STI 2018 Leiden

23rd International Conference on Science and Technology Indicators

"Science, Technology and Innovation Indicators in Transition"

STI 2018 Conference Proceedings

Proceedings of the 23rd International Conference on Science and Technology Indicators

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ISBN: 978-90-9031204-0

The catching-up of Asian and European countries in ICT: from a new patent data perspective[1]

Na Zhang[*], Julie Callaert[**] and Bart van Looy[**]

[*] zhangna0610@mail.dlut.edu.cn
Faculty of Business and Economics, Dalian University of Technology, Linggong Road 2, Dalian, 116024 (China)

[**] Julie.callaert@kuleuven.be; bart.vanlooy@kuleuven.be
MSI, Faculty of Business and Economics, KU Leuven, Naamsestraat 69, Leuven, 3000 (Belgium)

Introduction

ICT is considered as the fifth wave of technology paradigm, bringing new engines of economic growth for developed and emerging countries (OECD, 2004; Tseng, 2009). A number of countries have issued policies to promote the ICT development for innovation and economic growth. The main policy areas include support for ICT R&D, provision of venture finance to innovative entrepreneurs, and technology diffusion to businesses (OECD, 2012).

According to OECD statistics (2017), the US ranks top in terms of ICT R&D expenditure (USD 500 billion), followed by China (USD 409 billion), which overtook the EU28 (USD 386 billion) in 2015. Patents in China, Japan, Korea and the US account for between 70% and 80% of all patents in ICT. The figures show that Asian countries are reaching technological leadership in some ICT subsectors, while European countries are lagging behind in their innovation process. There is a growing need for Asian and European countries to evaluate and predict their technology level and to find out any predicaments they face to enhance their competitiveness in ICT.

Some scholars have studied the ICT development characteristics in a specific economy, such as the US and China (Hicks et al., 2001; Gao et al., 2013). Others have compared technology innovation capability and knowledge flows among economies (Tseng, 2009). Recently, some scholars have paid more attention on latecomers' catching-up characteristics in particular fields of ICT, including computer science (Guan & Ma, 2004) and transistor-liquid crystal display (Hu, 2012).

Until now, latecomers' technology level has been evaluated by comparing their competitive advantage and technology gaps with some countries with relatively good performance in a specific field of ICT. This kind of static methodology makes time series analysis difficult. In fact, technology catching-up of latecomers is a dynamic and cumulative process, which includes imitation, adoption and assimilation of mature technology from first movers. Thus, there is an increasing need to assess the catching-up characteristic of latecomers from a longitudinal perspective.

[1] This work was supported China Scholarship Council. We additionally acknowledge Xiaoyan Song (ECOOM – KU Leuven) for her data processing support.

Technology life cycle analysis (TLC) is an important method to analyse technology levels of different countries from a long-term and dynamic perspective. Several studies have used the TLC model to examine the catching-up process (Wong & Goh, 2012). As the catching-up of latecomers includes two processes – imitation and self-propagation – it is adequate to depict catching-up by two TLC curves. Whereas previous studies applied one dataset to depict double TLC curves, we have developed two different data sets, one for each curve. This new data perspective depicts the two catching-up curves more accurately.

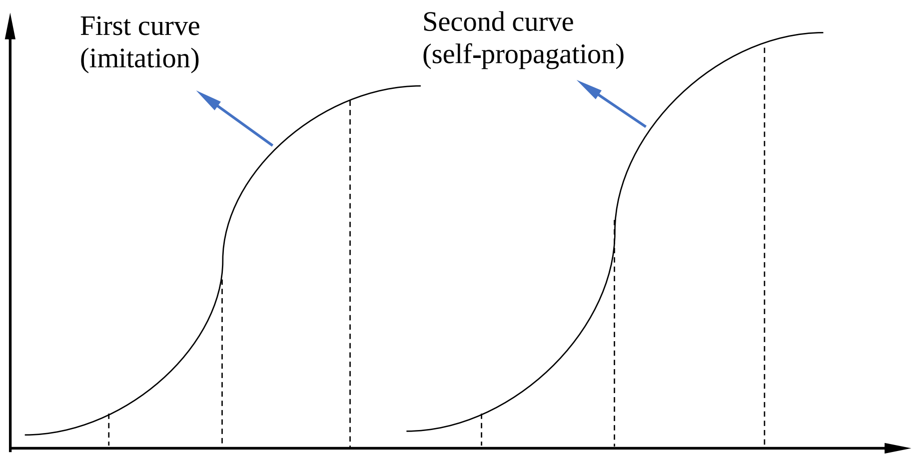
In our study, we take US as the first mover (benchmark) in ICT and we examine the catching-up characteristics of Asian countries (Japan, Korea and China) and Western countries (Germany, Great Britain and France). We consider the take-off time and growth rate in double TLC curves, hence characterizing their catching-up patterns. We use USPTO granted patent data from 1960 to 2014 and we apply logistic modelling to reveal different catching-up patterns among Asian and Western countries. We discuss some implications for catching-up countries in ICT.

Methodology and data

Logistic model and its taxonomy

Past research on technology development argues that technological innovation spreads among adopters, following an S-curved pattern (Anderson, 1999; Gao et al., 2013). Assuming that catching-up includes a shift from imitation to self-propagation, a two serial S-curve becomes suitable for modelling the catching-up process (Figure 1).

Figure 1: Two serial S-curve for modelling catching-up as a sequence of 2 processes.



We use two simple logistic growth models to depict the two serial S-curves as follows:

$$\mathrm{Y}_1(\mathrm{t}) = \frac{K_1}{1 + \exp(-bT + c)} \tag{1}$$

$$\mathrm{Y}_2(\mathrm{t}) = \frac{K_2}{1 + \exp(-dT + e)} \tag{2}$$

Where K_1 and K_2 are ceiling values for the first and second curves respectively; b and d are the growth rates; c and e are constants. 0.1K, 0.5K and 0.9K are break points of four stages (emergence, growth, maturity and recession). The starting time of the growth stage for the first and second curve are as follows:

$$T_{0.1} = \frac{d - ln9}{b} \tag{3}$$

$$T_{0.1} = \frac{e - ln9}{d} \tag{4}$$

The growth time is defined as the time of growth stage and maturity stage, where the ceiling value starts from 0.1K and reaches 0.9K. The growth times for the first and second curve are as follows:

$$T_{0.1-0.9} = T_{0.9} - T_{0.1} = \frac{ln81}{b} \tag{5}$$

$$T_{0.1-0.9} = T_{0.9} - T_{0.1} = \frac{ln81}{d} \tag{6}$$

The ceiling value represents carrying capacity; the growth rate represents the maximum development speed; and the starting time of the growth stage represents take-off time of technology (Anderson, 1999).

We adopt Meyer's (1994) taxonomy of bi-logistic models and we apply it to catching-up patterns. In doing so, four patterns can be discerned in terms of take-off time and growth rate of the two growth curves (imitation and self-propagation):

- **Sequential growth** occurs when the second growth curve starts once the first growth curve almost reaches its saturation for continuous development. There are two possible phenomena: the growth rate of the second curve is equal to the first one; or the growth rate of the second curve is slower than the first one but with longer pulse, indicating a longer growth of self-propagating.

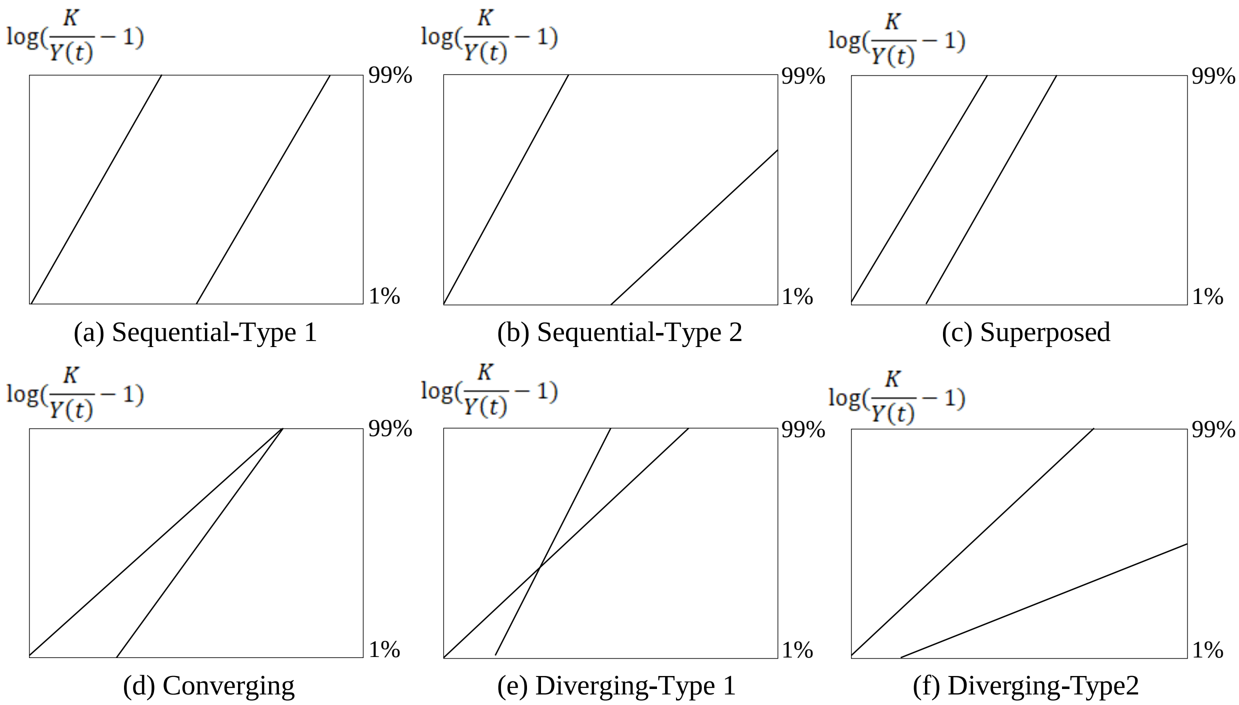
- **Superposed growth** occurs when the second growth curve emerges at the point where the first curve reaches about 20-50% saturation. The overlapping occurrence of processes causes the first technology curve to co-evolve with the second one.

- **Converging growth** occurs when both curves emerge at different points in time but culminate at the same time. The second technology curve has a faster growth than the first one, which reflects supply-push efforts for improving technology capabilities.

- **Diverging growth** occurs when both curves emerge at approximately the same time but grow at different rates. There are two possible phenomena: the longer pulse in the second curve emanates from the success of developing new growth avenues, which exhibits prolongation of second curve; or the other is the shorter and faster pulse in the second curve overtaking the first and reaches culmination faster, when the supply-push efforts had yet to develop self-propagating behaviour, thus the prolonged impact did not occur.

Figure 2 shows the different catching-up patterns based on double logistic model[2].

Figure 2: Patterns of catching-up, based on logistic modelling
(Source: Meyer, 1994 and own model).



Note that the Sequential-Type 2 was not included in Meyer (1994)'s taxonomy. We incorporated this type as a common case in the context of catching-up.

As shown in Figure 1, growth rates for the Sequential-Type 1 and Superposed patterns are considered equal ($b_1 \approx b_2$); the difference between both lies in the take-off time of the second logistic curve. For the Sequential-Type2, the first curve has higher growth rate than, the second ($b_1 \geqslant b_2$). In the Converging pattern, for the second logistic curve to converge to the first curve at the point of culmination, the growth rate of the second curve is necessarily higher than that of the first ($b_1 \leqslant b_2$). For the Diverging pattern, two types are defined: when $b_1 \geqslant b_2$, the second curve has a longer pulse (Type 2); when $b_2 \geqslant b_1$, the second curve has a shorter and faster pulse (Type 1).

Data

Patent data, which are publicly available over long time series, provide information on technology development and innovation activities (Gao et al., 2013). It has often been found that a cumulative stock of patents over time generally follows an S-shaped curve (Anderson, 1999). Patent data can hence be used as an index for measuring technology growth.

We consider only USPTO grant data to standardize for differences between patent offices, the unit of innovation and to prevent a home bias effect, making cross-country comparison possible (Wong and Goh, 2012). The reason for choosing USPTO is that the US represents the largest and most technologically advanced market in the world, with approximately half of

[2] There is a special case where the complete second curve takes place before the first one, indicating that the self-propagating process happens before the imitation curve. This case is not included as a catching-up pattern.

the patents being foreign-owned; and the number of US-granted patents for each country are roughly proportional to national GDP. Moreover, US places less limits on the patenting of inventions involving software, compared to other large patent offices.

Among the many ICT-related technology classifications, we consider the aggregate and the breakdown of nine growth drivers as defined in the 'IT839 Strategy[3]' from the Korean Ministry of Information and Communication (2004). These ICT subfields are Mobile Telecom (MOB), Broadband and Home-network (NET), Digital Television and Broadcasting (DTV), Computing (COM), Intelligent Robot (ROB), Radio Frequency Identification (RFID), Information Technology System on Chip (SOC), Embedded Software (ESW), and Digital Contents and Software Solutions (SOL). These subfields and their USPC concordance are shown in Table 1.

Table 1. ICT subfields and USPC concordance.

Subfield	**USPC classes**	**Subfield**	**USPC classes**
MOB	340, 375, 379, 701	**RFID**	342, 343, 455
NET	370	**SOC**	438, 711, 716
DTV	345, 348, 349, 353, 367, 381, 382, 386	**ESW**	341, 712
COM	235, 361, 365, 700, 708, 710, 713, 714, 719	**SOL**	705, 707, 715, 717
ROB	318, 706		

As stated earlier, we introduce a novel measurement method for modelling both catching-up curves (imitation and self-propagation) by making use of two different datasets. We start from USPTO granted patents between 1960 and 2014. The imitation curve for country x is modelled by considering US patents with a domestic family member (filed in the national patent office of country x) and a foreign applicant (i.e. no applicant from country x). By considering domestic filings with foreign applicants, we capture technology development in country x that is conceived abroad, which reflects the imitation stage. For the second curve (self-propagation) we consider USPTO patents, filed by domestic applicants (i.e. applicants from country x), but with no domestic patent family member (i.e. no filing in the national patent office of country x). The presence of country x in foreign markets and the absence of foreign applicants, reflects that country x itself is propagating its technology development abroad.

If we take Korea as an illustration, the first (imitation) curve is built on USPTO patents with a KIPO family member, where the KIPO patent assignee is from any foreign country (and there is no Korean assignee). The second (self-propagation) curve is built on USPTO patents with no KIPO family (or no family at all), but with at least one USPTO assignee from Korea. Note that for US (as the 'first mover'), there is only one curve: the data consist of USPTO patents with no family member in foreign offices, and at least one US assignee.

We consider the top seven countries in terms of the total number of granted ICT patents in USPTO[4]: US, Japan, Korea, Great Britain, Germany, France and China. The US is considered as the first mover; and we analyse catching-up characteristics of three European countries (Great Britain, Germany and France) and three Asian countries (Japan, Korea and China).

[3] IT839 stands for eight services, three infrastructures and nine growth drivers in the next generation.
[4] Source: own calculations.

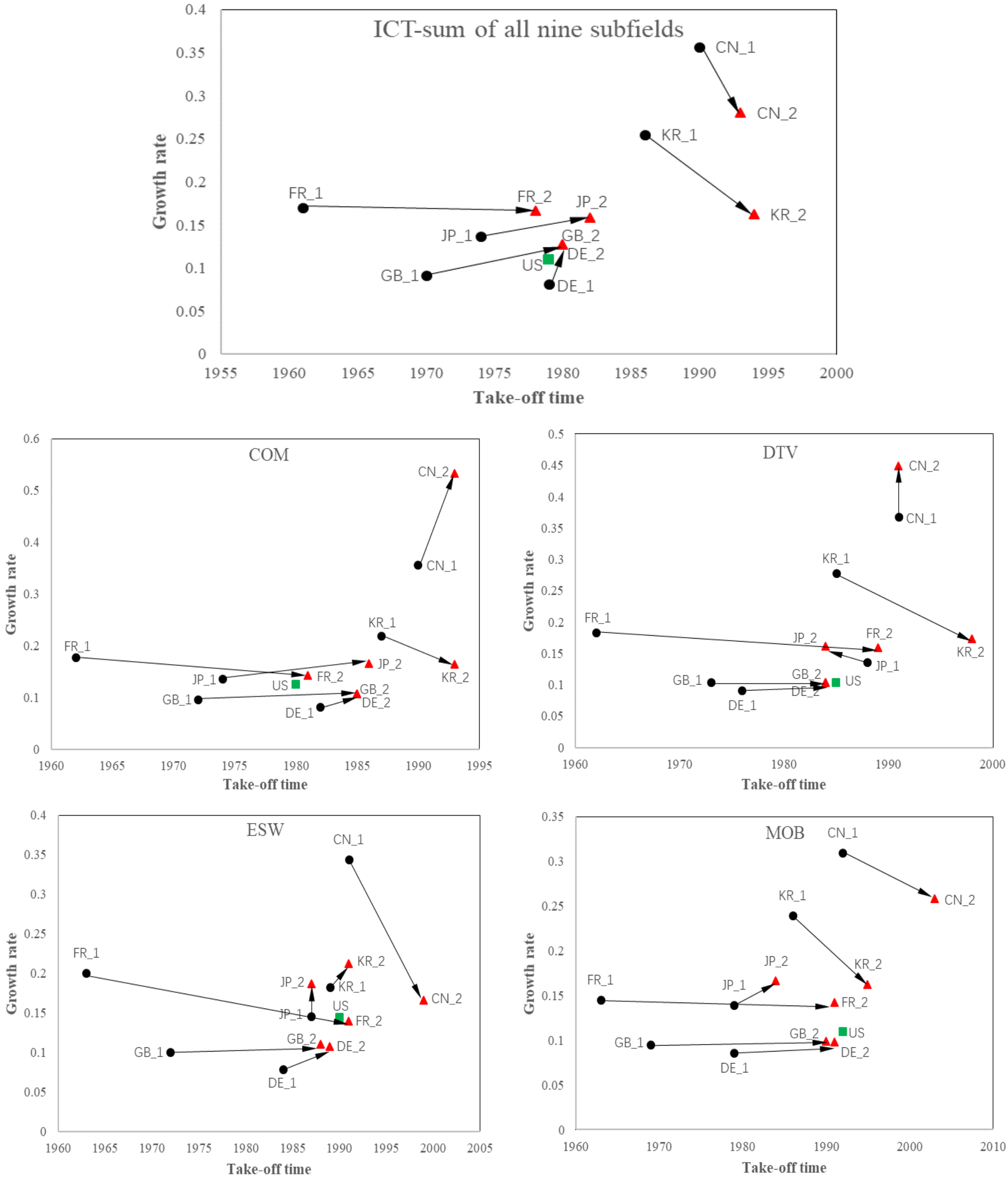
Thus, in the first (second) curve, we use USPTO patents with (with no) a UKPTO (GB), DPMA (DE), INPI (FR), JPO (JP), KIPO (KR), SIPO (CN) family member for Great Britain, Germany, France, Japan, Korea and China, respectively.

Results and analysis

Comparison of take-off time and growth rate

We use Loglet lab 4.0 to calculate the parameters of the logistic models (Eq. (1) and (2)) for the first and second curve. This software simulates the data with thousands of iterations based on Monte Carlo simulation, hence results are highly reliable.

Figure 3: Take-off times and growth rates by ICT subfield.



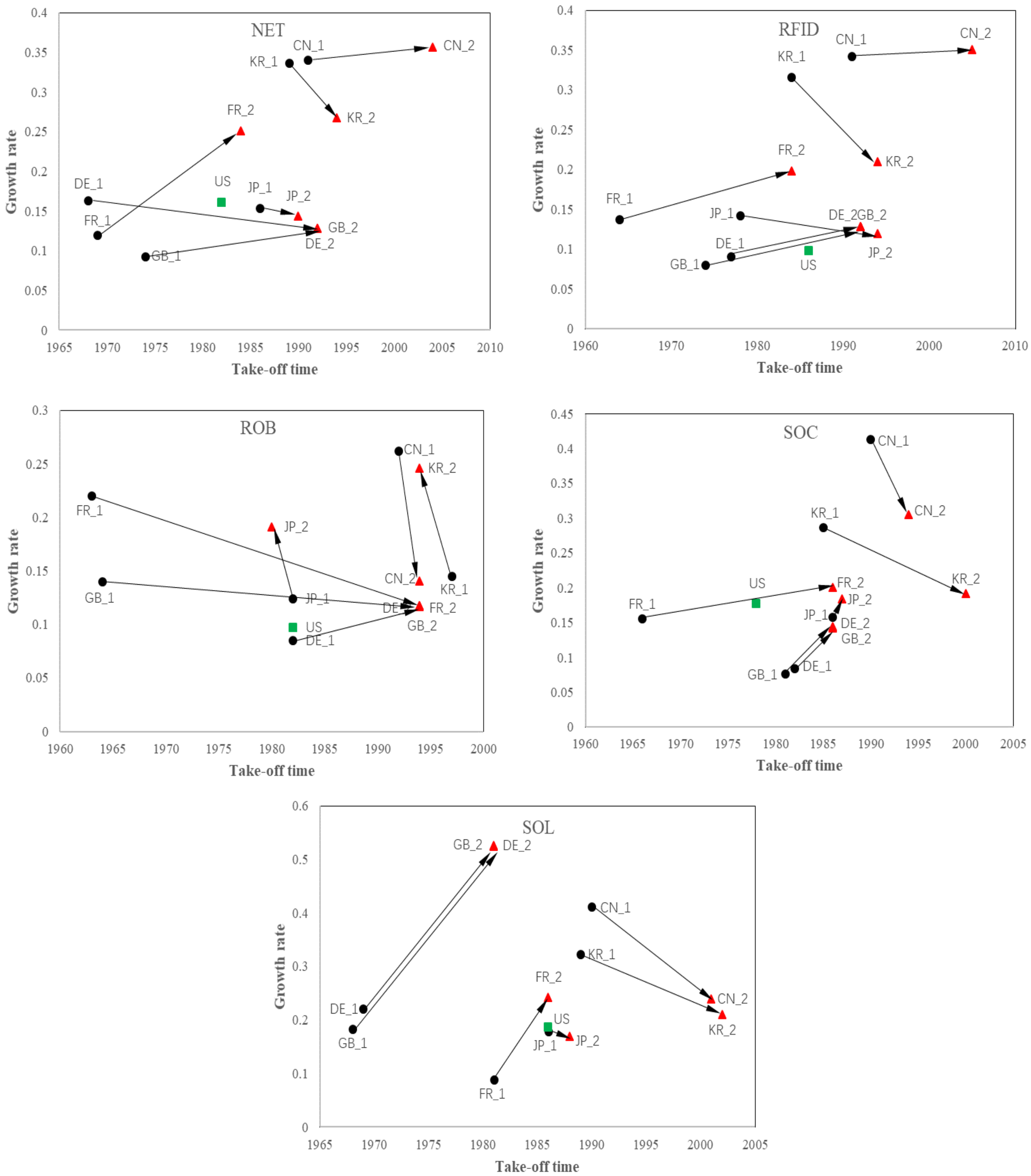


Figure 3 shows the TLC characteristics for the seven countries in the aggregate of the ICT subfields, as well as for each subfield separately. The horizontal axis denotes take-off time of first and second curve, and the vertical axis denotes growth rate of first and second curve. The first and second curve are represented by a circle and a red triangle respectively.

Overlooking the graphs for the separate subfields, it becomes clear that there are many field-specific dynamics and differences. For reasons of conciseness however, we discuss only the aggregated (first) graph; which by no means suggests that we consider field-specificities as irrelevant.

For the aggregate of the ICT subfields (Figure 3, first graph), a distinct pattern is observed for China and Korea. Their take-off time for both curves (imitation and self-propagation) is considerably later (between 1985 and 1995) than for the other countries (between 1960 and 1980). Furthermore, the growth rate for China and Korea is distinctively higher than for the other countries. These high growth rates for the first phase reflect a very rapid imitation. In the second curve (self-propagation), the growth rate for China and Korea drops significantly; but it is still higher than the growth rate for most other countries. As higher growth rates imply shorter growth times, the observations suggest that China and Korea have difficulties in obtaining sustainable development, due to insufficient accumulation in their imitation stage.

The pattern for the third Asian country, Japan, is more similar to the pattern for the western countries: earlier take-off times (with France being especially early in the imitation stage), and lower growth rates that are not decreasing like those for China and Korea.

Note also the specificity of the German pattern, with a very short time period between take-off of the first curve and take-off of the second curve; this indicates a very rapid transformation from imitation to self-propagation.

Synthesis of catching-up patterns
Table 2 shows the catching-up patterns of six countries in the aggregate and in the nine ICT subfields separately, characterized by the typology presented in Figure 2.

The type in black (i.e. Sequential-1 and Superposed) means a 'neutral' transmission from the first to second process, without significant changes of growth rate and time. The type in blue means a 'healthy' development for this country, while the type in red means an 'unhealthy' development. For European countries, it is necessary to increase their growth rate, thus an increase of growth rate (including Converging and Diverging-1 in blue) is healthy. For Korea and China, it is necessary to get sustainable development, thus a shorter growth rate but longer growth time (including Sequential-2 and Diverging-2) is healthy.

For the aggregate of the ICT subfields (Table 2, first row), France represents 'neutral' development, while other five countries represent 'healthy' development. However, NET in Germany, ESW and ROB in France, ROB in Great Britain, and RFID in Japan is 'unhealthy', and ESW in Korea, and COM in China is 'unhealthy'.

Table 2. Catching-up patterns of six countries in nine subfields.

Country / Field	**Germany**	**France**	**Great Britain**	**Japan**	**Korea**	**China**
TOTAL	Diverging-1	Sequential-1	Converging	Diverging-1	Sequential-2	Diverging-2
COM	Superposed	Sequential-1	Superposed	Superposed	Diverging-2	Converging
DTV	Converging	Sequential-1	Superposed	*	Sequential-2	Diverging-2
ESW	Converging	Sequential-2	Superposed	*	Converging	Sequential-2
MOB	Superposed	Sequential-1	Superposed	Converging	Diverging-2	Sequential-2
NET	Sequential-2	Converging	Converging	Superposed	Diverging-2	Sequential-1
RFID	Converging	Diverging-1	Converging	Diverging-2	Diverging-2	Sequential-1
ROB	Converging	Sequential-2	Sequential-2	*	*	Diverging-2
SOC	Diverging-1	Diverging-1	Diverging-1	Diverging-1	Sequential-2	Diverging-2
SOL	Converging	Diverging-1	Converging	Superposed	Sequential-2	Sequential-2

Note: Asterick (*) mean exceptional case where second curve precedes first curve in time.

Conclusion

With ICT as an engine of economic growth, the mapping and monitoring of catching-up behaviour has high policy relevance for countries in trying to follow pace. US is generally considered as a first mover. Using a novel way of measuring and combining two sequential S-shaped catching-up stages (imitation and self-propagation), we compare the catching-up dynamics of three European and three Asian countries. The novelty on our approach is that we base both curves on separate datasets. Starting from USPTO patents for country x, we base the imitation curve on US patents with domestic family members but foreign assignees. The self-propagation stage is modelled by considering patents filed at UPSTO, with no domestic family member, but with domestic assignee(s). Based on these datasets, take-off time and growth rate parameters are estimated for the two distinct stages (imitation and self-propagation) whereby the combination of information on both curves reveals the specific catching-up pattern of the considered countries.

Applying this to the analysis of the seven most highly ranked countries in ICT patenting (3 Asian, 3 EU), and considering US as the first mover, reveals several observations. China and Korea start late but grow very fast in both stages. The caveat from such a dynamic is a short growth timer, leading to a lack of incubation and consequently an absence of potential to obtain sustainable growth. Japan's catching-up pattern is much more similar to that of European countries. They embark on their developments earlier, and they have longer growth periods, allowing for incubation and more sustainable developments. In general, Germany, Great Britain, Japan, Korea and China are presenting a healthy development trend, while France presenting a neutral development. However, they have several 'unhealthy' subfields which need more attention to be paid.

Apparently, even when trying to catch-up, nothing should be done in a hurry except catching fleas.

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