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Determinants of frontier innovation and technology adoption: cross-country evidence

Emil Gelebo, Alexander Plekhanov and Florent Silve

Summary

Most conventional macroeconomic measures of innovation, such as research and development (R&D) spending or patenting, focus on frontier innovation in contrast to the adoption and adaptation of existing technologies. To capture technology adoption at the country level, this paper exploits a novel measure of innovation based on the innovation intensity of a country's exports. While broadly similar factors influence patenting and innovation intensity of exports, important nuances emerge. While higher patenting is mainly associated with higher per capita income, better education and a higher degree of financial development, innovation intensity of exports appears to be more closely linked to the size and openness of the economy and the lack of natural resource rents. While higher levels of R&D spending by both businesses and governments are associated with higher patent output, only business R&D appears to be positively linked to a more innovation-intensive structure of exports.

Keywords: innovation, technology adoption, exports

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Contact details: Alexander Plekhanov, European Bank for Reconstruction and Development, One Exchange Square, London, EC2A 2JN, UK. Email: plekhana@ebrd.com.

Emil Gelebo is at the London School of Economics; Alexander Plekhanov and Florent Silve are at the European Bank for Reconstruction and Development

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1. Introduction

Why are some economies more successful at innovating than others? This question has long preoccupied policy-makers as virtually every country's development policy puts an emphasis on innovation. There is a broad consensus that innovation relies on availability of skills, on a high degree of economic openness, R&D inputs, supportive business environment and policies that nurture creativity (see, for example, Furman et al., 2002).

At the same time, a more nuanced answer to this question may depend on what is understood by innovativeness of an economy. Innovation is typically identified with ground-breaking technologies, new ideas that move the global technological frontier. However, firms constantly work to improve their products and introduce new ones, even though few of these newly launched products are truly new on a global scale. A recent detailed survey of innovation (the fifth round of Business Environment and Enterprise Performance Survey with an innovation module) suggests that only around 4 per cent of new products introduced by firms in emerging Europe and Central Asia are new to the global market (in Israel, an advanced economy close to the technological frontier, this share is around half – see EBRD, 2014).

Most new products result from the adoption of existing technologies developed elsewhere, which may be customised by firms to better serve the needs of the local market. Even though these innovations do not push the global technology frontier they can significantly improve productivity of the firm that implements them and thus contribute to improvements in aggregate productivity.

This paper offers a novel measure of innovativeness of an economy aimed at capturing and emphasising the technology adoption angle. This measure combines data on patent intensity of various industries based on the US data with time series data on structures of country exports. Essentially, the measure reflects patent intensity of a representative export product of a country.

Measured this way, the level of innovation intensity of exports of emerging Asia – relative to the world's average innovation intensity of exports – has been rising fast while the level of innovation intensity of advanced countries' exports has been declining somewhat relative to the world average – reflecting increasing fragmentation of supply chains.

The paper then analyses the determinants of innovation intensity of exports in a large sample of countries. Its main contribution is to contrast the determinants of innovation intensity of exports and those of patent output per worker, a commonly used measure of frontier innovation.

While both measures have a number of common determinants, such as high quality of economic institutions, the analysis reveals important nuances. While patent intensity is correlated with national wealth, average level of education and financial development, innovation intensity of exports is linked most closely to population size and trade and financial openness. Natural resource rents do not have a significant effect on patenting, but they exhibit a strong negative relationship with innovation intensity of exports. In terms of innovation inputs, patent intensity is positively linked to both government and business R&D spending, but only business R&D appears to be related to higher innovation intensity of exports. The results hold important lessons for the tailoring of innovation policies to create an environment that is conducive to the type of innovation that is suitable to a country's development stage (see Hoekman et al. (2005) for examples of how innovation policy objectives and strategies can correspond to different country typologies).

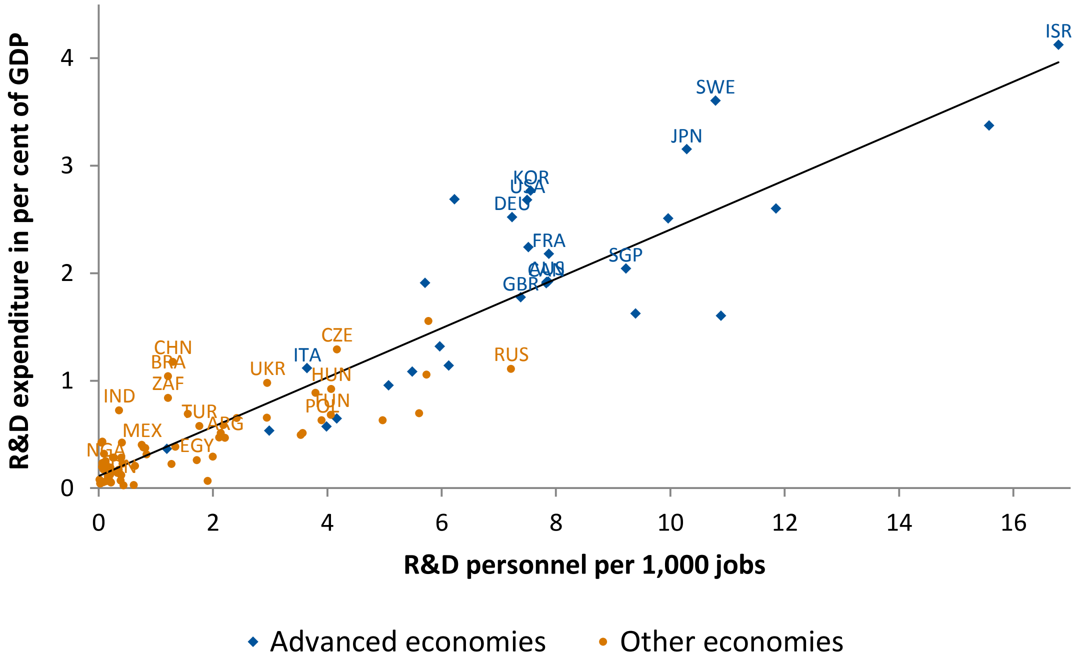
This paper is organised as follows: section 2 provides a brief review of measures of innovation at the country level, introduces innovation intensity of exports as a complement and examines how the innovation intensity of selected countries has performed over the last two decades. Section 3 discusses potential determinants of innovation in a cross-country context. Section 4 presents the results of cross-country analysis of determinants of innovativeness of economies, measured both in terms of patent output per worker and in terms of innovation intensity of exports. Section 5 concludes.

2. Measuring innovation at the country level

2.1. Measures of frontier innovation: patent output and R&D spending

A common approach to measuring innovation inputs is to look at research and development (R&D) personnel or R&D spending in an economy. These measures generally paint a similar picture, although with some nuances (for instance, both Russia and China spend a similar proportion of their GDP on R&D, around 1 per cent, yet R&D personnel as a share of total employment is several times higher in Russia than in China, Chart 1). By and large, R&D activity in developing economies remains much more limited than in advanced economies.

Chart 1: R&D personnel and expenditure

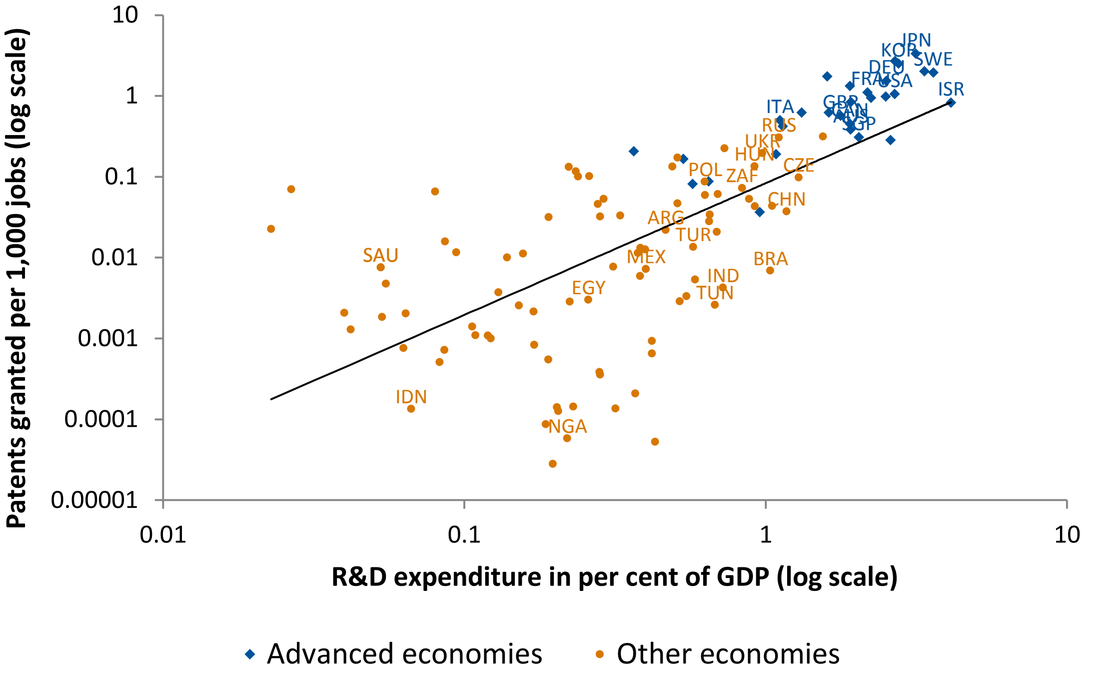


Source: UNESCO.

How effective R&D spending is and how productive R&D employees are may depend on various other inputs that are typically associated with higher innovation potential, such as the quality of human capital or the quality of legal frameworks for innovation. For instance, even though a positive relationship exists between R&D expenditure and the number of patents held by firms or individuals from a given country – a common measure of frontier innovation output – this relationship is far from perfect (Chart 2).[1] It is stronger for advanced markets but weaker in developing countries where the levels of R&D spending and patenting are generally lower. Many large emerging markets, including Brazil, China and India, patent little relative to their levels of R&D spending, let alone the size of their economies.

[1] Patents are counted depending on the country of origin of the patent holder rather than the jurisdiction where they are granted. For instance, a patent awarded by the US Patent Office to a Slovak firm is counted towards the patent output of the Slovak Republic.

Chart 2: Patents and R&D spending



Sources: UNESCO, WIPO.
Note: Logarithmic scales, averages over the period 1996-2011.

These differences are partly explained by the fact that patenting is a narrow measure that captures a limited range of innovations. Not all innovations are patented, and the propensity to apply for patents crucially depends on the legal system and local practices as well as on the sectors in which economies specialise (see, for instance, Cohen, Nelson and Walsh (2000) and Moser (2013)). Moreover, the extent to which patents are converted to commercialised innovation also varies across countries. Further, not all patents are equal: some may correspond to trivial modifications of existing products (incremental innovation); whereas others may cover break-through technologies like laser (radical innovation).

Nonetheless, patents provide a useful consistent measure of innovation across countries used, with various modifications, in a large number of studies (for example, Hall, Griliches and Hausman (1986); Hall, Jaffe and Trajtenberg, 2000, 2001).

2.2. Innovation intensity of exports

Patent output, R&D spending and related measures of innovation focus primarily on innovation at the technological frontier and do not necessarily capture adoption of existing technologies by firms. At the same time, technology adoption is particularly important for emerging markets and developing economies, where the potential for catching up with the technology frontier is especially high (see, for instance, Kravtsova and Radosevic (2012) for evidence for eastern Europe). And even in advanced economies, adoption of technologies developed elsewhere makes an important contribution to productivity growth (Eaton and Kortum (1996)).

To obtain a broader measure of economies' innovativeness that takes technology adoption into account, common measures of frontier innovation can be combined with measures of sophistication of economic output, for instance measures based on a country's export mix (see, for instance, Hausmann and Klinger, 2007, for analysis of export complexity). The measure is constructed as follows. First, various industries are characterised in terms of their innovation content. Second, countries are characterised by average of innovation intensity of their export industries, weighted by the volume of exports. While this measure is rooted in patent output data, it in fact captures what countries produce competitively rather than what they patent. It is also insightful as a more sophisticated structure of countries' exports is generally associated with better long-term growth prospects (see, for instance, Hausmann, Hwang and Rodrik, 2007).

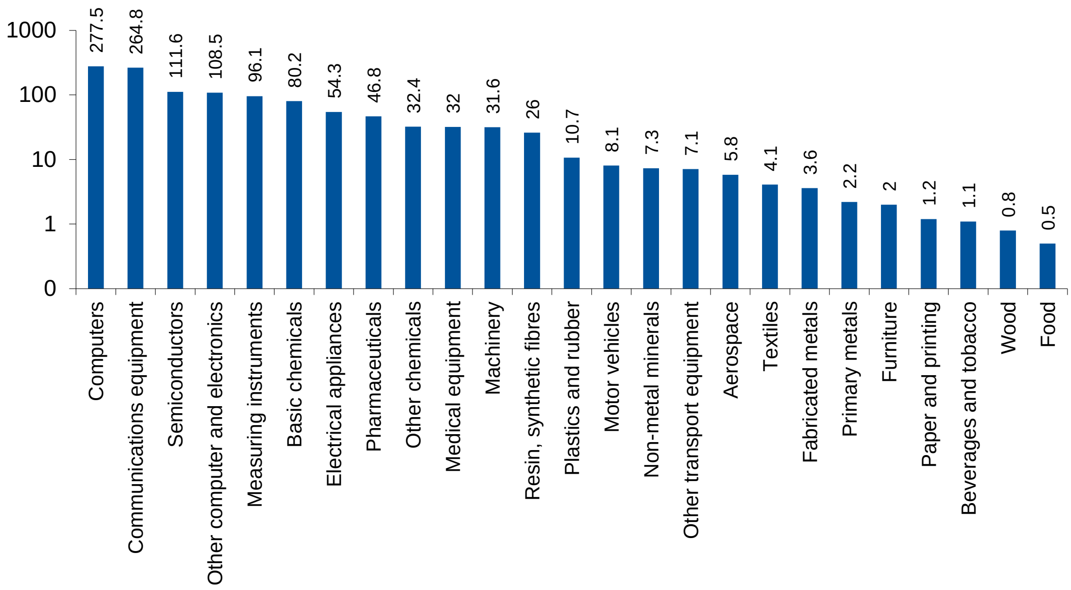
The intrinsic "innovation intensity" of various industries can be measured using data on patent applications per worker in these industries in the United States. Patent intensities do not perfectly reflect the amount of innovation in various industries (incentives to submit patent applications may vary across industries), but on balance patent intensities provide a reasonable approximation of the role of innovation across different sectors based on observable data. On average, firms in industries that patent more tend to introduce new products more frequently, and the life span of these products tends to be shorter, prompting firms to continuously innovate.[2]

The United States is chosen as a reference point as the largest consumer market (giving strong incentives to patent) as well as the world leader in R&D. This makes it easier for each industry to fully realise its innovation potential in the United States. Since patent intensities of industries are measured based on US data, the estimates are not affected by differences in legal systems or culture. Lower patent outputs of the same industries in other jurisdictions thus reflect a combination of lower incentives to patent and a less supportive innovation environment.

Unsurprisingly, computing equipment, communication equipment, chemicals and pharmaceuticals are among the most innovation-intensive industries, while textiles, food and beverages and wood processing are among the least innovation-intensive (Chart 3).

[2] Evidence from firm-level surveys is consistent with this, see, for instance, EBRD (2014).

Chart 3: Innovation intensity of industries



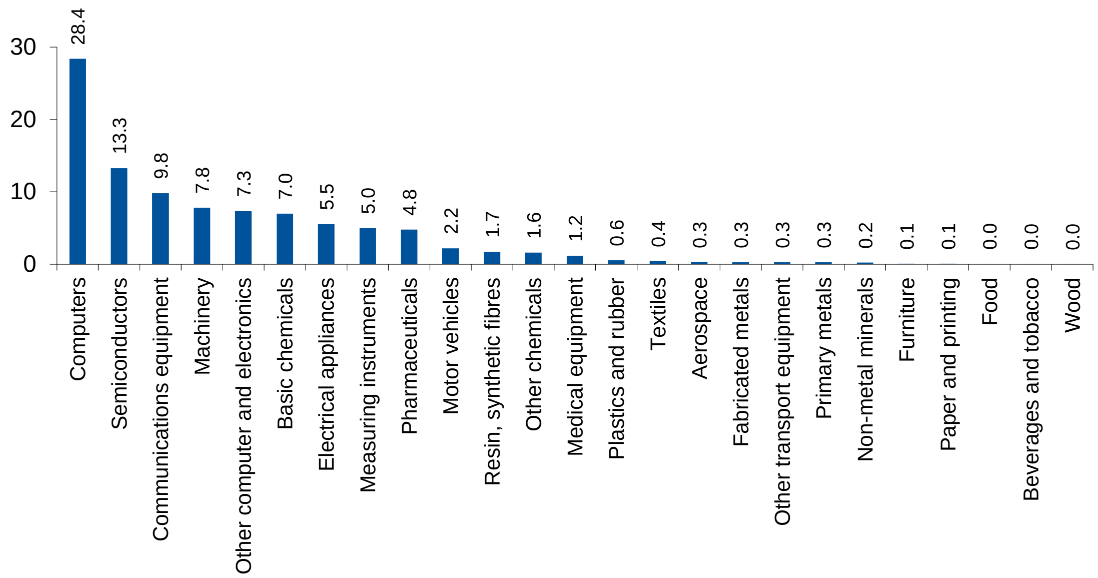
Sources: USPTO.
Note: Based on 2004-08 averages, logarithmic scale. The values correspond to the number of patents per 1,000 jobs in the United States.

The measure reflects innovation potential of different industries (based on the experience in the United States) rather than realised innovation in these industries in different countries. Indeed, emerging market firms producing in innovation-intensive industries are not necessarily directly involved in frontier innovation in these industries. However, the nature of these sectors suggests that emerging market exporters in these industries will tend to roll out new products more often.

Production of innovation-intensive goods may, in some instances, be limited to assembly without complex processing and may not entail major spillovers in terms of knowledge and innovation. At the same time, by participating in global value chains in these industries, firms tend to develop skills and expertise that over time enable them to move up the value added chain and produce original innovation (Hwang, 2007). One example of how this transformation may occur is manufacturing of telecommunications equipment in China. While foreign direct investment played a key role in promoting technology adoption in this sector in China, over the years Huawei, a local firm, has become a major multinational player and one of the world leaders in the industry. Likewise, new or modernised industries tend to catalyse development of local supply chains. For instance, top-tier automotive parts suppliers in emerging markets can reach quality close to international best practice (see Sutton (2005) for evidence for China).

The estimates of innovation intensities of individual industries can then be used to characterise the export product mix of countries and that of global trade. If one looks at the innovation intensity of total world exports, major contributions come not only from the sectors with the highest innovation intensity but also from key manufacturing sectors such as machinery and motor vehicles (Chart 4) – sectors that have medium innovation intensity but contribute a lot to global trade. Thus the latter products also play an important role in defining overall innovation intensity of a country's exports.

Chart 4: Contribution of various industries to innovation intensity of world exports, in per cent of total



Sources: USPTO, UN Comtrade, Feenstra et al. (2005) and authors' calculations.
Note: Based on 2012 trade flow data. Contributions add up to 100 per cent.

Analysis of exports has its limitations – in particular, comprehensive data are only available for the structure of merchandise exports leaving out services (from call centres to IT consulting), which are becoming increasingly innovation-intensive. On the other hand, looking at exports rather than the total output of an industry has the advantage of picking up goods that are competitive in international markets and thus are more likely to be closer to the innovation frontier.

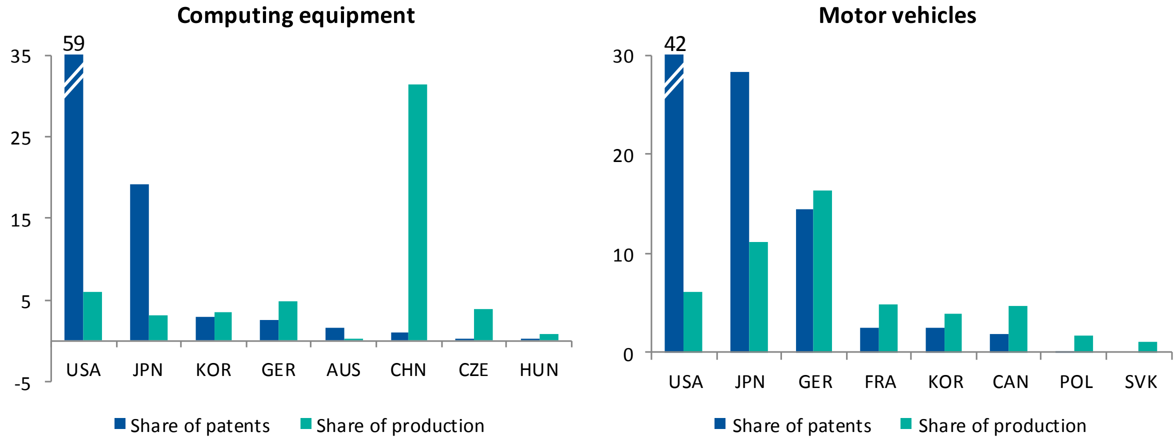
Further adjustments to data are needed to account for price movements in particular industries: in particular, prices tend to fall in innovation-intensive industries relative to less innovation-intensive ones as innovation boosts productivity and reduces production costs. Export values are thus expressed in base year prices using the United States export deflators.[3]

Finally, the innovation intensity of an economy's exports is expressed in per cent of the innovation intensity of the global economy (based on the evolving product mix of the world's total trade). An innovation intensity score above 100 means that an economy's exports are more innovation-intensive than global exports.

The resulting innovation intensity measure puts an emphasis on technology adoption and is distinct from patent-based measures of innovation. Certain countries may do well at adopting technologies without making a major contribution to developing them. In fact, within the most innovation-intensive industries, such as computer equipment, countries that account for a large share of the world's patents are often different from countries that account for a large share of international trade (Chart 5), even though in other industries, for instance vehicle manufacturing, contributions to patenting and exports are broadly aligned.

[3] Country-specific deflators are not available. US deflators are used as approximation since exporters face similar trends in prices.

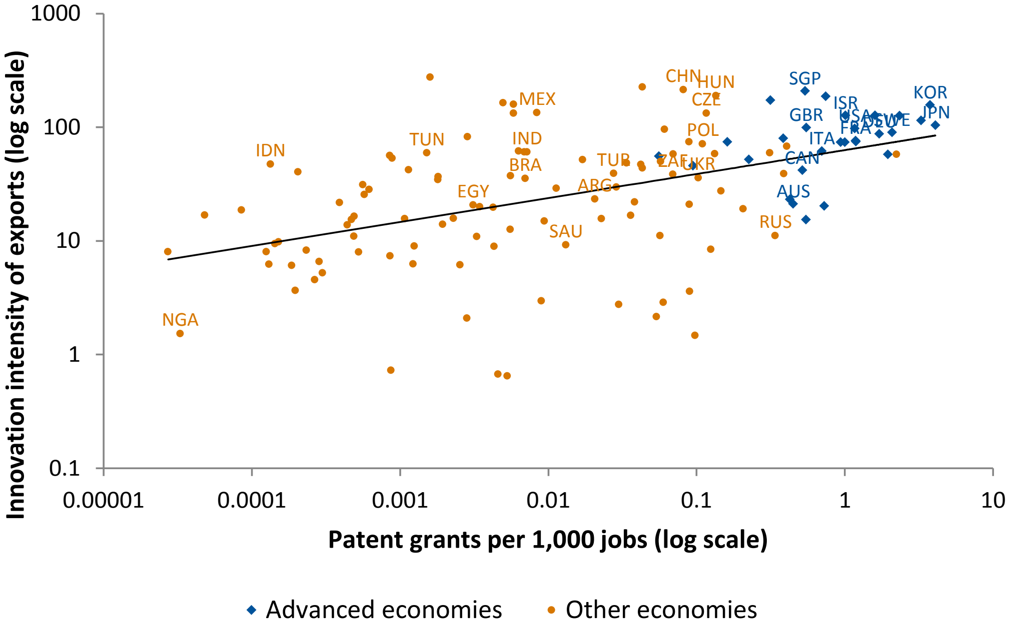
Chart 5: Contribution of various countries to exports and patents, in per cent of total



Sources: WIPO, UN Comtrade, authors' calculations.
Note: Based on 2012 data.

Despite these differences, innovation intensity of exports and patenting are positively correlated (Chart 6). Indeed, many advanced economies, including the United States, Israel, Japan and Korea, tend to be among leaders both in terms of patenting and in terms of innovation intensity of exports. At the same time, a number of emerging markets, for instance China and Mexico, appear to have stronger positions in adopting existing technologies, as reflected in higher innovation intensity of exports relative to patent output.

Chart 6: Innovation intensity of exports and patents



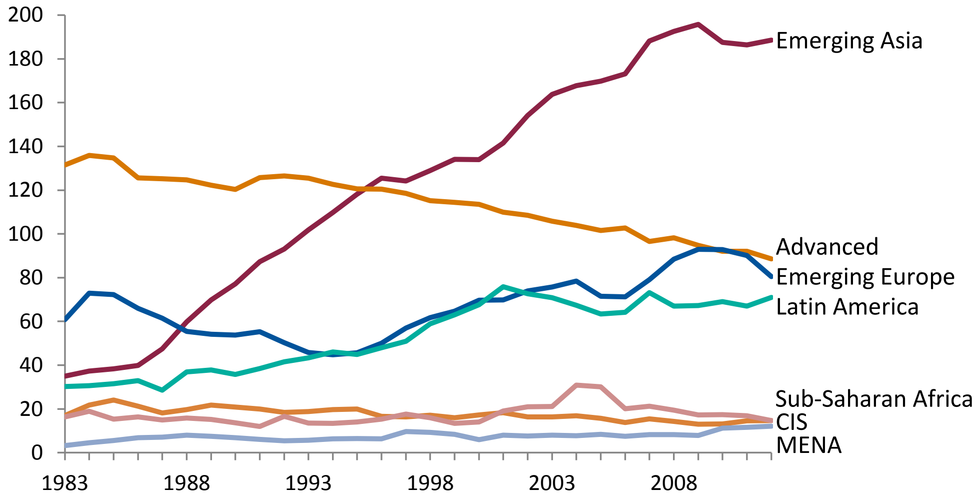
Sources: USPTO, UN Comtrade, Feenstra et al. (2005), WIPO, Penn World Tables, authors' calculations.
Note: Based on averages over the period 1996-2011. Innovation intensity of exports is measured in per cent of innovation intensity of world exports.

2.3. Evolution of innovation intensity of exports

Globally, innovation activity has been increasingly shifting from advanced economies to emerging markets. The last decades have seen a major shift in the production of innovative goods with an increasing role for foreign direct investment and rapid fragmentation of production chains (see Baldwin, 2011). Emerging markets also account for an increasing share of global R&D spending (see, for instance, Thursby and Thursby, 2006).

These broader trends are reflected in the evolution of the innovation intensity index (Chart 7). Among emerging markets, emerging Asia has seen the fastest growth, and innovation intensity of output has also increased in emerging Europe and Latin America, while the innovation intensity of exports in advanced economies has declined somewhat in relative terms.

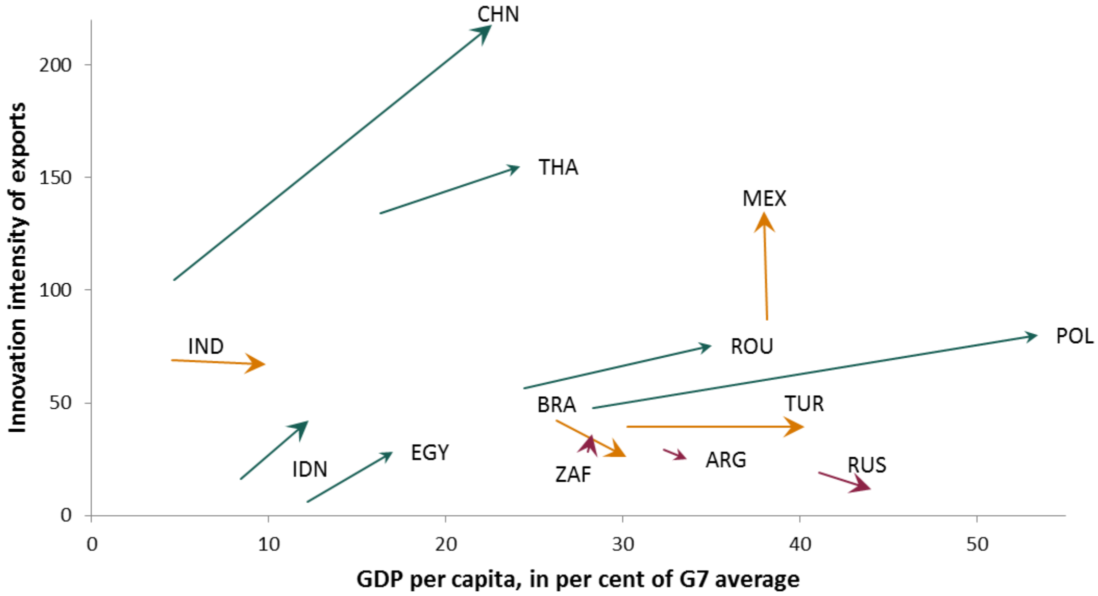
Chart 7: Changes in innovation intensity of exports



Sources: USPTO, UN Comtrade, Feenstra et al. (2005) and authors' calculations.
Note: Weighted averages.

Beyond these broad trends, there are substantial differences in the performance of individual emerging markets on this measure, which can be compared with their performance in terms of convergence (Chart 8). Over the past two decades, many large emerging markets achieved substantial degree of convergence in terms of their income per capita compared with the average income per capita of the G7 countries and at the same time they increased innovation intensity of their exports (green arrows on the chart, sloping right and upwards, for instance, China, Poland and Egypt). At the same time, several large emerging markets have achieved little or no income convergence and have not increased innovation content of their exports (red arrows). These include commodity exporters such as Russia and South Africa, as well as Argentina.

Chart 8: Changes in innovation intensity of exports and income per capita, 1991-92 to 2011-12.



Sources: USPTO, UN Comtrade, Feenstra et al. (2005) and authors' calculations.
Note: Arrows show movements from average values in 1991-92 to average values in 2011-12. GDP per capita is based on 2005 constant prices at purchasing power parity and expressed in per cent of the simple average of GDP per capita of the G7 countries.

A small number of countries managed to achieve some degree of income convergence with relatively low and stagnant innovation intensity of exports by leveraging their traditional comparative advantages in sectors such as textiles (yellow arrows). Examples include India and Turkey. Only one large emerging market economy (in G20) has seen a considerable increase in innovation intensity of exports with virtually no convergence – Mexico. In part, this may reflect much increased but relatively shallow processing of goods manufactured for US multinationals following conclusion of the NAFTA agreement, and in part it may reflect poor productivity growth in other sectors of the economy, including services, in the environment of low competition and high informality.

By and large, however, emerging markets that performed well in terms of economic convergence were those with substantial increases in innovation intensity of their exports. The next section briefly discussed the determinants of innovation in a cross-country context, while the subsequent section examines if these differ depending on whether innovation at the level of an economy is proxied by innovation intensity of exports or patent output.

3. Determinants of innovation

Generally, innovation is a complex process requiring various general and specialised inputs. Thus countries at a higher stage of development (measured, for instance, by GDP per capita at purchasing power parity) are typically better positioned to innovate – consistent with patterns shown in Charts 1 and 2. Similarly, innovation outcomes tend to be directly affected by R&D inputs (measured, for instance, by spending on R&D as a percentage of GDP or the number of R&D employees per 1,000 workers).

Countries with better economic institutions can be expected to be more innovative on average. Poor economic institutions manifesting themselves in high incidence of corruption, weak rule of law or burdensome red tape can substantially increase the cost of introducing new products and make returns to investment in new technologies substantially more uncertain. As a result, risk-adjusted returns to innovation may look less attractive when economic institutions are weak. A number of empirical studies (for example, Habiyaremye and Raymond (2013) and Mahagaonkar, 2008) document a negative relationship between corruption and innovation.

Silve and Plekhanov (2015) further show that exports in innovation-intensive industries are particularly sensitive to the quality of institutions. This implies that over time countries with better institutional environments are more likely to develop more innovation-intensive structures of production and exports as their innovation intensive industries grow relatively faster and their share in total output increases.

A particular aspect of institutions linked to innovation is the strength of intellectual property rights. Strong property rights reduce uncertainty with respect to returns to innovation. At the same time, they also may make inputs into innovation process more costly if innovation requires purchasing patents and licences.

Both frontier innovation and adoption of existing technologies rely on adequate workforce skills (see, for instance, Nelson and Phelps, 1966) – both general (for instance, managerial skills) and highly specialised (for example, in the areas of science and engineering).

Higher economic openness can also support innovation. Openness to trade and investment facilitates adoption of new technologies including through participation in global value added chains, in particular in emerging markets (Coe et al., 2009; Lichtenberg and Van Pottelsbergh de la Poterie, 1998). In fact, estimates suggest that many advanced economies also derive a major part of their productivity growth from abroad (Eaton and Kortum, 1996).

Further, firms that export their goods are able to spread the fixed costs of innovation over a larger customer base and thus exports can support innovation (see, for instance, a survey by Wagner, 2007). By the same token, larger economies with larger domestic markets may find it easier to innovate due to higher domestic demand for new products. Economic openness can also expose domestic producers to stronger competition with foreign products, thus incentivising innovation (for example, Aghion et al. (2005) and Bloom et al., 2011).

Availability of finance may also play an important role, as firms may abandon development of new products if the requisite funding cannot be obtained. Banking deregulation and the deepening of financial systems have been found to be associated with greater innovation and more patenting (see, for instance, Chava et al. (2013) for evidence for the United States;

Benfratello, Schiantarelli and Sembenelli (2008) for Italy and Bircan and de Haas (2015) for Russia).

Innovation may also be affected by an abundance of natural resources in the economy although its impact is ambiguous. In general, a higher dependence of the economy on natural resources is likely to reduce an average firm's economic incentives to innovate as a large proportion of value added in the economy is derived from activities that to a lesser extent rely on continuous innovation. While constant innovation and adoption of the best technologies is a prerequisite for maintaining a competitive position in industries such as the automotive sector, having a competitive edge in natural resource exports depends primarily on natural resource endowments (see, for instance, Welsch (2008) for evidence of a negative relationship between natural resource dependence and innovation). At the same time, the availability of natural resource revenues may enable governments (as well as universities and firms) to finance research and development.

The next section investigates these relationships empirically.

4. Empirical analysis

4.1. Data

Innovation outcomes are analysed in a large cross-section of more than 90 advanced, emerging market and developing economies for which data are available for the period 2010-13 (see Annex 1 for a list of countries).

Information on GDP and populations is taken from the Penn World Tables 8.0. The quality of the overall economic institutions is proxied by the average of the four World Bank Governance Indicators: rule of law, control of corruption, government effectiveness and regulatory quality (see Kaufmann et al., 2009). For a narrower measure of innovation-related institutional quality, the Intellectual Property Rights (IPR) component of the International Property Rights Index compiled by the Property Rights Alliance is also included (Property Rights Alliance, 2013).

Data on average educational attainment are taken from Barro and Lee (2013). Trade openness is measured as the ratio of the sum of exports and imports to GDP, while financial openness is measured by the Chinn-Ito index (Chinn and Ito, 2006). Financial development is captured by the ratio of domestic credit to private sector to GDP (as reported in the World Bank World Development Indicators). Data on natural resource rents to GDP are taken from the same source. R&D spending by sector has been obtained from UNESCO.

Table 1 presents descriptive statistics for the variables for the largest country sample used.

Table 1: Descriptive statistics

Variable	Mean	Std. Dev.	Min	Max
Innovation intensity of exports	0.54	0.51	0.01	2.34
Patent intensity	0.56	0.97	0.00	4.77
GDP per capita, US$	15,937	14,077	479	71,607
Population, thousands	46,400	133,000	319	1,220,000
World governance indicators, average	0.28	0.93	-1.39	2.06
Intellectual Property Rights Index	5.6	1.6	0.0	8.6
Average years of tertiary schooling	0.48	0.36	0.01	1.59
Trade openness	95.9	61.6	29.4	427.5
Financial openness	1.01	1.58	-1.86	2.44
Private credit, % of GDP	75.2	59.2	12.9	295.1
Natural resource rents, % of GDP	8.4	10.9	0.0	53.5
Business R&D spending, % of GDP	0.41	0.71	0.00	3.48
Government R&D spending, % of GDP	0.09	0.11	0.00	0.42
University R&D spending, % of GDP	0.16	0.23	0.00	0.91

Source: Authors’ calculations.

4.2. Results

The baseline specification is a simple cross-sectional regression for the averages over the period 2010-13:

$$Innovation_i = \alpha + \beta X_i + \gamma Z_i + \varepsilon_i$$

where $Innovation_i$ is the logarithm of a country's patent intensity (number of patent grants per 1,000 workers) or innovation intensity of exports relative to the intensity of total world exports, X_i are country characteristics of interest for innovation such as GDP per capita, population, institutional quality, quality of human capital, openness to trade and financial flows, financial development and natural resource rents, Z_i is a set of innovation input variables, which includes R&D spending by business, government and higher education relative to GDP, and ε_i denotes the error term. The model is first estimated by OLS.

Overall, the results reported in Table 2 suggest certain differences in terms of factors that affect patent output of an economy and innovation intensity of its exports.

Table 2: Determinants of patent intensity and innovation intensity of exports

	[1]	[2]	[3]	[4]	[5]	[6]	[7]	[8]
Variable	IIE	Patint	IIE	Patint	IIE	Patint	IIE	Patint
GDP per capita, log	-0.002	1.742	0.000	1.293	-0.112	1.162	-0.251	0.789
	-0.145	(0.386)***	-0.144	(0.348)***	-0.151	(0.465)**	-0.188	(0.467)*
Population, log	0.229	-0.057	0.183	-0.188	0.163	-0.184	0.209	-0.154
	(0.057)***	-0.12	(0.066)***	-0.117	(0.058)***	-0.116	(0.060)***	-0.129
WGI	0.33	0.584	0.237	0.574				
	(0.195)*	-0.487	-0.213	-0.425				
WGI * High WGI dummy					-0.184	0.53	-0.203	0.659
					-0.21	-0.426	-0.228	-0.491
WGI * Low WGI dummy					1.171	1.154	1.321	1.864
					(0.372)***	-1.03	(0.371)***	(0.937)**
Intellectual Property Rights	-0.037	-0.109	-0.038	-0.025	-0.04	-0.029	-0.05	-0.028
	-0.067	-0.145	-0.07	-0.127	-0.059	-0.12	-0.054	-0.109
Average years of tertiary schooling	-0.03	1.447	-0.17	0.768	0.083	0.871	0.221	1.043
	-0.329	(0.562)**	-0.418	(0.436)*	-0.386	(0.516)*	-0.38	(0.515)**
Trade openness	0.003	-0.002	0.003	-0.001	0.004	-0.001	0.005	0
	(0.002)*	-0.002	(0.002)**	-0.002	(0.002)**	-0.002	(0.002)**	-0.002
Financial openness	0.116	-0.092	0.117	-0.165	0.076	-0.177	0.109	-0.174
	(0.066)*	-0.172	(0.070)*	-0.132	-0.068	-0.127	-0.068	-0.136
Private credit to GDP	0.001	0.004	0.002	0.008	0.003	0.009	0.003	0.01
	-0.002	-0.003	-0.002	(0.003)***	-0.002	(0.003)***	-0.002	(0.003)***
Natural resource rents	-0.053	-0.027	-0.043	0.002	-0.035	0.005	-0.027	0.035
	(0.011)***	-0.023	(0.015)***	-0.021	(0.014)**	-0.022	(0.014)*	-0.026
Business R&D over GDP			0.154	0.609	0.263	0.638	0.274	0.661
			-0.177	(0.258)**	(0.128)**	(0.261)**	(0.124)**	(0.226)***
Government R&D over GDP			0.512	5.867	0.128	5.949	0.293	6.807
			-0.961	(1.743)***	-0.89	(1.767)***	-0.845	(1.518)***
University R&D over GDP			0.111	-1.434	0.528	-1.366	0.7	-1.226
			-0.593	-1.156	-0.599	-1.221	-0.649	-1.296
Number of obs.	95	66	91	66	91	66	88	63
R^2	0.62	0.8	0.58	0.86	0.63	0.86	0.62	0.85

Source: Authors' calculations.
Note: The dependant variables are the logarithm of international patents granted per 1,000 workers (Patint) and the logarithm of innovation intensity of exports (IIE), averages over the period 2010-13. Robust standard errors in parentheses. Values significant at the 1 per cent level are marked with ***; at the 5 per cent level, with **; at the 10 per cent level, with *. Columns 1-6 are estimates by ordinary least squares; Columns 7 and 8 are estimates by two-stage least squares with lagged values of income per capita, trade openness and natural resource rents used as instruments.

For instance, the results suggest that rich countries tend to patent more, yet there appears to be no association between income per capita and innovation intensity of exports. This may be due to increasingly successful technology adoption by less developed countries over the last decades. While lower-income countries may lack various general and specialised inputs needed to innovate, lower cost of labour may give these economies a certain competitive edge when it comes to technology adoption.

As expected, better economic institutions are associated with more innovation-intensive exports and to some extent more patenting. In columns 5 and 6 the marginal effect of improving institutions is estimated separately for countries with relatively strong institutions and countries with relatively weak institutions (the specifications include additional interaction terms between the quality of institutions and dummy variables for the group of countries with the average world governance indicator above the sample mean and for the group of countries with the average world governance indicator below the sample mean). The results suggest that the marginal effect of improving institutions is stronger (and has a higher statistical significance) in countries where institutions are relatively weak. An improvement in the quality of economic institutions of around half a standard deviation in a country with below-average economic institutions (roughly equivalent to the difference between the average World Governance indicator values of Albania and Ukraine) is associated with a 40 to 50 per cent increase in patent output. An improvement in the quality of institutions of this magnitude is also associated with a 60 per cent increase in innovation intensity of exports. At the same time, the variable measuring the strength of intellectual property rights is not statistically significant.

Further, higher average years of tertiary education are associated with a higher patent output. The link with innovation intensity of exports appears to be weaker; perhaps the quality of skills (as opposed to the quantity of schooling) is notoriously hard to measure. Relevant vocational and managerial skills, in particular, may not be captured by available indicators such as years of schooling or enrolment ratios.[4]

The results confirm that both the size of the market (captured by population included alongside GDP per capita) and economic openness (measured by the ratio of exports and imports to GDP) are associated with higher innovation intensity of exports. An increase of 30 percentage points of GDP in trade openness (half a standard deviation) is associated with a 9 to 15 per cent increase in innovation intensity of exports. At the same time, no strong link is found between patent output and economic openness or the size of the economy.

In addition, a positive, albeit weaker, association is found between financial openness of the economy, captured by the Chinn-Ito Index and innovation intensity of exports (higher values of the index correspond to free cross-border movement of capital and low values correspond to more restrictive regimes (Chinn and Ito, 2006)). In sum, the results suggest that commercialisation of innovation and adoption of technologies in particular benefit from trade openness, financial openness and a large market size. The overall level of financial development in an economy, measured by the ratio of private sector credit to GDP, is also associated with better innovation performance.

Abundance of natural resources in the economy, measured by natural resource rents (that is, revenues net of extraction costs) as a percentage of GDP, does not appear to have an impact on patenting. At the same time, the export output of natural resource economies tends to be significantly less innovation-intensive. This in part reflects the higher weight of commodity sectors in exports (by construction). However, it also likely reflects the negative impact of natural resource rents on firms' incentives to innovate. While the availability of natural resource revenues may enable governments (as well as universities and firms) to finance

[4] Test score-based measures such as the OECD Programme for International Student Assessment (PISA) are available only for a small subset of countries.

research, which offsets the negative impact natural resources may have on patent output, it does not necessarily strengthen firms' incentives to commercialise innovation.

The results indicate the expected relationship between R&D inputs and innovativeness of economies and further suggest that the split of research and development spending between firms, academic institutions and governments also plays an important role. Both business R&D spending and government R&D spending are associated with higher patent output, and the effect of a dollar of government R&D spending is estimated to be higher (columns 3 and 5). However, only business R&D appears to have a positive effect on innovation intensity of exports (columns 4 and 6).

4.3. Additional checks

The results from the above regressions should be viewed as indicative of the general relationships between innovation and country characteristics rather than as causal relationships. For instance, causality in the relationship between patent intensity and GDP per capita may run both ways. Wealth may help countries to innovate, but innovation can also help countries to improve their productivity and increase their income per capita faster. Likewise, innovation can help countries to increase their exports and reduce the observed dependence on natural resources.

To take partial account of such reverse causality, similar regressions were estimated using values of income per capita, trade openness and natural resource dependence with a lag of 10 years as instruments for their current values. The results remain broadly unchanged (reported in columns 7-8). The results remain broadly unchanged if a longer lag is used to create instruments.

5. Conclusion

This paper introduced a new country-level measure of innovativeness of economies: the innovation intensity of exports. This measure aims to better capture adoption of existing technologies of firms as an important dimension of innovation that drives productivity growth while traditional measures of innovation based on patent counts and R&D spending tend to focus on frontier innovation – development of goods new to the global markets.

The differences between innovation intensity of exports and patent output are most striking for emerging markets. Many countries in emerging Asia and emerging Europe achieved remarkable increases in innovation content of their exports while their patent output lagged behind. Large emerging markets that saw large increases in innovation intensity of exports over the last two decades also tended to be the ones that managed to achieve a substantial degree of income convergence towards the levels of large advanced markets.

The empirical analysis shows that both measures of innovation are positively associated with the quality of economic institutions. Moreover, the estimates suggest that the quality of economic institutions plays a particularly important role in countries with a low initial level of institutional quality

Beyond strong economic institutions, the analysis reveals certain differences in terms of factors linked to greater innovation intensity of exports and those linked to higher patent output. The innovation intensity of exports is closely associated with the size of the economy and its openness to trade and financial flows, unlike the patent output. At the same time, while patent output does not appear to be affected by natural resource wealth, resource abundance appears to suppress innovation as measured by export content.

Further, while both business R&D spending and government R&D spending are associated with higher patent output (and the link between government R&D and patents appears to be stronger), only business R&D is associated with greater innovation intensity of a country's exports.

Overall, the findings hold particular relevance for developing countries, for which innovation through technology adoption and adaptation is especially important. Further improvements in the innovation potential of developing economies need to come from improvements in economic institutions, greater economic openness and measures that encourage business spending on R&D.

Annex 1: Countries in the sample

Albania
Algeria
Armenia
Australia
Austria
Bahrain
Bangladesh
Belgium
Benin
Bolivia
Botswana
Brazil
Bulgaria
Burundi
Cameroon
Chile
Colombia
Costa Rica
Cote d'Ivoire
Croatia
Cyprus
Czech Republic
Denmark
Ecuador
Egypt
El Salvador
Estonia
Finland
France
Germany
Ghana
Greece
Guatemala
Guyana
Honduras
Hong Kong
Hungary
Iceland
India
Indonesia
Iran
Ireland
Israel
Italy
Japan
Jordan
Kazakhstan
Kenya
Korea Rep.
Latvia
Lithuania
Malawi
Mali
Malta
Mauritania
Mauritius
Mexico
Moldova
Morocco
Mozambique
Nepal
Netherlands
New Zealand
Nicaragua
Pakistan
Panama
Paraguay
Peru
Philippines
Poland
Portugal
Qatar
Romania
Russia
Saudi Arabia
Senegal
Singapore
Slovenia
South Africa
Spain
Sri Lanka
Sweden
Switzerland
Tanzania
Thailand
Trinidad and Tobago
Turkey
Uganda
Ukraine
United Arab Emirates
United Kingdom
United States
Uruguay
Venezuela
Vietnam
Zambia

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