different from zero.

16. We have controlled the results also for the impact of the change in unit labor costs (ULC) following Amendola *et al.* (1998), chap. 7. Due to data constraints, we have the data only for a selected number of countries and for a limited set of sectors (see the Appendix A for details). The change in ULC (ULC′) in the period 1985–98 is generally negative except from Mexico. The change in ULC is generally higher for low-tech sectors where their initial level was particularly low at the beginning of the period. It is correlated negatively with the change in FDIs and positively with the initial level of tertiary enrolments in technical subjects. This also introduces multicollinearity in the regressions affecting the precision of the estimates. As explained in Appendix A, we have to introduce this variable in the dataset as an aggregate for High-Tech, Medium-Tech, and Low-Tech groups. Therefore, we added this variable to specification S3, the coefficients were not statistically significant, and the sign and the significance of the technological variables were not affected. Only in (S3), for the high-tech sectors, ULC' has been found to be positive and significantly different from zero (the value of the estimated coefficient is 0.005***) without changes in size and significance of the other coefficients.

17. This finding that only the "technology growth adaptation effect" is statistically significant to explain trade performance is consistent with the results for a group of OECD countries in Laursen (1999).

18. We thank a referee for pointing this out.

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APPENDIX A

(A.1) *Sectoral disaggregated data and concordance tables*

Patents granted by the USPTO are classified into 410 technological classes according to the "USPC." We use a particular level of aggregation suitable to the objectives of this paper which groups these classes into 25 industries, as presented in the "Technology Assessment and Forecast Report" of the USPTO (available at http://www.uspto.gov/go/taf/brochure.htm). Trade data (expressed in current dollars) are from the United Nations COMTRADE database and are classified according to the "Standard International Trade Classification, revision 2" at the disaggregation level of 3-digit. Therefore, in order to match export and patent observations, we have built a concordance table to assign SITC sectors to the 25 industries considered here.

The choice of analyzing the impact of technological activities on competitiveness at the aggregation level of 25 sectors is driven by two considerations. On the one hand, as emphasized in this paper, the relation of interest displays important sector-specific characteristics. As a consequence, it would be more accurate to assess whether technological progress translates into export success at the finest sectoral level available. On the other hand, there is no one-to-one relationship between goods exported by firms, generally identified with few sectors (core-business), and techniques involved in production, belonging to different technologies and innovative areas. Therefore, high levels of disaggregation would possibly bring to statistical inconsistencies in the analysis of the impact of technology on trade. Thus, the concordance table established to match export and patent data into 25 groups represents a reasonable compromise.

Given the different nature of SITC and USPC classifications, it is not possible to assign directly each export sector to one of the 25 technological classes. It is instead necessary to verify the correspondence between 3-digit SITC sectors and the 410 USPC classes, in turn grouped into the 25 industries used in this paper. We associate firstly SITC sectors to classes of the "Standard Industrial Code" (through concordance tables, courtesy of Pamela Lowery, Illinois Weslayan University), and then the latter to those of the USPC (using the "Concordance Between the USPC System and the SIC System" of the USPTO).

The 25 industries are also ordered into three groups of different technological intensity, as defined by OECD (1986) which assigns sectors classified by the "International Standard Industrial Classification" to the "high-," "medium-," or "low-tech" category. To do this, we use concordance tables between SITC Rev.2 and ISIC Rev.2 (Maskus, 1989).

Table 7 describes the correspondence between the various classifications used for the empirical analysis. The first column presents the original definitions of the 25 industries considered, following the "Technology Assessment and Forecast Report." The other columns report the associated sectors of the SITC and ISIC classifications and their technological intensity.

(A.2) *Productivity, skills, foreign direct investment, and research and development*

These variables are used in specification S3 to represent determinants of exports other than patenting activities. Data are aggregated at the country level.

MVA, *FDI*, and *R&D* are expressed in current dollars. MVA_j is computed by dividing the total manufacturing value added of country j by its population. FDI_j is the total direct investment inflows received by country j from foreign firms, divided by the country's GDP. $R\&D_j$ is the research & development expenditure financed by productive enterprises of country j, divided by the country's GDP. TTE_j is the number of tertiary enrolments in technical subjects in country j divided by its population.

These variables are expressed as a percentage of the population or as a percentage of the GDP to control for size effects in the statistical exercises.

Moreover, given the importance of considering cross-country productivity measures relative to a frontier value of productivity, the manufacturing value added variable is also modified and included in the regression analysis under specification 3 (S3) in a second format. The rate of growth of *MVA* is accordingly computed by taking the rate of change of the difference in the levels of productivity between the sample countries and the United States (assumed to be the "productivity frontier") in 1985 and 1998.

Data come from the UNIDO Scoreboard Database which uses miscellaneous statistics from National Account Statistics of the UNSD (for MVA), World Bank and UNCTAD (for FDI), UNESCO (for R&D and TTE).

Table 8 presents a correlation matrix for the variables that are statistically significant in specification S3. The pairwise correlation coefficients show no problem of multicollinearity between our regressors. Only three of them display a significant correlation of 0.4 or more, and the highest value (−0.69 between TTE' and TTE^{t-1}) is easily explained by the fact that countries lagging behind in the initial year in terms of skill endowments grew faster than the others.

Table 7

Technological classes for patents—*USPTO classification*	Export sectors—*SITC Rev.2*	Groups for R&D—*ISIC Rev.2*	Technological intensity—*OECD definition*
Computing and data processing	75	3825	High
Electronics and components classes	776,778	3832	High
Optics–radiant energy–photography	88	385	High
Communications and networking	76	3832	High
Other science and engineering, measurement, nuclear	871,873,874	385	High
Biochemistry	592,54	3522	High
Electricity and electric power	35, 771, 772, 773, 774, 775	383-3832	Medium
Chemical engineering	591,32,33,34,522, 531,532,554	351 + 352-3522	Medium
Organic chemistry	233,51,58,28,43, 524,551,553,56	351 + 352-3522	Medium
Surgery–body care–cosmetics	872,667,897	390	Medium
Materials–compositions–explosives	57,598,95,523,533, 661,662,663,688	351 + 352-3522, part of 381	Medium
Material or article handling	744,745,749	3829	Medium
Heating–cooling–buildings–fluid/gas handling	691,697,741,81	3829	Medium
Earthworking and civil engineering	723	382-3829-3825	Medium
Vehicles and transportation	722,78,79,625	3843	Medium
Motors–engines–pumps	71,743	382-3829-3825	Medium
Rotary machines and mechanical power	742	382-3829-3825	Medium
Music–education–games	642, 892, 893, 894, 896, 898	342, part of 3909 + 3902	Low
Agriculture and farming	00,01,02,03,04,05, 06,07,08,09,11,12, 21,22,29,232,42, 721,727,27,41	31	Low
Office devices–paper handling–coatings	725,726,25,641,895	341	Low
Textiles and apparel	26,65,61,724,84,85	32	Low
Tools–hardware–pipes–joints	695,628,677,678, 679,684,685,686, 687,689, 693	37, 381	Low
Receptacles–containers–supports–partitions–furniture	692,83,621,82	381,332,32	Low
Manufacturing–assembling–metal working	694,699,73,664, 665,666,671,672,673, 674,675,676,681,682,683	37,36,381	Low
Machining and cutting	696,728,24,63	331, 341, 381	Low

(A.3) *Unit labor costs*

Unit labor costs measure the cost of labor per unit of value added. We used the UNIDO Industrial Statistics Database which contains data on industries classified at the 4-digit level of ISIC (Revision 2). Argentina, Brazil, and China have an insufficient number of observations on different industries and years to be included in the empirical analysis. The remaining countries conversely are satisfactorily covered in the UNIDO Database. Nonetheless, the available years for the three variables used to compute ULC (Employment, Wages and salaries, and Value added) are different for the different economies considered: Colombia 1985–98, India 1985–97, Malaysia 1985–97, Mexico 1987–94, Singapore 1985–94, Thailand 1986–94.

Table 8. *Correlation matrix for significant regressors of specification S3 (n = 225)*

	ST	*GR*	*SG*	*MVA′*	*FDI′*	*R&D′*	*TTE′*	TTE^{t-1}
ST	1							
GR	0.04	1						
	(0.51)							
SG	−0.05	0.05	1					
	(0.42)	(0.49)						
MVA′	0.13*	0.17**	−0.12*	1				
	(0.05)	(0.01)	(0.07)					
FDI′	0.01	0.03	−0.15**	−0.15**	1			
	(0.94)	(0.68)	(0.03)	(0.02)				
R&D′	0.07	0.01	−0.10	0.04*	0.49***	1		
	(0.27)	(0.89)	(0.12)	(0.05)	(0.00)			
TTE′	0.02	−0.11	0.02	0.02	−0.13*	−0.02	1	
	(0.73)	(0.10)	(0.71)	(0.78)	(0.05)	(0.78)		
TTE^{t-1}	0.03	0.08	0.09	0.02	−0.4***	−0.01	−0.69***	1
	(0.61)	(0.22)	(0.20)	(0.76)	(0.00)	(0.86)	(0.00)	

Notes: Test-*t* in parentheses.
* Significant at the 90% level.
** Significant at the 95% level.
*** Significant at the 99% level.

Given the different nature of ISIC, SITC, and USPC classifications, it is not possible to assign directly each industry in the UNIDO Database to one of the 25 technological classes representing the export and technological variables used in the empirical exercises at the disaggregated sectoral level. It is instead necessary to aggregate the ISIC sectors into the three groups of different technological intensities, as defined by OECD (1986). In order to do this, the same correspondence presented in Table 7 between 3-digit SITC sectors, the 25 groups of USPC technological classes and the "high-," "medium-," or "low-tech" categories is utilized. Therefore, for each of the six countries considered in the analysis, ULC is calculated for high-, medium-, and low-tech industries.