Multinational technology and intellectual property management

- Is there global convergence and/or specialization?

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Abstract

The paper gives various indications of market and technology diversification as well as of global market and technology convergence (rather than specialization) in the context of managerial, legal and economic convergence. The results show that different countries focus on a wider but increasingly similar set of markets for R&D outputs in form of patents, which implies increasing intra-national market diversification and inter-national market convergence. The results also show that different countries focus on a wider but increasingly similar set of technologies that are patented, which implies increasing intra-national technology diversification and inter-national technology convergence. In addition, intellectual property (IP) legal convergence takes place as newly industrialized countries (NICs) have strengthened their IP regimes in compliance with TRIPS and subsequently do so in the context of their indigenous innovation policies. Asian NICs have significantly increased their international patenting and supply of patented inventions. Altogether, this puts new demands across countries on multinational technology and innovation management skills, and in particular multinational IP management skills.

Keywords: Technology convergence; market convergence; revealed technological advantage; revealed market advantage; technological specialization; market specialization; diversification; patent statistics; technology management; intellectual property management; intellectual property regime; internationalization; catch-up

1 Background and purpose

Looking at the countries in the world it is clear that most of them do not influence globalization very much. At the same time globalization substantially influences almost all countries, e.g. regarding their consumption, trade, and investment decisions, including innovation and technology management decisions. In the context of globalization as a phenomenon at aggregate level, it is then natural to ask whether there are any indications of international convergence and/or specialization in some sense. On the one hand globalization might lead to large-scale conformity, standardization and homogenization, or in biological systems terms to competitive exclusion and loss of diversity. On the other hand technological opportunities and possible diversity increases over time. In addition, the rates of adoption and diffusion of new technologies and innovations may be country-specific so that essential differences across countries will persist.

The general purpose of this paper is to explore developments along a number of dimensions of convergence and their interrelations in a global context, and the ensuing implications of any signs of convergence for technology management. This purpose will be pursued by characterizing convergence in economic, legal, management, market, and technology terms. Quantitative empirical results have been collected for various indicators of market convergence and technology convergence through patent statistics, and qualitative information related to especially legal convergence of intellectual property (IP) legal systems has been collected through field studies in Asia, Europe, and US.[1]

The paper is structured along the various types of convergence with sections for frame of reference with key concepts and literature (where specific research questions are derived), methodology, empirical data analysis, discussion and managerial implications, and finally conclusions.

2 Frame of reference and literature

2.1 Key concepts

The concept of convergence in general refers to the increasing similarities (or equivalently decreasing differences or dissimilarities) across two or more entities over time. Here we will distinguish between the following dimensions or types of convergence across national entities (countries):

1. **Economic convergence**, i.e. decreasing economic differences between different countries, e.g. differences in gross domestic product (GDP) per capita, differences in rates of economic growth, differences in international trade patterns, and differences in

[1] The paper will not deal with military R&D and technology, however, which is obviously an important factor in geopolitical developments including economic developments. Although military technologies are increasingly being patented and licensed internationally, patent statistics offer limited possibilities for drawing conclusions regarding internationalization of military R&D and technology.

quality and longevity of life. Economic convergence is an overarching type of convergence for contextualizing other types of convergence.

2. **Legal convergence**, i.e. decreasing differences between legal systems in different countries, e.g. the intellectual property rights (IPR) systems.
3. **Management convergence**, i.e. decreasing differences between different countries in terms of national management styles, strategies, skills, and methods. This focus then includes strategic management decisions in companies with different nationalities and whether these decisions become increasingly similar. Decisions regarding which technologies to develop and patent, and where in the world to patent them then constitute two types of decisions that we will focus especially on, as further described below.
4. **Market convergence**, i.e. companies with different nationalities increasingly prioritizing similar sets of national markets in their international patenting.
5. **Technology convergence**, i.e. companies with different nationalities increasingly investing in, developing, and patenting similar sets of prioritized technologies.[2]

New quantitative empirical data analysis is presented for market and technology convergence, while qualitative information on the other dimensions of convergence is used to frame and contextualize the quantitative results. Market and technology convergence are both closely related to management convergence, and can actually be regarded as subsets or sub-dimensions of the latter since they are related to convergence of management decisions (see below). Management convergence is moreover closely related to the institutional economic and legal environment that firms operate in, since differences in local institutional environments might result in local and differentiated management strategies and decision patterns. The IP legal system in a country is finally guiding decisions of organizations and individuals in a way that supposedly leads to increased welfare and economic growth for the country, since most IP legal systems are by and large formed on a utilitarian rather than on a moral rights basis.

A concept closely related to convergence is specialization. Here we distinguish between two main types of specialization related to market and technology convergence, respectively. First, a country (or company or other entity) can be or become more narrowly focused on few(er) markets or technologies. This is thus a country-specific state or process of specialization, *independent of the specialization of other countries*. We therefore call this type of specialization **intra-national specialization**, with its opposite (i.e. a focus on a wider range of markets or technologies) being **intra-national diversification**. Second, a given country can be more focused (in some sense) on a specific market or technology, *relative to other countries* on average. This is then a state of that country's inter-national specialization in that

[2] This concept has to be distinguished from the concept of technological convergence, as pioneered by Rosenberg (1963), and the related concepts of technological confluence by Jantsch (1967) and technology fusion by Kodama (1992), meaning that two or more technologies increasingly become combined or jointly developed in various new products.

specific market or technology. One can then study the process of increasing or decreasing **inter-national specialization** (or inter-national divergence), either in a separate market or separate technology or on a more aggregate level of separate sets of markets or technologies. The opposite to inter-national specialization is **inter-national convergence**, i.e. when countries become increasingly similar in their focus on various markets or technologies relative to other markets or technologies.[3] This will be further described in the methodology section.[4]

2.2 Previous literature and research

2.2.1 Economic convergence

Economic convergence is addressed here as an overarching dimension of convergence, closely related to all the other dimensions of convergence. As industrialization and technological developments were set in motion historically at different paces and places, interrelated economic and technological gaps increased across countries, resulting in increased divergence. As globalization proceeds one could expect a subsequent transition to convergence to the extent that countries and companies are able to catch-up technologically and economically, which in turn is influenced by managerial and political skills, endowments, institutional structures and other factors. Economic convergence does not necessarily imply other dimensions of convergence, however, since similar economic results may in principle be produced by dissimilar means. In fact, division of labor, investments in R&D and education, free international trade and dynamic comparative advantages, e.g. through learning and technological specialization, have long been advocated as conducive for economic catch-up, see e.g. Abramovitz (1986), Cantwell (1999), Freeman et al. (1982), Patel and Pavitt (1994) Santangelo (2005), Scherer (1999) and Schumpeter (1942). At the same time it is not clear that economic and/or technological catch-up is at all possible under certain conditions. As in most development processes initial conditions, early mover advantages, and history (path-dependence) matter. Technological leaders may be able to maintain their leads through sustaining superior R&D investments, "evergreening" through IP protection, and limiting technological spill-overs.[5] Such a strategy may be successful for large advanced countries vis-à-vis small ones but less so, if at all, vis-à-vis large ones such as China and India because of

[3] All combinations of intra-national specialization/diversification and inter-national specialization/convergence processes are possible. Imagine e.g. that we study the use of dining tools in China and Europe. Let us now assume that one half of the Chinese people eats with forks while the other half eats with chopsticks, and that all Europeans eat with forks. If now the Chinese people eating with chopsticks would start switching over to forks we would get a process of intra-national specialization (due to an increased focus on forks only in China) and inter-national convergence (due to increasing similarities between China and Europe), while a reversed process would lead to intra-national diversification and inter-national specialization. A process where the Chinese people eating with forks would start switching over to chopsticks would lead to both intra-national specialization (due to an increased focus on chopsticks only in China) and inter-national specialization (due to increasing differences between China and Europe), while the reversed process would lead to intra-national diversification and inter-national convergence.

[4] Note that these conceptualizations do not only apply to markets and technologies, but also to products, resources, etc. Neither do these conceptualizations apply only to nations, but also to companies and other entities.

[5] As to the concept of evergreening, see Granstrand (2003, Ch. 10).

the attractiveness of their large domestic markets to foreign entrants from advanced countries. At the same time many countries have been able to technologically catch-up and there are few, if any, cases in history of sustained exclusivity of technological leadership, just as there are few if any cases of a country catching up technologically in the presence of a strong IP regime from the outset. Patent statistics provide early or precursory indicators in this context.

As to some empirical results about economic convergence across countries Baumol (1986) found clear signs of converging income per capita measures for 16 industrialized countries in the period 1870-1979. These signs of convergence are substantially weakened by sample selection bias and measurement errors, as shown by De Long (1988). Moreover, Summers and Heston (1991) found little evidence of economic convergence in a study of most of the non-communist world in the period 1960-1985. Thus, poor countries do not so far seem to have grown faster than rich ones on average over long periods of time. Despite a growing set of economic growth studies and studies in comparative economics it is therefore still an open question if there is economic convergence and if globalization will lead to more comprehensive rather than partial economic global convergence. It is also an open question how the economic and legal institutional environment constituting national innovation systems of various types impact innovativeness and economic performance and if the national innovation systems with all their differences after all converge.[6]

2.2.2 Legal convergence

It is a long standing issue in comparative law whether different legal systems will converge and if so to what, especially since there are no strong inherent universal concepts of justice and right according to legal anthropologists. More specifically in a Western context any convergence of the continental European civil law and the Anglo-Saxon common law legal systems is of interest and there are signs that some convergence is taking place, albeit far from any true harmonization. Still, an open question is which type of legal system is most conducive to innovation and economic growth and development. It might be argued that a common law system (being relatively more based on legal cases) is more flexible and reactive to new technologies and industrial developments than a civil law system (being relatively more based on certain theoretic principles), but adaptability in itself does not necessarily imply innovativeness. As to the patent system in the world, which is of special interest in this paper, international diffusion and harmonization of the various national patent systems has progressed steadily throughout centuries, although there is still a long way to go in international harmonization, see Granstrand (1999b, 2003). As to harmonization, which concerns not only codified laws but also law enforcement, law adherence and court practices (e.g. regarding IP damage calculations), between developed and developing countries, a long-standing concern is the differences in strength in some sense of patent and IP systems across different countries, or the appropriability regimes more generally. The variations in national IP legal systems clearly impact both technological choices and marketing decisions. In certain countries, some technologies are not patentable, and in certain countries it is not worthwhile

[6] For descriptions of various national innovation systems, see e.g. Edqvist (1997), Lundvall (1992), and Nelson (1993).

to patent in general, due to e.g. weak enforcement or low patent infringement damages and rare injunctions. Moreover, differences in IP legal systems around the world increase multinational technology management costs and uncertainties. On the other hand, different IP legal systems also have different impacts on economic growth and development for countries in different development stages (see e.g. Kim, 2011, and Park and Ginarte, 1997, for related studies).

2.2.3 Management convergence

Comparative management studies in general are growing and many national differences have been identified and analyzed, see e.g. Edfelt (2009). Whether these national differences decrease on average over time, i.e. that there is management convergence, is by and large an open question as well. Still, there is some evidence (often anecdotal) that suggests that such convergence takes place after all. The expansion of multinational corporations (MNCs), the role of multinational management consultancy firms (mostly US) and managerial service firms (like accounting and financial service firms), the internationalization of financial markets, harmonization of international accounting standards, the international mobility of managers, international competition on input/output markets and so on are all factors that tend to lead to increasing management convergence in the longer run.

As to technology management more specifically, comparative management studies are few. Studies of chief technology officers (CTOs) identify certain similar features among them (see Adler and Ferdows, 1990, and Herstatt et al., 2007). Some evidence from studies of technology management practices in US, European and Japanese MNCs also suggest a certain convergence of technology management practices as these MNCs increasingly internationalize and compete on international markets, not only output markets but also input markets, e.g. markets for talent. An example of such convergence practices is the increasing use of external technology acquisition strategies and open innovation. At the same time there are many distinctive national features and practices, e.g. the degree of centralization of R&D (see Granstrand, 2000b). Regarding use of open innovation or external technology acquisition strategies, these depend on the developmental stage of a company and a country. Needless to say a company or a country trying to catch-up is more dependent upon external technology than a technological leader, everything else equal (see e.g. Abramovitz, 1986, and Mansfield, 1988).[7] A country will then benefit from a resource base congruent with technological opportunities (Abramovitz, 1990) and an R&D production structure apt to absorb technological spill-overs (Abramovitz, 1991, Beelen and Verspagen, 1994).

Further case study evidence indicates a certain convergence in multinational R&D and multinational technology management as to location (e.g. in Bangalore and/or Silicon Valley) and role of foreign R&D labs in MNCs. Early industrialized countries like Holland and Sweden with small domestic markets became early internationalizers of their sales, production and R&D (Granstrand et al., 1992b). Companies like Philips and SKF already in

[7] If technological diversity or complexity is also taken into account, technological leaders are also dependent upon open innovation and more so the more diverse and expensive the technology base of the leader is.

the 1970s had a substantial amount of R&D located abroad.[8] They reorganized their worldwide R&D and product development from local-for-local to local-for-global development and distinguished between demand and supply led R&D labs. These management practices then became increasingly adopted by companies in large countries like US and Japan.

Studies of the international adoption and diffusion of managerial inventions also suggest that management convergence takes place. As to new managerial inventions (techniques, methods, models, etc.) one can see how old ones like the multidivisional form (M-form) of corporate organizations, technological forecasting techniques, capital budgeting techniques, and later on venture capital organizations diffused around the world among advanced MNCs. Especially Japan then developed a number of additional ones in production and technology management, like Kanban, total quality management (TQM), just-in-time (JIT), Kaizen, and patent mapping in intellectual property management (IPM) (see e.g. Granstrand, 1999b). In this context a study by Lillrank (1995) indicates that organizational innovations are typically more difficult to transfer across cultural, national, and industrial borders than are innovative management principles and tools, suggesting different rates of convergence.[9]

In this process of cross-national learning and knowledge transfer, management principles and strategies could possibly converge to some international best practices, especially if globalization leads to decreasing importance of local (national) factors, which would otherwise require differentiated management strategies. This leads us to study two types of management strategies, and the corresponding dimensions of convergence: Market convergence (related to the relative importance of various output markets) and technology convergence (related to the relative importance of various technological areas).

2.2.4 Market convergence

The concept of market convergence can relate to different aspects of markets, including market integration (see e.g. Goldberg and Verboven, 2005), price convergence (see e.g. Rogers, 2007), and product market convergence.

In this paper we define market convergence more specifically as the convergence of geographical output markets' relative importance for different countries of origin of products. It can thus be seen as a special form of management convergence, related to the output market decisions of managers. We especially focus on new product markets, and use patent statistics on aggregate national level as a proxy of this. Thus, this convergence is related to the

[8] SKF was probably one of the world's most globalized companies in the 1970s, not the least regarding R&D and production. A 'global forecasting and supply system' was introduced with global coordination of local for global R&D and production in response to Japanese competition. A multinationally manned central R&D lab with foreign location was created as a hub for world-wide R&D. (See Granstrand, 1982, and Granstrand and Fernlund, 1978.) In 2011 SKF was still an essentially Swedish European company but with a non-Swedish CEO as well as a non-Swedish CTO.

[9] Based on cases like these Vernon's international product life-cycle (PLC) theory could be seen to apply also to management developments. The model may continue to apply in this area (despite all criticisms voiced over it in general, see Cantwell, 1995). If so, Western companies could expect to learn in the future from Chinese and Indian management, not least in the area of technology management (e.g. in large scale R&D and production, software development, and bio-tech).

management strategy decision "where to patent". With a patent in a specific country, the patent holder can exclude others from commercializing (through both manufacturing and selling) the patented invention in that country. Therefore, one can assume that patentable inventions are patented in the countries/markets where the inventor/inventing firm has or will have some form of technology-based business (including both product and technology sales) during the estimated length of the effective patent protection and where the inventor/inventing firm finds it likely that the benefits from patent protection are greater than the patent costs (applications costs, renewal fees, and costs of the information disclosure related to the patent application), taking into account the risk of being subjected to competing imitations and the protection provided by the IP legal system and its strength of patent legislation and enforcement in the country in question (see e.g. Granstrand, 1999b). Now, the related research question that will be probed empirically in this paper is: *Do the sets of country markets selected by inventive firms/individuals for patenting become increasingly similar, i.e. is there a market convergence globally?* This question has to our knowledge not previously been studied.[10]

2.2.5 Technology convergence

The number of worldwide patent applications has steadily grown during recent decades. According to World Intellectual Property Organization (WIPO) estimates the number of applications has increased from 926 000 in 1985 to 1 908 000 in 2008, corresponding to a compounded annual growth rate (CAGR) equal to 3.2%. Moreover, the number of priority filings, which excludes double counting of patent applications for the same invention to many different patent offices, has increased from 579 000 in 1990 to 881 000 in 2007, corresponding to a CAGR equal to 2.5% (using the WIPO statistics on patent families as a measure).

Looking more deeply into the technological areas in which various countries file patents, different countries' technological specializations have been investigated in a range of studies, including the ones by Archibugi and Pianta (1994), Cantwell (1989, 1991), Cantwell and Vertova (2004), Dosi et al. (1990), Gambardella and Torrisi (1998), Pavitt (1982) and Soete (1981). The results of these studies have in general showed that inter-national technological specializations increase, and that the areas of specialization are cumulative, in turn giving rise to path dependencies. These increasing national technological specializations can be interpreted as technology divergence between countries, since high levels of specialization in various countries relative to other countries imply differences between them in terms of areas of specialty.

As to technological diversification, Archibugi and Pianta (1992) found a positive relationship between size of national technology bases and technological diversification and Cantwell and Vertova (2004) investigated this relationship further and concluded that countries have

[10] Some work has been published on related issues, see e.g. Bosworth's (1984) and Caviggioli's (2011) works on determinants of foreign patent applications to certain countries (from other countries) and foreign patent applications from certain countries (to other countries). These studies have however not had a global focus, but a focus on single countries or subsets of countries. Neither have they focused on convergence across different countries.

become less diversified (or more narrowly specialized) over the past 40 years. One explanation addressed in that paper is that international technology sourcing activities lead to different geographic locations focusing on what they do best. This goes in line with the model by Krugman (1987) in which specialization is predicted to be stable due to economies of scale and lock-in effects.

Besides showing increasing levels of inter-national technological specialization (i.e. technology divergence), Archibugi and Pianta (1994) showed convergences between OECD countries in a number of other economic and science and technology indicators, including GDP per capita, R&D intensity and external patents per unit of exports. They conclude that countries converge in these other indicators by becoming more technologically specialized and different in that aspect.

In contrast with the aforementioned studies on technological specialization, a study by Dalum et al. (1998) on trade specialization, which in that paper is assumed to be closely linked to technological specialization, shows that the development between 1965 and 1992 can be characterized by de-specialization (technology convergence). High revealed symmetric comparative advantages (RSCA) are shown to decrease while low ones are shown to increase over time.

Now, the related research question that will be probed empirically in this paper is: *Do the sets of technological areas developed and patented by inventive firms/individuals become increasingly similar, i.e. is there a technology convergence globally?*

3 Methodology

As described above, five different dimensions of convergence and their interrelations are elaborated in this paper, although the empirical evidence is focused on market and technology convergence, and to some extent legal convergence. The units of observation and analysis in general are the world's countries as recognized by agencies like WIPO and the United States Patent and Trademark Office (USPTO), and companies and inventions of various nationalities. The population frame of countries varies a little over decades (and of course quite a bit over centuries) but roughly consists of 170 countries in this study.

Quantitative data in form of patent statistics is used for market and technology convergence and specialization. A patent right is granted in a country for a specific invention and the set of patent rights in different countries for the same invention is called a patent family. The set of countries in a patent family indicates the selection of prioritized markets by the inventing individual, company or other agent. It is possible to assign a nationality to each patented invention based on the nationality of the applicant, or in case of several applicants the nationality of the first applicant named in the patent application as a proxy for national origin of the invention.[11]

[11] See e.g. Holgersson (2011) for a discussion of careful interpretation of patent statistics.

The selection of national markets for each patented invention of a certain nationality could then be compared across countries of origin, calculating an index of market difference (dissimilarity) as described in more detail below. This paper is based on data on aggregate national level, and therefore the selection of national markets can not be studied on individual invention level. Instead, we use the number of patent applications from a specific country of origin to different receiving offices as a measure of the market selection. The differences in choices of markets between different countries of origin are measured by three difference indices, as described below. Multiple indices are used to decrease the risk of misrepresentation due to index construction. In addition, the Herfindahl-Hirschman index is used as a measure of the market concentration and intra-national specialization from the point of view of a specific country of origin.

Each patented invention is classified into one main and often also into a few additional patent classes, corresponding to technological areas, assigned to it by the patent examiner. This gives an opportunity to construct an index of technology difference (dissimilarity) as described in more detail below. Here we have used US as a country of reference for patenting with the assumption that US is a highly prioritized market on average for inventors around the world. Using US as a reference country in patent information analysis is also common in previous research, see e.g. Patel and Pavitt (1994) and Granstrand et al. (1997). A set of difference indices, designed analogously with the ones above, are used for measuring technological differences as defined below.

Finally, qualitative information, mainly regarding IP legal convergence, underlying the discussion in the paper and the interpretation of data has been collected through documents, conference discussions and interviews (about 50) at country and company level in China, Europe, India, Japan, Korea, and US in connection with field visits during 2010 and 2011.

3.1 Quantitative datasets

We use two datasets on aggregate national level to study market and technology convergence, respectively. The first dataset consists of input/output matrices with receiving offices and countries of origins for all patent applications reported to WIPO from 1995 through 2008. These matrices were constructed from the patent statistics available from WIPO and they are primarily used to study inter-national market convergence or reversely inter-national market specialization. The second dataset consists of matrices with countries of origin and patent classes for all patent applications to the USPTO from 2005 through 2009. These matrices were constructed from the patent statistics available from the USPTO and they are primarily used to study inter-national technology convergence or reversely inter-national technology specialization.

3.2 Market difference indices

We introduce three different measures of differences (dissimilarities) between countries for each dimension of inter-national convergence (or reversely inter-national specialization), i.e. market and technology convergence. The concept of convergence in general refers to a process in which the difference or dissimilarity between two variables (or one variable and a constant) decreases as one or another variable (usually time) increases.[12]

The first measure of market differences is a market share difference index. When comparing two countries’ (a and b) foreign patent strategies, the total numbers of applications from a and b, respectively, to foreign patent offices are calculated, excluding a’s and b’s applications to a and b to decrease bias. Then, the shares of these applications going to the different foreign patent offices are calculated (totaling 100%). (Domestic patent applications – i.e. applications from country a to country a – are excluded, since these bias the share size of different countries heavily due to large differences in domestic patenting strategies.) The shares of foreign applications are then compared between countries to see the overlap of foreign patenting strategies. Our first market difference index, the **market share difference index**, between two countries, a and b, is then constructed by the following formula, (giving a difference or dissimilarity metric since $d_{ac} \leq d_{ab} + d_{bc}$):

$$d_{ab}^{MS} = d_{ba}^{MS} = \frac{\sum_{i=1}^{N} |s_{ai} - s_{bi}|}{2}$$

Here s_{ai} is the number of foreign patent applications from country a that is filed in country i divided by the number of all foreign applications from country a, excluding applications to country b to reduce bias. Hence, s_{ai} is the share of country a’s total number of foreign applications (excluding those to country b) that goes to country i. N is the total number of countries, excluding country a and country b. This gives a difference index d^{MS}, which is 1 when there is a complete difference and 0 when there is no difference at all.

The second market difference index used here is based on a modified version of the revealed comparative advantage (RCA), as introduced by Balassa (1965). Based on the RCA, Soete (see e.g. Soete, 1981, 1987) and others developed the concept of revealed technological advantage (RTA). Here we introduce the revealed market advantage (RMA) analogously to the revealed technological advantage. RMA of country a in market i is then defined as:

$$RMA_{ai} = \frac{p_{ai} / \sum_{i=1}^{N} p_{ai}}{\sum_{j=1}^{N} p_{ji} / \sum_{j=1}^{N} \sum_{i=1}^{N} p_{ji}}$$

Here p_{ai} is the number of foreign applications from country a to receiving office i, and N is the total number of countries.[13] This measure is larger than 1 for a country if the share of its foreign patent applications to a specific receiving office (country) is larger than the share of total foreign applications from various countries that is received by that specific receiving

[12] In index construction in general it is desirable that a difference or dissimilarity index is a metric distance measure, i.e. it has the triangle inequality property. E.g. the concept of technological distance between entities could then be operationalized as done in Granstrand (1994).

[13] Note that since p_{ai} is the number of foreign applications from country a to receiving office i, the following holds since a domestic patent application is not a foreign application: $p_{ai} = 0 \; if \; a = i$. Also note that this measure gives a small error due to the fact that one of the receiving offices differs in the comparison between each pair of nations of origin since patenting from one nation to its own patent office is excluded. However, no good way of excluding this error has been found.

office (country), and smaller than 1 if the opposite applies. Analogously with above, the **RMA difference index** between two countries, a and b, is defined as[14]:

$$d_{ab}^{RMA} = d_{ba}^{RMA} = \frac{\sum_{i=1}^{N} |RMA_{ai} - RMA_{bi}|}{2}$$

There are some problems related to this measure, since RMA can take on values between 0 and ∞ and thus is not bounded. Therefore we also introduce a third difference index, based on a symmetric RMA, a normalization giving a symmetric index as suggested by Dalum et al. (1998) in the case of revealed comparative advantage.[15] We thus define the revealed symmetric market advantage, RSMA, as:

$$RSMA_{ai} = \frac{RMA_{ai} - 1}{RMA_{ai} + 1}$$

The **RSMA difference index** is constructed as previously:

$$d_{ab}^{RSMA} = d_{ba}^{RSMA} = \frac{\sum_{i=1}^{N} |RSMA_{ai} - RSMA_{bi}|}{2}$$

The reason why three different indices are used is that the results from the statistical analysis are sensitive to the index construction. The market share difference index is e.g. in many cases mainly impacted by the largest markets, since they downplay the shares for the smaller ones. A large increase in importance of a specific output market in general for all countries leads to a convergence in this measure, by downplaying the differences in smaller markets. The RMA difference index on the other hand puts more weight on the smaller markets, since these are impacting the index as much as the larger ones. This might create an overweight in importance for otherwise rather unimportant output markets. Therefore, using more than one index in a sensitivity analysis reduces the risk of misrepresentation and misinterpretation.

In addition to the difference indices, the Herfindahl-Hirschman index is calculated and used as a measure of the foreign market concentration from a specific country of origin. Thus, this is defined in the usual way as:

$$H_a^M = \sum_{i=1}^{N} \left(\frac{p_{ai}}{\sum_{j=1}^{N} p_{aj}} \right)^2$$

Here p_{ai} is the number of foreign applications from country a to receiving office i, and N is the total number of countries. This is used as a measure of the intra-national market specialization (or reversely market diversification, defined as in previous studies as $1 - H_a^M$).

[14] Note that the division by two is kept for consistency, although it does not limit the index measure to a number between 0 and 1 in this case.

[15] Other forms of normalizations have also been used, e.g. logarithmic transformation as in Soete and Verspagen (1994).

3.3 Technology difference indices

Three technology difference indices are introduced analogously with the ones above in order to measure the technology convergence (or inter-national specialization). Our first technology difference index, the **technology share difference index**, is a technology distance measure between two countries, a and b, constructed by the following formula:

$$d_{ab}^{TS} = d_{ba}^{TS} = \frac{\sum_{i=1}^{M} |s_{ai} - s_{bi}|}{2}$$

Here s_{ai} is the share of all US patent applications from country a that belong to US patent class i and M is the total number of US patent classes. Hence, $s_{ai} = p_{ai}/\sum_{i=1}^{M} p_{ai}$ where p_{ai} is the number patent applications from country a in patent class i. This again gives a metric difference index d^{TS}, which is 1 when there is a complete difference and 0 when there is no difference at all (i.e. there is no technological distance between country a and b).

The second measure of technology difference is based on the revealed technological advantage, RTA of country a in technology i, as traditionally defined:

$$RTA_{ai} = \frac{p_{ai}/\sum_{i=1}^{M} p_{ai}}{\sum_{j=1}^{N} p_{ji}/\sum_{j=1}^{N}\sum_{i=1}^{M} p_{ji}}$$

Here p_{ai} is again the number patent applications from country a in patent class i, M is the total number of patent classes, and N is the total number of countries. Thus, RTA indicates whether or not a technology's patent share in a country is larger than the technology's share of all patents (across countries).[16] Note that the denominator in RTA may get arbitrarily small, e.g. for a new technology i. Thus, RTA is an unbounded measure. Based on RTA, we introduce the **RTA difference index** between two countries, a and b:

$$d_{ab}^{RTA} = d_{ba}^{RTA} = \frac{\sum_{i=1}^{M} |RTA_{ai} - RTA_{bi}|}{2}$$

The revealed symmetric technological advantage, RSTA, is defined as:

$$RSTA_{ai} = \frac{RTA_{ai} - 1}{RTA_{ai} + 1}$$

The **RSTA difference index** is introduced as previously:

$$d_{ab}^{RSTA} = d_{ba}^{RSTA} = \frac{\sum_{i=1}^{M} |RSTA_{ai} - RSTA_{bi}|}{2}$$

[16] Careful use of concepts and terminology is called for in this context. Note e.g. that:

$$RTA_{ai} = \frac{p_{ai}/\sum_{i=1}^{M} p_{ai}}{\sum_{j=1}^{N} p_{ji}/\sum_{j=1}^{N}\sum_{i=1}^{M} p_{ji}} = \frac{p_{ai}/\sum_{j=1}^{N} p_{ji}}{\sum_{i=1}^{M} p_{ai}/\sum_{j=1}^{N}\sum_{i=1}^{M} p_{ji}}$$

Thus, a simple algebraic rearrangement shows that the RTA-measure also indicates if a country's patent share in a technology is larger than the country's share of all patents (across technologies). Therefore, the traditional interpretation in terms of a country's relative technology specialization just as well could be phrased in terms of a technology's relative country specialization.

Finally, the Herfindahl-Hirschman index is again calculated and used as a measure of the technology concentration from the point of view of a specific country of origin. This is defined as:

$$H_a^T = \sum_{i=1}^{M} \left(\frac{p_{ai}}{\sum_{j=1}^{M} p_{aj}} \right)^2$$

Here p_{ai} is the number of US patent applications from country a in patent class i, and M is the total number patent classes. This is used as a measure of the intra-national technology specialization (or reversely technology diversification, defined as in previous studies as $1 - H_a^T$).

3.4 A note on the statistical tests

All difference indices are calculated for all comparison pairs of countries of origin, resulting in $\frac{N^2-N}{2}$ unique difference indices for each year and each type of index, with N number of countries (170+, but slightly varying in the different datasets). However, in many cases data is missing, resulting in a significantly lower number of unique difference indices, as presented in the empirical results.

The Student's paired t-test is used to test the change in differences between two years. For changes in market differences, the years 1995 and 2004 are compared. The reason why 2004 was chosen as the latest year is that the WIPO statistics lag somewhat, and data from some major countries' patent offices, including India's, is still not included for later years.[17] However, for some of the descriptive statistics later years are also included. For changes in technology differences, the years 2005 and 2009 are compared as they are the earliest and latest years with data freely available and accessible on the USPTO website.

Even though the distributions studied in this paper in general are symmetric and unimodal, they are not normally distributed, especially not the unbounded RTA-based difference indices. Therefore, the Wilcoxon signed-rank test is used to complement the Student's t-test.

4 Empirical evidence

4.1 Market convergence

Changes in three market difference indices, as described above, are used to measure inter-national market convergence and/or specialization. The market difference indices are created in the comparison of two countries of origins of the patent, and all comparison pairs of countries are included in the analysis. Hence, each country of origin is compared with all other countries of origin regarding their foreign patent applications. Since we are interested in investigating signs of convergence, we focus on the unique country comparisons with available numbers for both 1995 and 2004, all in all 2080 ones. We measure convergence as

[17] Missing data in WIPO's statistics is a source of potential error in this study.

the change in the market difference indices from 1995 through 2004. A positive change indicates inter-national market specialization and a negative change indicates inter-national market convergence in patenting patterns.

Based on the full set of market difference indices for 1995 and 2004, respectively, an analysis of the change is performed and the results are presented in Table 1. Our statistical analysis shows significant decreases in all three market difference indices between 1995 and 2004.

Table 1 Summary of statistical results of market convergence and concentration

	n	1995 Mean	2004 Mean	Mean change	% Change	Estimated median of change
d^{MS}	2080	0.65578	0.51853	-0.13724***	-20.93%	-0.1647###
d^{RMA}	2080	288.7	142.0	-146.61***	-50.81%	-58.77###
d^{RSMA}	2080	22.825	18.787	-4.038***	-17.69%	-4.047###
H^{M}	65	0.4817	0.2996	-0.1821***	-37.80%	-0.1548###

Notes:
* Mean change different from zero with 0.05 significance (paired t-test)
** Mean change different from zero with 0.01 significance (paired t-test)
*** Mean change different from zero with 0.001 significance (paired t-test)
# Median change different from zero with 0.05 significance (Wilcoxon signed-rank test)
Median change different from zero with 0.01 significance (Wilcoxon signed-rank test)
Median change different from zero with 0.001 significance (Wilcoxon signed-rank test)

The decreases in market difference indices indicate that there has been an inter-national market convergence between 1995 and 2004 (i.e. that the inter-national market specialization has decreased). Table 1 also includes results regarding the Herfindahl-Hirschman index, which is here used as a measure of the intra-national market specialization (or reversely market diversification) of a specific country of origin, or more specifically a measure of the market concentration of its foreign patent applications. The results show a decline in market concentration. These two results together indicate that countries have widened their markets for patenting, becoming more intra-nationally diversified in terms of output markets, at the same time as the differences between various countries of origin have decreased in terms of their output markets, indicating inter-national market convergence.

The market concentration is further illustrated in Figure 1 where the worldwide average of the market concentration is presented for the years 1995 through 2008 together with the concentrations of a number of reference countries. An issue that impacts the results of the worldwide average is the fact that new countries of origin are added and included in the average each year. These countries commonly have little foreign patenting and therefore also quite high concentrations of foreign patenting (and thereby inflate the average). Therefore our main emphasis should be put on the adjusted worldwide average, since that average is constructed as an index based on the average in the first year, and where the changes between each year are only based on the countries with available data for both years of comparison (similar to what is done when using for example the paired t-test).[18]

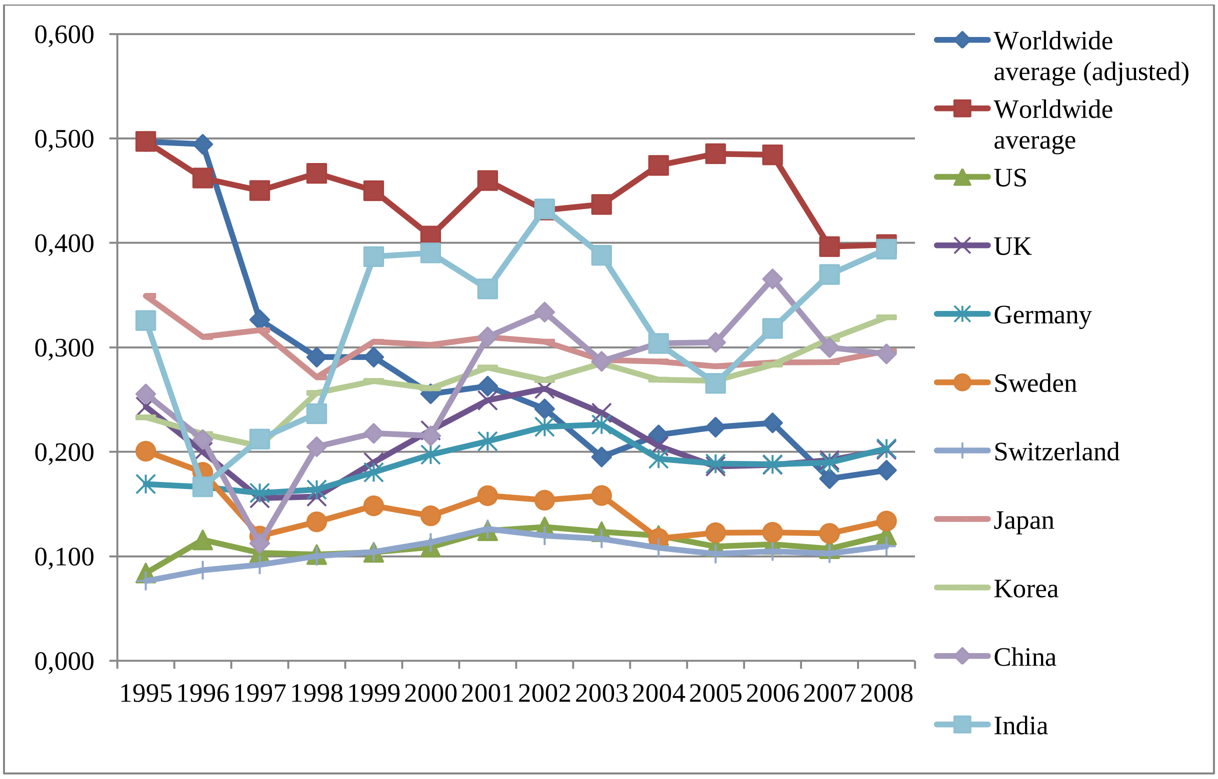

Figure 1 Concentration of markets for foreign patent applications

The difference between the adjusted and the unadjusted worldwide averages of concentration indicates that the major decline in concentration is found among countries where the foreign patenting is a recent phenomenon (or even introduced during the period of observation). This is indicated also by Table 2, since the countries with the largest decreases in market concentration from 1995 to 2008 have the same size of their absolute and relative decreases meaning that they had a Herfindahl-Hirschman index equal to 1 in 1995 (which is true only when the foreign patenting is performed on one market only). Hence, such major decreases in market concentration are phenomena existent among countries with limited foreign patenting in 1995.

[18] Note that missing data from various patent offices for different years might also impact the results for different years, but since this is only true for some small patent offices (except possibly India) this impact is expected to be small.

Table 2 Growth (or decrease) in market concentration from 1995 to 2008

Country of origin	Abs Growth (% Growth)	Country of origin	Abs Growth (% Growth)
Panama	-0.92 (-92%)	Slovakia	-0.03 (-19%)
Cuba	-0.91 (-91%)	Israel	-0.03 (-8%)
Monaco	-0.88 (-88%)	Portugal	-0.02 (-15%)
Chile	-0.84 (-84%)	Ireland	-0.01 (-9%)
Iceland	-0.83 (-83%)	Norway	-0.01 (-8%)
Croatia	-0.82 (-82%)	Greece	-0.01 (-7%)
Tunisia	-0.80 (-80%)	South Africa	-0.01 (-6%)
Brunei Darussalam	-0.79 (-79%)	Cook Islands	0.00 (0%)
Saudi Arabia	-0.78 (-78%)	Côte d'Ivoire	0.00 (0%)
Singapore	-0.76 (-76%)	France	0.00 (1%)
Barbados	-0.76 (-76%)	Turkey	0.00 (1%)
Thailand	-0.70 (-70%)	Finland	0.01 (9%)
Uruguay	-0.67 (-67%)	Czech Republic	0.02 (12%)
Belarus	-0.63 (-63%)	Italy	0.02 (11%)
Indonesia	-0.62 (-62%)	Netherlands	0.02 (16%)
Malaysia	-0.62 (-62%)	Luxembourg	0.03 (35%)
Vanuatu	-0.61 (-61%)	Switzerland	0.03 (44%)
Bermuda	-0.60 (-60%)	Germany	0.03 (20%)
Sri Lanka	-0.46 (-46%)	United States of America	0.04 (43%)
Hong Kong (SAR). China	-0.44 (-44%)	China	0.04 (15%)
Cyprus	-0.39 (-79%)	Hungary	0.04 (36%)
Slovenia	-0.37 (-67%)	Australia	0.05 (26%)
Netherlands Antilles	-0.18 (-21%)	Liechtenstein	0.06 (48%)
Poland	-0.15 (-34%)	Austria	0.06 (49%)
Canada	-0.12 (-22%)	Brazil	0.06 (48%)
European Patent Office	-0.11 (-11%)	India	0.07 (21%)
Sweden	-0.07 (-33%)	Spain	0.08 (89%)
Denmark	-0.07 (-30%)	Romania	0.09 (53%)
New Zealand	-0.06 (-25%)	Republic of Korea	0.10 (41%)
Japan	-0.05 (-15%)	Ukraine	0.12 (24%)
Mexico	-0.05 (-15%)	Unknown	0.13 (104%)
Belgium	-0.05 (-24%)	Argentina	0.14 (93%)
United Kingdom	-0.04 (-17%)	Bulgaria	0.27 (180%)
Russian Federation	-0.04 (-17%)		

4.2 Technology convergence

Few, if any, studies on technology convergence (or reversely inter-national specialization) have previously been performed including data on all countries active in (US) patenting. Moreover, previous studies have commonly used either the RTA-index or other indicators giving equal weight to small and large technological areas. In this study we use three different indices to control for biases due to index constructions. We use the US market as a reference market, as it is probably the world's most important market for patenting currently, and include data on all available countries. The use of US as a reference market might slightly bias the measures depending on closeness to the US, and this needs to be taken into consideration. However, in this case the changes over time are of most interest, and therefore this bias is expected to have little impact. We use the statistics on various countries' patenting in the 404 different US patent classes, and calculate three technology difference indices analogously with the market difference indices above and as described in the methodology section above. Changes in these indices are used to indicate inter-national technology convergence (when differences decrease) or inter-national technology specialization (when differences increase). We base the statistical analysis on the unique country comparisons with available numbers for both 2005 and 2009, which amount to 3570 ones. The results are presented in Table 3.

Table 3 Summary of statistical results of technology convergence and concentration

	n	2005 Mean	2009 Mean	Mean change	% Change	Estimated median of change
d^{TS}	3570	0.91999	0.89610	-0.02389***	-2.60%	-0.01728###
d^{RTA}	3570	609.0	681.3	72.3***	11.87%	-37.30###
d^{RSTA}	3570	65.628	65.768	0.140	0.21%	0.2758#
H^T	85	0.2631	0.2021	-0.0610*	-23.19%	-0.01658#

Notes:
* Mean change different from zero with 0.05 significance (paired t-test)
** Mean change different from zero with 0.01 significance (paired t-test)
*** Mean change different from zero with 0.001 significance (paired t-test)
# Median change different from zero with 0.05 significance (Wilcoxon signed-rank test)
Median change different from zero with 0.01 significance (Wilcoxon signed-rank test)
Median change different from zero with 0.001 significance (Wilcoxon signed-rank test)

Our results show that there is a decrease in the technology share difference index (d^{TS}), indicating technology convergence. The change in the RTA difference index (d^{RTA}) has a mean above zero, but a median below zero. This indicates a skewness in the distribution, which has been confirmed also by graphical analysis. Hence, the statistical results from the analysis of the RTA difference index does neither indicate convergence, nor specialization. The RSTA difference index (d^{RSTA}, which is a symmetric version of d^{RTA}) shows an (insignificant) increase.[19] To summarize, the results mainly indicate inter-national technology convergence, although with some signs of inter-national technology specialization according to certain measures.[20] Finally, the intra-national technology specialization, measured by the

[19] Interesting to note is how the normalization of the RTA-index (d^{RTA}) into the RSTA-index (d^{RSTA}), severely reduces the significance of the statistical results, showing the sensitivity of RTA-based results to a transformation of the unbounded RTA-measure into a bounded RSTA-measure.

[20] To explain this we need to consider the index constructions. The technology share difference index (d^{TS}) is a measure of the differences in the shares of two countries' patent applications in different patent classes, meaning that the largest patent classes have most impact on the measure. The RTA and RSTA difference indices (d^{RTA} and d^{RSTA}) are normalized in this regard and give equal weight to differences in all patent classes (giving larger weight to many small classes). Therefore, we can conclude that while the differences measured with RTA and RSTA could possibly be increasing (inter-national technology specialization), the same main technological areas (patent classes) tend to grow larger or smaller in importance for all countries (inter-national technology convergence).

Herfindahl-Hirschman index, is decreasing, meaning that there is intra-national technology diversification.

Continuing to the more descriptive statistics, some interesting developments in terms of US patents can be seen in Table 4. Many newly industrialized countries, including Korea, China and India, have impressive GDP growths. The compounded annual growth rates (CAGR) in constant prices between 1996 and 2009 are 4.1% for Korea, 9.8% for China, and 6.8% for India[21]. However, their growths in US patenting and patent productivity measured as granted patents per capita are even steeper than their GDP growths (although from very low levels), see Table 4. The CAGRs of the number of patents granted in the US over the same time period are 14.6% for Korea, 31.7% for China, and 25.6% for India. Brazil and Russia on the other hand do not show similar increases in patent rankings or patent productivity, although they had fairly high levels initially in the studied time period compared to some of the other NICs.

The climbing of China and India on the rankings of foreign US patentees is even more noteworthy due to their still comparatively low patent productivity. Hence, there is still room for a continued growth. If China would have had the same productivity as e.g. Sweden in 2009, China would have been granted approximately 150 000 US patents. Another interesting fact is that if the growth of granted patents between 1996 and 2009 continues with the same pace[22], China will pass Japan as the top foreign country in terms of the number of US patents per year within approximately 12 years, i.e. around 2020, which is a year targeted in China's long term science and technology (S&T) development plans for the transition into an innovation-oriented economy. China will then not only be an economic superpower (as is already the case as proved by China passing Japan as the world's second largest economy after the US in 2010), but also an innovative superpower. The legal changes in China in terms of IPRs as discussed below will here play an important role, and one can actually talk about future IP superpowers, as IP is likely to become even more important in the future world economy.

The recent developments in China and India leads to a related question: Which are the technological areas in which China and India increase their patenting the most? This question is addressed in Table 5 and Table 6 where the patent classes in which absolute patenting has increased the most from these countries are listed. Note that the majority of the patent classes are related to electronics and information and communication technologies (ICTs). Part of the explanation for this might be a relatively high propensity to patent in hi-tech industries, see e.g. Brouwer and Kleinknecht (1999). Also note that eleven out of the top 20 patent classes in these countries are on both lists. This gives an illustration to the conclusion above, namely that the same patent classes tend to grow large throughout the world.

[21] Calculations are based on UN statistics.
[22] Japan: 3.4% per year, China: 32% per year.

Table 4 Top twenty foreign countries regarding number of patents granted in the USA in the period 1996-2009, including patents per million capita

Rank	Country	1996	Per M capita	Country	2003	Per M capita	Country	2009	Per M capita
1.	Japan	23053	183	Japan	35515	279	Japan	35501	279
2.	Germany	6818	83.3	Germany	11444	139	Germany	9000	109
3.	France	2788	46.6	Taiwan	5298	-	Korea	8762	181
4.	UK	2454	42.2	Korea	3944	83.6	Taiwan	6642	288
5.	Canada	2232	75.4	France	3868	62.4	Canada	3655	108
6.	Taiwan	1897	-	UK	3631	60.9	UK	3175	51.6
7.	Korea[1)]	1493	33.2	Canada	3427	108	France	3140	48.9
8.	Italy	1200	21.0	Italy	1722	29.7	China	1655	1.25
9.	Switzerland	1112	157	Sweden	1521	170	Israel	1404	196
10.	Sweden	854	96.5	Netherlands	1325	82.0	Italy	1346	22.5
11.	Netherlands	797	51.3	Switzerland	1308	178	Netherlands	1288	77.6
12.	Belgium	488	48.3	Israel	1193	185	Australia	1221	57.3
13.	Israel	484	87.5	Australia	902	45.3	Switzerland	1208	160
14.	Australia	471	25.7	Finland	865	166	Sweden	1014	110
15.	Finland	444	86.6	Belgium	622	60.3	Finland	864	162
16.	Austria	362	45.5	Austria	592	72.8	India	679	0.567
17.	Denmark	241	45.9	Denmark	529	98.2	Belgium	594	55.8
18.	Spain	157	3.98	Singapore	427	103	Austria	503	60.1
19.	Norway	139	31.7	India	342	0.312	Singapore	436	92.0
20.	Russia[2)]	116	0.782	Spain	309	7.38	Denmark	390	71.3
	22. Singapore	88	24.5	21. China	297	0.233	24. Russia	196	1.39
	25. Brazil	63	0.384	24. Russia	203	1.40	28. Brazil	103	0.532
	27. China[3)]	46	0.0383	27. Brazil	130	0.716			
	30. India	35	0.0360						

Notes:

1) Korea = Republic of Korea (South Korea)

2) Russia = Russian Federation

3) China, mainland excl. Hong Kong

Sources: USPTO statistics on patents, UN statistics on populations

Besides the absolute increase of patent numbers in these classes, an important observation is that at least China's patent shares increased steeply over the short time between 2005 and 2009. In e.g. the heat exchange patent class, China's patent share has grown from 0.5% to 9.6%. China's average increase in patent shares between 2005 and 2009, averaged over all 404 patent classes, is 0.56%-units, while China's share of foreign patent applications in the

US during the same time has increased more than threefold from 0.58% to 1.95% (with a similar increase in the share of foreign granted patents in the US).

India's patenting does not grow as fast as China's. India's average patent share over all different classes has even decreased with 0.10%-units. However, India's share of foreign patent applications in the US has in this short time period increased from 0.56% to 0.80% (again with a similar increase in the share of granted patents).

Table 5 Top 20 US patent classes where China has increased its patenting the most between 2005 and 2009

		Absolute numbers			Patent shares		
Patent class	**Ranked after increase in absolute numbers**	**2005**	**2009**	**Growth**	**2005**	**2009**	**Growth (%-units)**
361	Electricity: Electrical Systems and Devices	8	128	120	0.55%	6.05%	5.49%
439	Electrical Connectors	54	145	91	2.99%	7.02%	4.03%
370	Multiplex Communications	6	85	79	0.22%	1.61%	1.39%
382	Image Analysis	5	55	50	0.37%	2.10%	1.74%
707	DP: Database and File Management or Data Structures (Data Processing)	6	47	41	0.49%	1.64%	1.15%
324	Electricity: Measuring and Testing	2	30	28	0.12%	1.73%	1.61%
345	Computer Graphics Processing and Selective Visual Display Systems	5	32	27	0.25%	1.24%	0.99%
709	Multicomputer Data Transferring (Electrical Computers and Digital Processing Systems)	3	29	26	0.19%	0.88%	0.69%
362	Illumination	6	31	25	0.63%	2.31%	1.68%
438	Semiconductor Device Manufacturing: Process	9	34	25	0.20%	0.69%	0.49%
713	Support (Electrical Computers and Digital Processing Systems)	1	26	25	0.10%	1.39%	1.29%
165	Heat Exchange	2	24	22	0.47%	9.56%	9.09%
378	X-Ray or Gamma Ray Systems or Devices	3	25	22	0.65%	3.58%	2.93%
327	Miscellaneous Active Electrical Nonlinear Devices, Circuits, and Systems	1	21	20	0.09%	1.70%	1.61%
455	Telecommunications	6	26	20	0.26%	0.77%	0.51%
340	Communications: Electrical	1	20	19	0.07%	1.07%	1.00%
375	Pulse or Digital Communications	9	28	19	0.57%	1.23%	0.66%
714	Error Detection/Correction and Fault Detection/Recovery	1	20	19	0.09%	0.96%	0.87%
379	Telephonic Communications	1	19	18	0.11%	2.44%	2.33%
532	Organic Compounds (includes Classes 532-570)	5	23	18	0.24%	0.83%	0.60%
						Avg. for all classes:	**0.56%**

Source: USPTO statistics

Table 6 Top 20 US patent classes where India has increased its patenting the most between 2005 and 2009

		Absolute numbers			Patent shares		
Patent class	**Ranked after increase in absolute numbers**	**2005**	**2009**	**Growth**	**2005**	**2009**	**Growth (%-units)**
714	Error Detection/Correction and Fault Detection/Recovery	2	43	41	0.17%	2.06%	1.89%
707	DP: Database and File Management or Data Structures (Data Processing)	6	43	37	0.49%	1.50%	1.01%
370	Multiplex Communications	7	37	30	0.26%	0.70%	0.45%
375	Pulse or Digital Communications	2	23	21	0.13%	1.01%	0.89%
532	Organic Compounds (includes Classes 532-570)	61	78	17	2.88%	2.82%	-0.05%
711	Memory (Electrical Computers and Digital Processing Systems)	9	23	14	0.70%	1.44%	0.74%
709	Multicomputer Data Transferring (Electrical Computers and Digital Processing Systems)	12	24	12	0.76%	0.73%	-0.03%
713	Support (Electrical Computers and Digital Processing Systems)	2	13	11	0.20%	0.70%	0.49%
710	Input/Output (Electrical Computers and Digital Processing Systems)	0	10	10	0.00%	0.92%	0.92%
717	DP: Software Development, Installation, and Management (Data Processing)	7	17	10	1.50%	2.05%	0.55%
382	Image Analysis	6	15	9	0.44%	0.57%	0.13%
715	DP: Presentation Processing of Document, Operator Interface Processing, and Screen Saver Display Processing (Data Processing)	4	12	8	0.55%	0.89%	0.35%
365	Static Information Storage and Retrieval	3	10	7	0.15%	0.42%	0.27%
455	Telecommunications	3	10	7	0.13%	0.30%	0.17%
327	Miscellaneous Active Electrical Nonlinear Devices, Circuits, and Systems	9	14	5	0.85%	1.13%	0.29%
705	DP: Financial, Business Practice, Management, or Cost/Price Determination (Data Processing)	4	9	5	0.52%	0.46%	-0.06%
708	Arithmetic Processing and Calculating (Electrical Computers)	1	6	5	0.43%	2.14%	1.71%
718	Virtual Machine Task or Process Management or Task Management/Control (Electrical Computers and Digital Processing Systems)	1	6	5	0.56%	2.30%	1.74%
726	Information Security	0	5	5	0.00%	0.51%	0.51%
340	Communications: Electrical	0	4	4	0.00%	0.21%	0.21%
						Avg. for all classes:	**-0.10%**

Source: USPTO statistics

5 Discussion and managerial implications

In summary, our empirical results indicate:

1. Continuous growth of international patenting.
2. Inter-national market convergence of patenting according to all our indicator tests.
3. Inter-national technology convergence according to some of our indicator tests.
4. Decreases in both market and technology concentrations of patenting, i.e. increasing market diversification as well as technology diversification.

For detailed interpretations of these results, the importance of definitions and operationalizations of intra-national diversification/specialization, and inter-national convergence/specialization must be kept in mind. Inter-national technology specialization defined and measured by RTA and RSTA indicators is by and large prevalent according to many previous studies. However, since the RTA and RSTA types of operationalizations mainly used in previous studies of inter-national technology specialization are normalized in a way that gives equal weight to all technological areas, large as well as small, the trends in the most important technological areas are possibly given too limited emphasis in those studies. Thus RTA and RSTA indices could lead to overemphasis on technology specialization, especially if technology concentration is high with a long thin tail. One ought therefore to be cautious when interpreting results and drawing managerial implications based on only the RTA and RSTA difference indices. Depending on how technological areas are defined (e.g. depending on which level the patent classes are defined in a hierarchical patent classification system) there can be more or less biased effects. The more narrow the classification, the more emphasis is likely put on small technological areas. In this study 404 classes of US patents are used, which must be considered a narrow classification, and therefore our technology share difference index does more adequately express the trends in the largest (in terms of patenting) technological areas, then showing increasing similarities between countries in such terms.[23]

Further, it should be noted that inter-national market convergence and inter-national technology convergence could conceivably be negatively correlated. If consumption patterns converge throughout the world at the same time as different countries become increasingly technologically specialized relative to each other, the relative importance of various output markets for different countries of origin will likely converge (inter-national market convergence). On the other hand, if industries across countries increasingly work in similar technological areas, i.e. in case of inter-national technology convergence, this could conceivably promote market specialization across countries rather than market convergence.

As the results indicate, intra-national market diversification as well as technology diversification increases. This in turn indicates an expansion of both the market base (set of output market areas) and the technology base (set of areas of technological inputs) for various countries. Contrary to what one could expect from a competition point of view, this expansionary process is in turn co-evolving with both market convergence and (based on our index) technology convergence. Management in major industries in various countries then seems to adopt the strategy to compete in similar major market areas and in similar major technological areas. This in turn likely leads to more competitive encounters between companies of different nationalities and to the extent that these companies in turn are multinational to more competitive encounters between the same leading MNCs from various countries across markets and technologies. The resulting impact of these encounters upon marketing management and technology management is then conceivably leading to even more increased management convergence, at least in certain management aspects, everything else equal. If managerial strategies and skills are decisive for survival in competitive games, competitive exclusion would then likely eliminate inferior management and less than best practices in case of sustained market and/or technological convergence. As for developing

[23] One could possibly then counter-argue that the technology share difference index used here gives too much weight to patent intensive technological areas and too little weight to other areas. This leads us to emphasize the need for further research with a more axiomatic approach to index construction to reduce bias.

countries catching up, some scholars argue that technology management skills for imitative catch-up are different from innovation management skills. However, in the case of Japan, there have been few signs of substantial differences of that kind, and few signs of any economic importance of such differences in a transition to a more innovative stage (Granstrand, 1999). The trend toward more open innovation, which is an inherent feature of catching up, is likely reinforcing such a development pattern.

One management area linked to technology management in particular, but also to marketing management, is IP management. In light of the significant growth of patenting in general and international patenting in particular, the strong growth of international technology licensing, and on top of that the international dispersion of patentees, IP management becomes increasingly important and then as a corollary multinational IP management, including management of licensing and international technology trade (see e.g. Arora et al., 2001, and Granstrand, 2004). Moreover, internationalization of R&D and technology sourcing and exploitation likely increases internationalization of IP operations. As the multinational competitive encounters increases internationally, and the patents to support technology-based businesses not only increase in volume and importance but also become increasingly dispersed across more players, the so called IP assembly problem becomes more complex and costly to manage.[24] This in turn requires technology management skills in responding to patent blockage by various technology acquisition strategies, like licensing, cross-licensing, patent pooling, invent around R&D, etc. together with various IP legal strategies.

Technology and market diversification and convergence with more localized technology specialization moreover likely lead to more open innovation and collaborative encounters, and collaborative encounters also increases the need for skills in IP management, including skills in coping with the IP assembly problem and the IP sharing problem. Finally, previous studies show a strong positive correlation between technology diversification and economic growth at company level in various countries.[25] If now there is technology and market convergence in addition to technology diversification, a prediction is that economic convergence will increase. This is a testable hypothesis that falls outside the empirical scope of this paper to probe, and is thus suggested for further research.

As to technology, market and management convergence in relation to IP legal convergence, multinational IP management has to deal with differences in IP legal systems across countries, which increases management costs. If these systems converge, there will be substantial cost-savings and a likely increase in IP management convergence as well.

There are in fact indications of convergence of IP legal systems, albeit at a slow pace. The Agreement on Trade-Related Aspects of Intellectual Property Rights (TRIPS) and its World Trade Organization (WTO) enforcement has on average strengthened the often weak IP

[24] The IP assembly problem refers to the problem to assemble the necessary IPRs in order to do business, see Granstrand (1999).

[25] See e.g. Cantwell et al. (2004) and Granstrand et al. (1992, 1997) for studies of the links between increasing technological diversification, increasing in-house R&D together with increasing external technology acquisition, i.e. increasingly open innovation, and economic growth.

regimes in developing countries, inducing an upward convergence to levels in developed countries who exercise external pressure on developing countries to switch to a strong IP regime. Internal conditions within developing countries may however induce them to try to choose a suitable transition time period for switching from a weak to a strong patent system and appropriation regime. Since the patent system is not very industry specific (i.e. it is a "one size fits all" type of system, criticized among others by Thurow, 1997) and development stages of industries may differ widely in developing countries, the optimal timing of such a switch or transition is hard to find and is in addition likely to be subjected to industry lobbying. Nevertheless, as countries, industries and companies climb the development ladder(s), i.e. move ahead from a more imitative catch-up stage to a more innovative forging ahead stage, it is likely that from a national economic point of view the aggregate benefits from a strong IP regime (e.g. in attracting inward foreign direct investments in R&D and hi-tech production, incentivizing domestic R&D investments and technology trade, as well as reducing imitation from countries trailing behind technologically) at some point on average outweigh the benefits from a weak IP regime (e.g. incentives for imitative entrepreneurship, piracy, counterfeiting and domestic diffusion of new technologies).[26] [27]

This strengthening of IP regimes for domestic economic purposes has taken place in Japan and Korea and is clearly taking place in China and India. All these countries have with varying time lags recognized the importance of indigenous innovation for economic development and have subsequently introduced various innovation inducing policy measures, including the strengthening of the IP regime and the IP legal system. One may even venture to say that IP policies and IP issues at large have gradually become more closely linked to innovation issues than to traditional trade issues in these countries.[28] Russia is a bit of a special case with a recently developed patent system, much patterned on Western ones, but still with very little patenting by domestic industry and very little IP litigation. It is also noteworthy in this context that few if any countries with an open economy have historically been able to effectively catch-up technologically in the presence of a strong IP regime domestically and abroad. Neither has any country (in an open economy) been trying, let alone been able to, forge ahead with a weak IP regime domestically, after once having caught-up.

The case of China is of special interest for various reasons. China introduced new patent laws in the 2000s, just as Brazil and India (see e.g. Li, 2010 and Mukherjee, 2006). These laws essentially strengthen the patent system, needless to say for national economic purposes.[29]

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[26] The role of strong IP regimes for attracting inward FDIs has been studied empirically by e.g. Mansfield (1994, 1995) and the role of strong IP regimes for economic growth by e.g. Park and Ginarte (1997).

[27] Some form of co-existence of strong and weak parts in different industries or regions is feasible, at least temporarily.

[28] Traditionally trade related issues mostly concern trade on product markets (e.g. piracy, counterfeiting, parallel imports, and access to medicines) rather than trade on technology markets.

[29] Throughout the whole history of patent system developments, changes have frequently been enacted with protectionist purposes. A major example is the US switch to a much stronger pro-patent era in the early 1980s as a response to Asian competition, a switch that subsequently led to substantial strengthening of the IP systems worldwide. The patent system in fact opens up many possibilities to opportunistic protectionist behavior. E.g. at the detailed level of inventive step requirements for patentability of an invention in a country, a high step requirement may be used by a developing country to be able to more freely reject patent applications from

China is then in a mixed mode of actual IP enforcement, being weak in some areas and regions and strong in others. Foreign companies and countries have prepared a certain set of strategies for appropriating invention benefits in a weak IP regime in China (see e.g. Keupp et al., 2010), while being less prepared for a new strong IP regime. In general, Western technology and marketing management then tend to be more concerned about appropriation strategies in weak IP regimes than the long-term competitive implications of increasing IP portfolios and IP management skills in countries that switch from weak to strong IP regimes.

Finally, as to economic convergence as an overarching issue at macro level, it is hard to conceive of a world with sustained absence of economic convergence in the presence of convergence in other essential dimensions, including technology, market, management, and legal convergence. Economic convergence could on the other hand conceivably be present in a world with absence of some or all of technology, market, management, and legal convergence. One may e.g. conceive of a world with countries with planned or market economies, common or civil law systems, East or West management styles, specialized technologies and specialized markets. To the extent that competitive forces, including competition between economic systems, can play out such a world is not likely sustainable, again with an, admittedly general, reference to competitive exclusion. Openness of economies – enabling economies of scale, larger returns on R&D, more R&D spill-overs, and more efficiency-inducing effects from cross-border mobility of resources – is sufficient for competitive exclusion to play out on a global level. However, openness of an economy is not a necessary condition as demonstrated by the breakdown of the Soviet empire under pressure from military competition, inferior technological innovativeness and economic ineffectiveness. Theoretically seen, equilibria with multiple optima along a development path is not likely to be stable, and practically seen, history has no clear illustration of that.

6 Conclusions

This paper addresses various dimensions of convergence in a global context – market, technology, management, legal, and economic convergence. An empirical analysis of market and technology convergence based on worldwide patent statistics has employed both new and old measures of convergence, specialization, and diversification of markets and technological areas among the world's countries. In addition field studies in Asia, Europe, and US with a focus on innovation and IP policies and management have been conducted. We may conclude that there are indications of global convergence in form of inter-national market convergence and to a certain extent inter-national technology convergence and IP legal convergence, together with intra-national market and technology diversification. This is in contrast to some previous research indicating increasing technology specialization. Market, technology, and IP legal convergences in turn likely imply increased convergence of multinational technology management, and then IP management, as an increasingly important part thereof. Whether

abroad, and a low step requirement may be used by a developed country to allow for patent strategies such as flooding (blanketing or thicketing) and evergreening by domestic large firms with numerous minor product and process improvements (see Granstrand 1999b, 2003).

these developments will lead to increased economic convergence is difficult to say on the basis of our current knowledge, but a testable hypothesis suggested for further research is that so is the case.

As to managerial implications, global developments of the sort discussed in this paper calls for increasing skills in multinational intellectual property management (IPM), increasingly becoming a core skill in multinational technology management (e.g. in licensing and litigation). This managerial implication is valid for both developed and developing countries. Increasing technology- and innovation-based competition from ANICs should then be of more concern for technology management in industrialized countries (ICs) than short-term concern over piracy, free-riding, counterfeiting, parallel imports, and other related issues. A companion policy implication, briefly put, is that countries around the world should worry more about innovation related IP issues than about traditional trade related IP issues in the years to come.

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