Knowledge flows and its geographic localization
: Empirical analysis of patent citations

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1. Introduction

For decades after the Second World War, many economies tried to promote economic development and technological development which supports it. However, few were successful, especially in the technological area relative to the advanced economies. In general, the technological gaps have widened, but exceptions do exist for some economies. These economies achieved tremendous technological progress and economic growth; they can be categorized as catching-up economies.

Our interest now is whether the technological progress of catch-up countries is sustainable or stable. Although remarkable catch-up was achieved, it is uncertain whether they will continue and maintain their catch-up track. In other words, the problem is to sustain their level of technological innovation. Furthermore, as the technological imitation done mainly in catching-up economies is becoming difficult, the prospect of sustaining past innovation seems to be obscure, if only by importing and imitating foreign technology.

Technological innovation can be regarded as the generation and exploitation of available knowledge flows. Meanwhile, knowledge flows also affect the level of technological innovation. Thus for innovation to be sustainable, it is necessary to promote the ability to use knowledge flows, and to preserve the knowledge flows in a fully exploitable form.

In relation to knowledge flows, much of the literature so far focuses on technology diffusion that mainly occurs through capital goods. However, knowledge flows are not confined to technology diffusion through goods and services. Rather, they tend to be disembodied. Some of the recent literature analyzes the process of knowledge flows from this perspective. An important finding is the geographic localization of knowledge flows, which concerns the possibility of exploiting the results of previous innovations within the national boundary. In particular, the policymaker who aims for maximum gains from public R&D expenditure is highly interested in this issue.

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However, previous literature mainly addresses knowledge flows and their geographic localization in advanced countries. We aim to analyze the sustainability or stability of innovations in terms of the characteristics of knowledge flows. We are specifically interested in the localization of knowledge flows in catching-up economies. We try to interpret the localization of knowledge flows as a proxy for the sustainability of the tremendous growth in the previous period.

In order to analyze localization, we use the patent citation data of the USPTO. Patent citations represent underlying knowledge connections between innovations. Although limitations exist, patent citation data are the only available indicator of knowledge flows and knowledge connections.

The paper proceeds as follows. First is an analysis of the literature and our hypothesis about geographic localization in catching-up economies as compared to advanced economies. The next section describes the data and methodology for analyzing localizations with patent citation data. Then the results of the geographic localization tests are presented.

2. Previous literature and hypothesis

2.1 Previous literature

Knowledge flows are increasingly becoming important for innovations. In fact, innovation and knowledge flows are regarded as being interlinked with one another. We can consider their relationship to be as follows.

First, as studies on the nature of innovation have grown, it is common that innovation is not an outcome of the inventor himself. Rather, innovation is the result of a complex process involving multiple inventors, directly or indirectly.

Second, historically, as time goes by, innovations are becoming increasingly entwined with other innovations. Innovation is achieved increasingly through networking with others. Communication and networking strategies are becoming important.

Third, while direct government intervention has diminished, its function to affect overall knowledge flows and to reap the results of innovations within a country is increasingly important. And innovation policy is mostly predicated on the existence of a geographic component to the knowledge spillover mechanism and the localization of knowledge externality (Jaffe *et al.*, 1993). A prominent line of recent research on the benefits of publicly-funded research has been the investigation of spillovers from government funding to other activities such as industrial R&D.[1] Therefore, knowledge flows are also becoming increasingly important overall.

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1 Ammon J. Salter and Ben R. Martin, The economic benefits of publicly funded basic research: a critical review, Research Policy, Volume 30, Issue 3, 1 March 2001, Pages 509-532

Past literature mainly focuses on the effects of spillovers in analyzing knowledge flows. Much of the recent research addresses the science-technology linkage and regional clustering. Knowledge flows at the national level are not analyzed as much as expected. This is because the main object of analysis is advanced economies. And the interest is not on the national level; the insufficiency of data corresponding to the national dimension also makes study more difficult.

The literature on spillovers is divided between the effect of spillovers and the form of spillovers including the location. First, in relation to the effect of spillovers, the existence of spillovers is regarded to augment the productivity of a firm or industry by expanding the general pool of knowledge available to it. As asserted by Griliches (1995), the level of productivity achieved by one firm or industry depends not only on its own research efforts but also on the general pool of knowledge accessible to it.

As for the form of spillovers, two main forms can be identified: (1) geographic spillovers and (2) spillovers across sectors and industries. Geographic spillovers imply benefits for firms located near research centers, other firms and universities. Evidence from bibliometric studies indicates a strong tendency for basic research to be localized (Salter and Martin, 2001).[2] Narin *et al.* (1997) present evidence for geographic effects at the national level. They find that inventors in each country preferentially cite papers authored in their own country. Katz (1994) shows that research collaboration within a country is strongly influenced by geographic proximity; as distance increases, collaboration decreases, suggesting that research collaboration often demands face-to-face interaction.

As computing technology develops, patent data can be used to analyze knowledge flows. Los and Verspagen (1996) analyze the locational origin of patents and papers cited in U.S. patents to determine the degree of spillovers of domestic sources of science and technology. They find that spillovers do exist but they vary across sectors and countries.

Jaffe and Trajtenberg (1999) examine the patterns of patent citation among the U.S., U.K., France, Germany, and Japan as an indicator of international flows of knowledge. They find significant evidence of geographic localization that fades slowly as knowledge diffuses over time. They also observe country differences, with Japan being highly localized. According to their research, it is certain that advanced economies reap most of their results from previous innovation, represented by the geographic localization of knowledge flows.

Regarding the catching-up economies in which we are interested, Hu and Jaffe (2003) argue that technology from advanced economies benefits catching-up economies. Imported capital goods, embodying new technology, directly increase the productivity of the using industries in the importing country, and researchers or inventors in less-developed countries can utilize the knowledge that they "import" to foster the development of indigenous new

2 Hicks et al. (1996) also find that research across countries is localized.

technologies. However, these knowledge imports are partially embodied in the import of high-technology goods, and partially disembodied in direct and indirect communication among researchers.

Technological innovation can be regarded as the generation and exploitation of knowledge flows. Hu and Jaffe (2003) and Jaffe *et al.* (1993) attempt to build a concrete analysis about knowledge targeted to be analyzed. They try to distinguish between the productivity benefits associated with the use of imported high-technology goods in production, and benefits arising because flows of knowledge from advanced economies facilitate research and invention.[3]

As asserted by Hu and Jaffe (2003), considering knowledge flows presupposes that knowledge use has a non-rival and non-excludable nature, upon which every economy can draw to facilitate its own technological innovation. They assert that while it is natural that advanced economies create most of this knowledge stock and the non-advanced economies tap into this stock, non-advanced economies are constrained by the availability of the channels of knowledge diffusion and their abilities to absorb and adapt new knowledge. If this characteristic of non-advanced economies is applicable to catching-up economies achieving rapid technological catch-up, then the level of technological innovation will inevitably diminish as imitation becomes more difficult. However, supposing that knowledge different from that of advanced countries is generated in catching-up economies, the availability of the channels of knowledge diffusion and their abilities to absorb new knowledge generated in those economies is more important. This can be conceptualized as the geographic localization of knowledge flows in catching-up economies.

Geographic effects or localization are not necessarily universal, and the level of geographic spillovers and interdependencies varies over time. It is doubtful that this localization of innovation can be applied to all economies. Geographic effects may be particularly important when the technological trajectories are highly indeterminate – in other words, when a wide range of possible paths of development increases the importance of tacit knowledge to the innovation process, thus raising the value of direct interactions in interpreting and applying new information. These untraded interdependencies form the collective property of the region and help the regional actors to expand their range of activities, drawing one another forward. All this suggests that each nation or region needs to maintain its own capability in research and development. Personal links and face-to-face interactions are essential not only for the research process but also for sharing and transferring knowledge quickly and effectively. Policies designed to support geographic agglomeration should help facilitate this interaction (Wolfe, 1996).

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3 There is a growing literature on international technology diffusion. But most of these studies focus on technology diffusion embodied in traded goods

2.2 Hypothesis

Based on the above discussion, our question is whether or not catching-up economies have the characteristics as advanced economies in terms of knowledge flows at the national level. Do catching-up economies – with a relatively weak base of innovation – have the same characteristics in terms of knowledge flows, in particular the geographic localization of knowledge flows within the national boundary? We analyze this point with evidence from Korea and Taiwan, which are regarded as typical catching-up economies.

In detail, we are interested in following question. Firstly, on the quantitative dimension, is there geographic component even in catching-up countries, and if so, is the degree equivalent to that of advanced countries? Second, on qualitative dimension, from where does catching-up get influenced and which meaning does this have for geographic localization of knowledge flows in catching-up countries. And lastly, what is the difference between Korea and Taiwan, and from which elements does this difference arise?

Regarding the geographic localization of catching-up economies at the national dimension, our hypothesis is as follows.

It is known that, although the catching-up countries achieved remarkable technological catch-up, they share some typical characteristics of non-advanced countries with other developing countries. These entail two sources of weakness in technological innovation. First, weak networking hinders technological innovation in late-industrializing countries. The distance to lead-user markets, typically located in advanced countries, and the distance to leading sources of technology, typically belonging to advanced firms, universities, or public research institutes located in advanced countries, can be pointed out. These distances impede the developing economies in appropriating the up-to-date knowledge flows which are essential in up-to-date innovation. Second, fragile technological infrastructure deters developing economies from technological innovation. Late-industrializing countries suffer relative shortages of specialized input resources, an inadequate public infrastructure, and a short history of innovation, which deters the building of cumulative technological capability.

Based on these weaknesses, it can be regarded that catching-up countries cannot generate essential technology and knowledge sufficiently, and must depend on external sources and acquire most of the essential technology from abroad. This highlights the possibility of a heavy dependence on an advanced country.

Hypothesis 1: The geographic localization of knowledge flows in catching-up countries does not exist due to heavy dependence upon external knowledge and fragile innovation base.

Even if the geographic localization exists, it can be inferred that the level of geographic localization of knowledge flows in catching-up countries is lower than that of developed countries. Meanwhile, if we consider that innovation must be intertwined with the exploitation of the knowledge flows, and thus the growth of technological capability might accompany the geographic localization of knowledge flows, we can assert that the degree of geographic localization can grow over time.

However, this growth may not exclude heavy dependence on advanced countries. Hu and Jaffe (2003) examine patterns of knowledge diffusion from the U.S. and Japan to Korea and Taiwan, using patent citations as an indicator of knowledge flow. Explicitly considering the roles of technology proximity and knowledge decay and diffusion over time, they find that it is much more likely for Korean patents to cite Japanese patents than U.S. patents, whereas Taiwanese inventors tend to learn evenly from both, and that both Korea and Taiwan are surprisingly reliant on relatively recent technology. This discussion presents the possibility and importance of external knowledge sourcing and the need to analyze it in detail. That is, if external knowledge sourcing is important than domestic one, from which is external knowledge sourcing achieved.

If technological growth may not exclude heavy dependence on advanced countries, it is possible that growth in the level of localization and heavy dependence coexist. We try to capture this phenomenon with the notion of weak geographic localization of knowledge flows. Weak localization represents being mostly biased toward another country, not on one's own country, although there is a biased dependence toward own country, in consideration of the pre-existing distribution of technological activities.

Hypothesis 2: Catching-up countries have been biased mostly toward country other than their own country, in comparison with the pre-existing distribution of technological activities. And the *nature* of the geographic localization of knowledge flows is different between advanced and catching-up countries.

At the same time, there may be differences between each country. There have been differences among the catching-up economies due to the characteristics of each economy, mainly the differing organizations that generate technological innovation. Therefore, furthermore we analyze the difference between Korea and Taiwan.

In addressing Korea and Taiwan, Nonaka's discussion is helpful. According to Nonaka (1988, 1994, 1995), organizational knowledge is created through a continuous dialogue between tacit and explicit knowledge. There are four patterns of interaction involving tacit and explicit knowledge: (1) from tacit knowledge to tacit knowledge (socialization); (2) from tacit knowledge to explicit knowledge (externalization); (3) from explicit knowledge to explicit knowledge (combination); (4) from explicit knowledge to tacit knowledge (internalization). Based on this framework, in comparing Japanese-style to western-style organizational knowledge creation, Nonaka argues that western strength lies in externalization and combination, while Japanese strength lies in socialization and internalization.

Nonaka's argument can be utilized to understand the dissimilarities between Korea and Taiwan. Korea, with large innovating firms, can be said to have strength in internalization like Japan, whereas Taiwan, with small innovating firms, can be said to have strength in externalization involving mainly explicit knowledge (Lee, 2003).

Based on this discussion, it is expected that Korea would achieve the localization of knowledge flows mainly through internalization of knowledge flows within each innovator, while Taiwan would achieve it mainly through interaction between innovators.

Lastly these issues are relevant for innovation policy, when considering the policy and experience of advanced countries. The advanced countries' policy implicitly presumes the geographic localization of knowledge flows. For catching-up economies, it is imperative to implement policies that enhance the geographic localization of knowledge flows around them.

3. Method of research and data: patent citation and localization

3.1 Patent citation and knowledge flows

We use patent citations as an indicator of knowledge flows from technologically advanced to developing economies.

Recently, much of the literature regards the validity of using patent citations as an indicator of knowledge flows (Jaffe *et al.*, 1993, 2000). Patent citation is a coarse and noisy measure of knowledge flow.[4] It does, however, provide insight into how knowledge may diffuse across geographic and technological regions as well as over time (Hu and Jaffe, 2003).

A patent is a property right in the commercial use of a device. If a patent is granted, a public document is created containing extensive information about the inventor, her employer, and the technological antecedents of the invention. Among this information are reference and citations. It is the patent examiner who determines what citations a patent must include. The applicant has a legal duty to disclose any knowledge of the prior art that she may have. And the examiner is supposed to be an expert in the technological area and be able to identify relevant prior art that the applicant misses or conceals (Jaffe et al, 1993, 2000).

The citations serve the legal function of delimiting the scope of the property right

4 Not all inventions are patented; not all knowledge flows are captured by citations; at best, citations capture only codifiable knowledge and cannot capture transfers of tacit knowledge.

conveyed by the patent. The granting of the patent is a legal statement that the idea embodied in the patent represents a novel and useful contribution over and above the previous state of knowledge, as represented by the citations. Thus in principle, a citation of Patent X by Patent Y means that X represents a piece of previously existing knowledge upon which Y builds (Jaffe et al, 1993, 2000).

Patent citation has two meanings for economic research. First, citation functions as proxy of paper trail of knowledge flows. The presumption is that citations are informative of links between patented inventions. The fact that patent Y cites patent X may indicate knowledge flows from X to Y.[5] Thus it is probable that knowledge flows do leaves a paper trail in the form of citations in patents (Jaffe et al, 1993). Second, citation received may be telling of the importance of the cited patent.

For the purpose of this paper, we focus on the first meaning. Patents are a proxy for bits of knowledge; patent citations are a proxy for a given bit of knowledge being useful in the development of a descendant bit. This makes it possible to use the probability of citation as a proxy for the probability of useful knowledge flow (Jaffe and Trajtenberg, 1999)

With regard to patent citations, it must be acknowledged that information on patent citations is meaningful only when used comparatively. That is, the evaluation of the patent citation intensity of an invention can only be made with reference to some "benchmark" citation intensity.

Patent citation has the following inherent characteristics. First, the number of citations received by any given patent is truncated in time, because we only know about the citations received so far. More importantly, patents of different ages are subject to differing degrees of truncation. Second, differences in Patent Office practices across time or across technological areas may produce differences in citation intensities that are unrelated to the true impact for which we use citations as a proxy (Hall *et al.,* 2001).[6]

The following discussion addresses the method with which we address the problem of citation data.

3.2 Fixed-effects approach

The basic approach is suggested and named by Hall *et al.* (2001). It involves scaling

5 However, there are problems in using patent citation data. There is substantial 'noise' in the data. In using citations as evidence of spillovers, or at least knowledge flows, from cited inventors to citing inventors, it is clearly a problem that many of the citations were added by the inventor's patent attorney or the patent examiner, and may represent inventions that were wholly unknown to the citing inventor (Hall et al., 2001).
6 Even if each patent issued made the same number of citations as before, the increase in the universe of citing patents would increase the total number of citations made.

citation counts by dividing them by the average citation count for a group of patents to which the patent of interest belongs.[7]

The fixed-effects approach assumes that all sources of systematic variation over time in citation intensities are artifacts that should be removed before comparing the citation intensity of patents from different cohorts. Citation intensities should be rescaled, and expressed as ratios to the mean citation intensity for patents in the same cohort.

This rescaling purges the data of effects due to truncation, effects due to any systematic changes over time in the propensity to cite, and effects due to changes in the number of patents making citations. Unfortunately, it also purges the data of any systematic movements over time in the importance or impact of patent cohorts even if there was, especially of fertility of invention.

This approach does not require one to make any assumptions about the underlying processes that may be driving the differences in citation intensities across groups. However, it does not distinguish between differences that are "real" and those that are likely to be artifactual even if there was. That is, under the fixed-effects approach, we do not attempt to separate "real" differences among cohorts from those due to truncation and propensity to cite effects, so any "real" effects that may be there are lost.

In sum, the fixed-effects rescaling aims to increase the signal-to-noise ratio in the data and allow comparability of citation counts over time by removing from the data variance components that are associated with truncation and also with possibly artifactual aspects of the citations generation process. If the citation-lag distribution, the fertility of different patent cohorts, and the propensity to cite have all been varying over time, there is no general way to identify separately the contribution of each of these to variations in observed citation rates (Hall *et al.,* 2001). This approach focuses on the second meaning of patent citation data, i.e. calculating the importance of patent.

3.3 Structural approach

The structural approach is also named by Hall *et al.* (2001). It attempts to distinguish the multiple effects on citation rates via econometric estimation. Once the different effects have thereby been quantified, the researcher has the option to adjust the raw citation counts to remove one or more of the estimated effects. In fact, this approach uses the citation frequency function

7 A patent that received say 11 citations and belongs to a group in which the average patent received 10 citations, is treated as equivalent to a patent that received 22 citations, but happens to belong to a group in which the average was 20. Likewise, such a patent would be regarded as inferior to a patent receiving just 3 citations but for which the group average was only 1.

and estimates it. This approach is found in Jaffe and Trajtenberg (1999), Hu and Jaffe (2001) etc.[8]

Caballero and Jaffe (1993) assume that the citation function depends on the probability of seeing or knowing about the idea according to years elapsed and the usefulness of old ideas in generating the new ones. The likelihood that any particular patent K granted in year T will cite some particular patent k granted in year t is assumed to be determined by the combination of an exponential process by which knowledge diffuses and a second exponential process by which knowledge becomes obsolete. Considering the above nature of patent citation data, the citation frequency differs across technological and geographic areas, and time.

The citation frequency function is as follows;

$$CF_{iT,jtg} = \alpha(i,j,g,T)\exp(-\beta_{1ij}L)(1-\exp(-\beta_2 L)) + \varepsilon_{iT,jtg}$$

$CF_{iT,jtg}$ is the frequency of country i's patents in year T citing country j's patents in technology area g in year t. The rate at which a piece of knowledge embodied in a patent becomes obsolete is measured by β_1. β_2 measures the rate of diffusion, i.e., all else equal, how fast a piece of knowledge travels across geographic and technological areas. i and j indicate the location of assignee. How the citation frequency differs across technological and geographic areas and time is captured by a number of shift parameters, which are collectively denoted by α. All α's enter in multiplicative form such as:

$$\alpha(i,j,g,T) = \alpha_{ij}\alpha_g\alpha_T$$

That is, citation frequency is set as a multiplicative function of cited year effects, field effects, and citation lag effects. This equation can be estimated by OLS or by non-linear methods, as in Jaffe and Trajtenberg (1999). Here the α parameters can be interpreted as the proportional difference in citation intensity for a given year or field relative to the base group. These parameters can therefore be used directly to adjust or normalize observed citations for these effects, if desired.

Here, the parameter α_{ij} and β_{1ij} can captures the pattern of geographic localization. Higher α can shift upward the citation function and this indicate the evidence of localization.

8 Hall et al. (2001) make the following assumptions. 1) Proportionality: the shape of the lag distribution over time is independent of the total number of citations received, and hence more highly cited patents are more highly cited at all lags. 2) Stationarity: the lag distribution does not change over time, i.e., does not depend on the cohort (application or grant year) of the cited patent.

And higher β denote the shorter citation lags.

This structural approach has limitation for using. First, they consider technological field only through six broad classifications. Second, they use the registration year of citing paper. But application year is more appropriate for economic implication. Third, they consider registration year of cited patent by five-year intervals. But it is not relevant when it is uncertain to which period and which interval is appropriate ex ante.

This approach aims to analyze the time effect. They are interested in the time effect of the citation lag, specifically, the obsolescence effect and diffusion effect. Their interest and the feasibility of empirical estimation result in some limitations, as discussed previously.

3.4 Revised fixed approach – method in this paper

Alternatively, we compare directly the geographic localization of the citations with the originating patent that they cite, as in Jaffe *et al.* (1993). Jaffe *et al.* compare the probability of a patent matching the original patent by geographic area, conditional on its citing the original patent, with the probability of a match not conditioned on the existence of a citation link. The non-citation-conditioned probability makes a baseline or reference value against which to compare the proportion of citations that match. They focus on the metropolitan area of the U.S.

We use the approach of Jaffe *et al.* (1993). Extending their approach, three methods for measuring the degree of localization are possible. First, localization can be measured as the extent of the original patent of a country cited by the same country. Second, localization can be measured as the extent in which the citing patent of a country cites a patent of the same country. Third, the relationship between all pairs of citing-cited patent can be considered.[9] Each method generates a control sample. Jaffe *et al.* (1993) employ the first approach. This paper chooses the second method, because it is more conservative and enables usage of a large set of data which then avoids biased results. This is essential, when considering the asymmetry between the numbers of citing versus cited patents in catching-up economies.

In this paper, we are interested in whether or not the localization of knowledge flows exists in catching-up economies. We make cohorts of citing-cited pairs of catching-up economies. In each cohort, we include all patents granted to catching-up economies, especially Korea and Taiwan. We build a corresponding control sample for each economy.

We then test the localization of advanced economies as a reference. Jaffe *et al.* (1997) test the localization of advanced economies (the U.S., Japan, the U.K., France, and Germany) by

9 This approach controls for the following, considering the nature of patent citation data: the application year of the citing patent, the application year of the cited patent, and the technological field of the cited patent. Controlling for these, we examine the country of the assignee of the cited as well as the citing patent. That is, we construct control samples which correspond to the application year of citing patent, registration year of cited patent, and the technological field of each patent.

using the structural approach. This reference sample is set to identify whether the extent of geographic localization differs between advanced and catching-up economies.

To further construct the control frequency, the following considerations are necessary. First, as asserted by the fixed effects approach, all sources of systematic variation over time in citation intensities are artifacts that should be removed. Second, as asserted by Jaffe *et al.* (1993), each country has different areas of technological focus, and the geographic localization of spillovers is partly due to this national technological specialization.

Therefore, we choose a control patent whose technological area and application year are the same as that of the cited patent. For each cited patent, a corresponding control sample of equal size, whose distribution across time and technological areas are identical to that of the cited patent, is made. Each control patent is paired with a particular cited patent, making it possible to compare the geographic location of the control patent with that of the cited patent cited by its counterpart in the citing-cited pair dataset. The frequency with which control patents match geographically on the national dimension with the originating patent is an estimate of the frequency with which a randomly drawn patent that does not belongs to a citation, but has the same technological and temporal profile as the citation, matches geographically on the national dimension. As asserted by Jaffe *et al.* (1993), if the citation match frequency is significantly higher, then that implies that citations are localized even after controlling for timing and technology.

This approach is more appropriate than the structural approach for analyzing raw data, particularly in the degree of geographic localization. The method of this paper is equivalent to applying the fixed effects approach to the citation flow as a proxy of knowledge flows.

And this approach must be extended to analyze the characteristics of the geographic localization of knowledge flows in catching-up economies. For the analysis, we construct a detailed definition of the geographic localization of knowledge flows. It can be defined in terms of the extent of bias toward a country, in consideration of the pre-existing distribution. Whether there is strong or weak localization can be defined in light of the extent of bias, considering the pre-existing distribution. Strong localization indicates a bias toward the innovation of own country; the country has a biased dependence on itself.

Meanwhile weak localization represents being mostly biased toward other country, not toward itself, although there is a biased dependence toward itself in consideration of the pre-existing distribution of technological activities. In this fashion, in countries with weak localization, another country emerges as the most important country in their technological innovation. And this important country emerges as the most influential country, compared to the pre-existing distribution of technological activities.

3.5 The Data

As previously indicated, the USPTO patent data, the NBER patent database specifically, is used. This patent database is comprised of patents registered from 1963 to 1999. It also contains data on patent citations made from 1975 to 1999. The data set extends from January 1, 1963 through December 30, 1999 (37 years), and includes all the utility patents granted during that period, totaling 2,923,922 patents. And the citations data includes all citations made by patents granted in 1975-1999, totaling 16,522,438 citations.

The patent data contain the each inventor's address, which identifies the country of residence. If a patent has multiple inventors, the country of the first inventor is used. This identification may not be appropriate for some cases, such as in the invention of an American employee in a Korean firm. But we assume that this problem is minor. And for the technological area, we use 417 patent classes based on the 1999 USPTO classification.

4. Geographic localization of knowledge flows and knowledge diffusion for catching-up economies.

The geographic localization of knowledge flows entails the possibility of exploiting the result of past innovations within the national boundary. Its importance can be summarized as follows. First, for technological innovation to be sustainable, it is necessary to promote the ability to use knowledge flows and preserve the knowledge flows in a fully exploitable form. For sustainable and stable innovation, the characteristics of knowledge flows, particularly geographic localization within the national boundary, are very important.

Second, while direct government intervention has diminished, the function to affect overall knowledge flows and to reap the results of the innovation within the country is becoming highly important. And innovation policy is mostly predicated on the existence of a geographic component to the knowledge spillover mechanism and the localization of knowledge externality (Jaffe *et al.*, 1993).

Before we tackle directly the localization of knowledge flows for catching-up economies with empirical data, we begin with a description of the patent citation data as a proxy for knowledge flows in catching-up economies.

Firstly, more mean citations were received by advanced economies than by catching-up economies. This finding implies that the quality of technological innovation in advanced economies is superior to that of catching-up economies. Another notable point is that the asymmetry between the number of citations received and the number of citations made is remarkable in catching-up economies, compared to advanced economies. If we interpret citations as flows of technological knowledge, it is probable that the impact of innovation of catching-up economies is much smaller than the impact received.[10]

For catching-up economies, mean citations received are 1.78 for Korean patents and 2.32 for Taiwan patents. It can be inferred that Taiwan's technological performance is superior to Korea in terms of quality.

<Table 1: Descriptive statistics of patent citation data>

	Total number of citations received	Mean citations received	Total number of citations made	Mean citations made
Advanced economies				
U.K.	424,334	4.33	399,789	6.14
France	328,599	3.85	363,202	5.59
Germany	849,007	3.84	928,903	5.47
Japan	1,983,983	4.71	2,186,492	5.60
U.S.	9,259,246	5.19	11,060,580	9.22
Catching-up economies				
Korea	26,404	1.78	84,155	5.68
Taiwan	46,410	2.32	115,280	5.77

Note: from 1975-1999 by registration base.

Based on the previous discussion, this section tries to estimate the localization of knowledge flows for catching-up economies with empirical data. First, we try to highlight the difference in the geographic location of advanced and catching-up countries. Second, we analyze the source of knowledge inflows and the nature of geographic localization, mainly focusing on catching-up countries. Third, we focus on highlighting the difference between Korea and Taiwan.

4.1 Geographic localization and the difference between advanced and catching-up countries

In this subsection, we try to highlight the difference between advanced countries and

10 This is why we construct a control set with patents that each patent cited.

catching-up countries, in terms of the degree of geographic localization of knowledge flows. In order for that, we try to estimate the degree of geographic localization of each country with empirical US patent citation data.

We also analyze the time trend of geographic localization, and make a simple trend analysis. Finally, we also estimate it after excluding self-citation regarded as the knowledge flows within same organization in order to confirm whether geographic localization holds even when we consider only the knowledge flows between technological innovators.

4.1.1 Overall result

The result of the estimation of localization in each country is presented in Table 2. It contains the proportion of citations that geographically matched the original patent for each geographic area and each dataset of the citing patent. It also contains the matching proportions for the control samples.[11] As Jaffe *et al.* (1993) assert, the weakness of the test for spillover localization is that it is difficult to separate spillovers from correlations due to a pre-existing pattern of geographic concentration of technologically-related activities. We use control variables as the proxy to reflect a pre-existing pattern of the geographic concentration of technologically-related activities.

Table 2 confirms that localization of knowledge flows exists in each country. Advanced economies, already analyzed in Jaffe, Trajtenberg and Henderson (1993) and Jaffe and Trajtenberg (1999), have geographic localization in knowledge flows. Catching-up economies, our point of interest, also have localization, though less than the advanced economies.[12]

These findings are supported by the fact that citations are domestic more often than the controls. For advanced economies, citations are domestic about 9 or 33 percent more often than the controls. Japan's citations are domestic about 33 percent more often than the controls. For the U.S., citations are domestic about 26 percent more often than the controls. Germany, France, and the U.K. are weaker than Japan and the U.S., although localization exists. The degree of their localization is 16 percent, 10 percent and 9 percent, respectively.

For the catching-up economies of Korea and Taiwan, citations are domestic about 5 or 11 percent more often than the controls. For Korea, citations are domestic about 5 percent more often than the controls. For Taiwan, citations are domestic about 11 percent more often than the controls. Therefore we find that there is also localization of knowledge flows in catching-up economies, although lower than advanced economies overall. The consideration that catching-up economies have heavy dependence upon external knowledge or technology makes it

11 We also perform a significance test, i.e. the t-statistic testing the equality of control proportions and the citation proportions.
12 The degree of localization of knowledge flows in Taiwan is comparable to that of the U.K. and France.

probable that catching-up countries does not have geographic localization of knowledge flows. However, our estimation confirms the geographic localization even in catching-up countries, irrespective of heavy dependence upon external knowledge.

<Table 2: Overall matching fractions>

	Number of Observations	Citation matching percentage(A)	Controls(B)	Degree of Localization(A-B)
Advanced economies				
U.K.	335063	0.1247795	0.0330154	9.18%***
France	304262	0.1318666	0.0281797	10.37%***
Germany	774084	0.2304233	0.0648979	16.55%***
Japan	2015025	0.4178514	0.0793259	33.85%***
U.S.	9251755	0.7480522	0.4820879	26.60%***
Catching-up economies				
Korea	79193	0.0678469	0.0135957	5.43%***
Taiwan	94736	0.126425	0.0132788	11.31%***

Note: *** represents significance at 0.01, based on t-test

We can now compare catching-up countries with advanced countries as a whole. It is evident that the degree of geographic localization is higher in advanced countries than in catching-up countries from the table 3. This fact represents that advanced countries reap much more results of previous innovation within the country than catching-up countries, and thus hints at the fragility of innovation base in catching-up countries.

<Table 3: Difference between advanced and catching-up economies>

	advanced countries			catching-up countries			Difference (A-B)
	citation matching percentage	control	Degree(A)	citation matching percentage	control	Degree(B)	
A	0.63273	0.0777	0.55503***	0.04176	0.01053	0.03123***	0.5238***
B	0.32151	0.05714	0.26437***	0.04176	0.01053	0.03123***	0.23314***

Note: A: advanced countries consist of U.K., France, Germany, Japan and US, B: advanced countries consist of U.K., France, Germany, and Japan

Note: *** represents significance at 0.01, based on t-test and F-test

4.1.2 Time trend in geographic localization of knowledge flows

In this subsection, we observe any possible changes in the pattern of geographic localization of knowledge flows in catching-up economies. In order to analyze the time trend, we measure the change in pattern as time goes by. Although the interest is in catching-up countries such as Korea and Taiwan, we also analyze Japan as a reference. Japan is regarded as a country that generates vigorous technological innovation. Moreover, like Korea and Taiwan, she is located in East Asia. And we also perform trend analysis to confirm our result.

Citation matching consists of geographic localization and growth in the pre-existing distribution captured by the controls. In Japan's case, the two ratios have grown at similar speeds. Specifically, the degree of geographic localization has a continuous growing trend.

In case of catching-up countries, however, the first ratio has grown faster than the second. From this it is can be suggested that the fast accumulation of technological innovation and technological catch-up accompanies the geographic localization.

<Table 4: trend of geographic localization in Japan>

	Citation matching percentage(A)	Controls(B)	Degree of Localization(A-B)
1970	0.1558	0.1093	0.0466
1971	0.1858	0.0752	0.1106***
1972	0.1574	0.0784	0.079***
1973	0.1847	0.0849	0.0998***
1974	0.1983	0.0883	0.1101***
1975	0.23	0.0961	0.1339***
1976	0.2324	0.0984	0.134***
1977	0.2596	0.113	0.1465***
1978	0.2636	0.1217	0.1419***
1979	0.2696	0.1276	0.1419***
1980	0.2845	0.1305	0.1539***
1981	0.3033	0.1439	0.1594***
1982	0.3145	0.1528	0.1617***
1983	0.3209	0.1613	0.1596***
1984	0.339	0.1681	0.1709***
1985	0.3507	0.1756	0.1751***
1986	0.3685	0.1893	0.1792***
1987	0.3894	0.1981	0.1913***
1988	0.4198	0.2069	0.2129***
1989	0.428	0.2173	0.2107***

1990	0.4506	0.2297	0.2209***
1991	0.4536	0.2385	0.2152***
1992	0.4552	0.2489	0.2064***
1993	0.4636	0.2575	0.2061***
1994	0.4724	0.25	0.2223***
1995	0.4841	0.258	0.2261***
1996	0.4892	0.2671	0.2222***

Note: *** represents significance at 0.01, based on t-test

All the catching-up economies show a strengthening trend of localization. In particular, the rising trend of localization in the 1990s is remarkable. We can infer that localization has strengthened in parallel to the increase in R&D investment and the growth of technological capability which is analyzed in much literature, especially in Kim (1997) and Hobday (1995).

However, the trend of Korea is weaker than that of Taiwan. Roughly speaking, Taiwan is 5 years ahead of Korea in terms of the localization of knowledge flows. This holds across all periods. We can infer that the technological development of Taiwan accompanies much more localization, compared with that of Korea.[13]

<Table 5: Trend of geographic localization in Korea>

	Citation matching percentage(A)	Controls(B)	Degree of Localization(A-B)
1979	0.0545	0	0.0545
1980	0.0213	0	0.0213
1981	0.0141	0	0.0141
1982	0.0109	0	0.0109
1983	0.0247	0	0.0247
1984	0.0132	0	0.0132
1985	0.0199	0	0.0199
1986	0.018	0	0.018
1987	0.0249	0	0.0249***
1988	0.0267	0.0033	0.0234***
1989	0.0172	0.0034	0.0138***
1990	0.0272	0.0048	0.0223***
1991	0.0355	0.0081	0.0275***

13 And if this represents technological capability, it is probable that the technological capability of Taiwan is superior to that of Korea.

1992	0.0433	0.0081	0.0351***
1993	0.0509	0.0129	0.038***
1994	0.0656	0.0136	0.052***
1995	0.0749	0.0194	0.0555***
1996	0.0703	0.0176	0.0527***

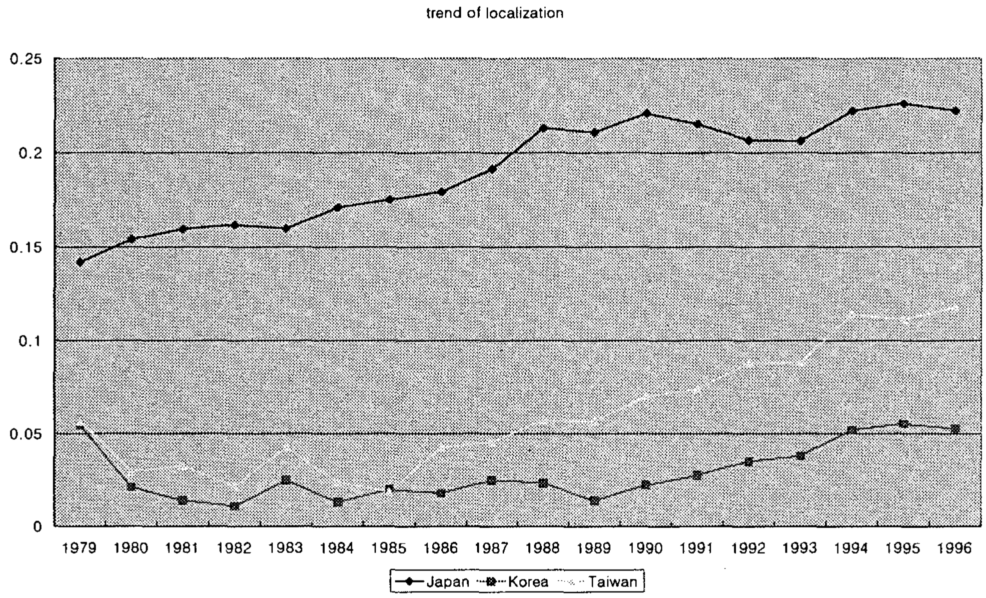
Note: *** represents significance at 0.01, based on t-test

<Table 6: trend of geographic localization in Taiwan>

	Citation matching percentage(A)	Controls(B)	Degree of Localization(A-B)
1977	0.0676	0.0152	0.0524
1978	0.0269	0	0.0269
1979	0.0676	0.0109	0.0567***
1980	0.0294	0	0.0294***
1981	0.0326	0	0.0326
1982	0.0215	0	0.0215***
1983	0.0478	0.0054	0.0424***
1984	0.0262	0.0022	0.0239***
1985	0.0199	0.0012	0.0187***
1986	0.0467	0.0042	0.0425***
1987	0.0472	0.0018	0.0454***
1988	0.0621	0.0047	0.0574***
1989	0.0619	0.0053	0.0566***
1990	0.0776	0.0075	0.0701***
1991	0.0856	0.0117	0.0739***
1992	0.1005	0.0128	0.0878***
1993	0.1005	0.0123	0.0881***
1994	0.1322	0.0182	0.114***
1995	0.1321	0.0209	0.1113***
1996	0.1428	0.0252	0.1177***

Note: *** represents significance at 0.01, based on t-test

Figure 1 Trend of geographic localization



We now try to perform simple trend analysis. After running regression on time it is shown that the degree of geographic localization of knowledge flows are increasing as time goes by. This fact represents that the development of technological innovation accompanies the geographic localization.

<Table 7: Trend analysis of degree of geographic localization for 3 countries>

	regression equation	R square	Adj R square	F value
Japan	degree = 0.09755+0.00485t	0.8334	0.8274	140.07
	(14.08) (11.83)			
Korea	degree = 0.01374+0.00195t	0.4104	0.3793	13.22
	(2.19) (3.64)			
Taiwan	degree = 0.0102+0.00539t	0.7806	0.7702	74.74
	(1.27) (8.64)			

Note: numbers in parenthesis indicate t-statistic

Therefore, in spite of the characteristics of catching-up countries, there are some development of geographic localization of knowledge flows in catching-up countries, which in adverse reflects the accumulation of technological innovation in those countries.

4.1.3 Pure localization

In this subsection we try to analyze whether previous results hold even when we only consider the knowledge flows between the innovators. In this analysis, the characteristics of patent citation data can be utilized.

From the patent citation data, it is possible to distinguish knowledge flows *within* the innovators from knowledge flows *between* innovators. Self-citations can function as a proxy for knowledge flows within the innovators.[14] By definition, a self-citation entails citing a patent that is assigned by its inventors to the same party as the originating patent. On one hand, citing patents that belong to the same assignee represents transfers of knowledge that are mostly internalized within the innovators. On the other hand, citations to patents of others are closer to the pure notion of diffused spillovers (Hall *et al.*, 2001)

Based on the distinction between self-citations and non-self-citations, we can distinguish between interaction between innovators and internalization within the innovators. Table 8 represents the matching proportion and control proportion excluding self-citations. It can be interpreted as the localization of interactions between the innovators or knowledge spillovers between innovators.

After excluding self-citations, localization still holds across both advanced and catching-up economies. However, the degree of localization is substantially weakened, especially in catching-up economies. For Korea, after excluding self-citations, citations are domestic about only 1.76 percent more often than the controls, compared to 5.43 percent when including self-citations. For Taiwan, after excluding self-citations, citations are domestic about 4.65 percent more often than the controls, compared to 11.31 percent.

The following inferences can be made. First, localization in catching-up economies mainly arises from the internalization of knowledge within the innovators. Second, interaction between innovators in catching-up economies is weaker than in advanced economies. Third, among catching-up economies, the degree of localization in Korea is much weaker than that of Taiwan, which is comparable to the U.K. and France. Localization in Korea owes much to that within innovators, compared to Taiwan.[15]

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14 In measuring the localization, some argue that it is more accurate to excluding self-citation because they are focusing the knowledge spillover (Jaffe et al, 1993). However, in this paper we regard the localization in light of evidence of sustainability of innovation, and therefore it is more desirable to include self-citations.

15 It is remarkable that the extent of localization from that within innovators in the U.S. and Japan is 18.9 percent and 23.2 percent respectively, compared to other countries, even other advanced countries. This implies that these two countries have active interaction between innovators, specifically, interaction between firms.

<Table 8: Overall matching fractions excluding self-citations>

	Number of Observations	Citation matching percentage(A)	Controls(B)	Degree of Localization(A-B)
Advanced economies				
U.K.	297855	0.0808178	0.0370461	4.38%***
France	270340	0.0778575	0.0321586	4.57%***
Germany	667540	0.1539533	0.0800205	7.39%***
Japan	1730070	0.3333645	0.0951524	23.82%***
U.S.	7487260	0.7088273	0.5198006	18.90%***
Catching-up economies				
Korea	73596	0.033317	0.0157168	1.76%***
Taiwan	64954	0.0616282	0.0150949	4.65%***

Note: *** represents significance at 0.01, based on t-test

When we compare advanced countries with catching-up countries as a whole, we can find that the degree of geographic localization is higher in advanced than in catching-up countries.

<Table 9: Difference between advanced and catching-up economies after excluding self-citations>

	advanced countries			catching-up countries			Difference (A-B)
	citation matching percentage	control	Degree(A)	citation matching percentage	control	Degree(B)	
A	0.57704	0.09568	0.48136***	0.03037	0.01281	0.01756***	0.4638***
B	0.24433	0.06969	0.17464***	0.03037	0.01281	0.01756***	0.15708***

Note: A: advanced countries consist of U.K., France, Germany, Japan and US, B: advanced countries consist of U.K., France, Germany, and Japan excluding US

Note: *** represents significance at 0.01, based on t-test and F-test

In sum, even though catching-up countries has shown geographic localization of knowledge flows and also rising trend as time goes by, irrespective of relatively fragile innovation base, it also holds that the degree of geographic localization is much lower in catching-up countries than in advanced countries. This represents that catching-up countries reap much less results of previous innovation within the country than advanced countries.

4.2 Knowledge diffusion and nature of geographic localization

In this subsection, we try to analyze the knowledge diffusion to catching-up countries using previous framework. In particular, we are interested in toward which country catching-up countries have been biased mostly in the knowledge inflows, in consideration of the pre-existing distribution of technological activities. In order to estimate the degree of influence by each country, we try to utilize the country composition of knowledge diffusion toward catching-up countries.

And this estimate can be utilized for analyzing the differing economic implication or importance of the geographic localization in the advanced and catching-up countries. This analysis helps to comprehend the relative importance which the localization of knowledge flows have in the knowledge flows of each country, and assessing how this localization is strong and whether this localization is strong or weak is also possible.

4.2.1 Knowledge diffusion and nature of geographic localization in advanced and catching-up countries

In this subsection, we analyze the country composition of the patents that each country cited, and compare it with the country composition of the relevant control samples.[16] Comparing the two datasets highlights the importance of localization in each country.

Table 10 shows the country composition of patents cited by each advanced country and, as a reference, that of their respective controls. As indicated before, the control variables are designed to reflect a pre-existing pattern of the geographic concentration of technologically-related activities. Therefore, comparing the two ratios reveals the characteristics in citing practices or the direction of knowledge flows, particularly knowledge inflows, of each country. The variable degree is calculated as the difference between the citation percentage and that of the controls.

The variable degree can be interpreted as the degree of the localization or dependence in the knowledge inflows in each country. Table 10 and 11 represent the proportion of each cited country, while simultaneously considering the pre-existing pattern of geographic concentration, with relation to each country including one's own country.[17] The variable degree for one's own country can be interpreted as the degree of the localization in knowledge flows in each country. For other countries, it shows the direction or degree of knowledge inflows[18], as well as importing and the acquisition of knowledge from that country.

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16 Of course, we approach localization in terms of knowledge inflows because of the asymmetry of citation data previously discussed.

17 We include the countries within 95 percent on cumulative dimension, and exclude countries showing negligible proportion for convenience.

18 In strict terms, it can be regarded as the degree of biasedness in knowledge inflows.

Remarkably, the variable degree has positive signs only for one's own country in the advanced countries, except for those countries that show negligible extent. Although all countries cite the U.S. most frequently, this is because most technological activities take place in the U.S.[19] Considering this pre-existing pattern, it is evident that all advanced countries much more often cite their own patents rather than that of other countries.[20]

As previously indicated, among advanced countries, Japan shows the highest degree, and the U.K. shows the lowest degree.

<Table 10: Country composition of cited patent for advanced countries>

	Citation percentage (%)(A)	Controls (%)(B)	Degree (%p)(A-B)
A. U.S. patents held by US			
U.S.	74.81	48.29	26.52
Japan	9.02	23.07	-14.05
Germany	4.53	8.08	-3.55
U.K.	2.73	2.66	0.07
France	1.95	3.12	-1.17
Canada	1.63	2.02	-0.39
Switzerland	0.9	1.45	-0.55
B. U.S. patents held by Germany			
U.S.	48.63	62.16	-13.53
Germany	23.04	6.49	16.55
Japan	12.3	13.56	-1.26
U.K.	3.71	3.76	-0.05
France	3.03	3.25	-0.22
Switzerland	2.16	1.65	0.51
Canada	1.18	1.84	-0.66
Italy	1.11	1.26	-0.15
C. U.S. patents held by France			
U.S.	56.08	61.39	-5.31
France	13.19	2.82	10.37
Japan	10.07	13.33	-3.26
Germany	7.68	8.24	-0.56

19 There can be also bias for the U.S., because we utilize the data of the USPTO which may function for U.S. innovators.
20 Though negligible, countries other than own country that have positive signs may represent interchange between two countries, i.e. the U.K. for U.S., Switzerland for Germany, the U.K. for France. This fact is partly analyzed in Jaffe and Trajtenberg (1999).

U.K.	3.95	3.85	0.1
Switzerland	1.63	1.6	0.03
Canada	1.37	1.79	-0.42
Italy	1.14	1.16	-0.02
D. U.S. patents held by U.K.			
U.S.	59.35	60.99	-1.64
U.K.	12.48	3.3	9.18
Japan	9.62	14.12	-4.5
Germany	7	8.1	-1.1
France	3.1	3.37	-0.27
Canada	1.49	1.65	-0.16
Switzerland	1.39	1.64	-0.25
Sweden	0.94	1.01	-0.07
E. U.S. patents held by Japan			
U.S.	42.25	64.19	-21.94
Japan	41.79	7.93	33.86
Germany	5.83	8.44	-2.61
U.K.	2.35	3.8	-1.45
France	1.96	3.31	-1.35
Switzerland	0.92	1.86	-0.94
Netherlands	0.83	0.9	-0.07

Note: For each country, we only show countries within a cumulative ratio of 95% in descending order

Table 11 shows the country composition of patents cited by each catching-up country and, as a reference, that of their respective controls. As indicated, Korea and Taiwan show localization of knowledge flows. That is, after considering the pre-existing pattern of geographic concentration, Korea and Taiwan show positive degree for their own country.

As we observe closely, however, an important observation can be made. In considering the pre-existing pattern, Korea cites Japan most frequently, which signifies that Japan, not Korea, emerges as Korea's most influential country. However, Taiwan shows the highest degree for her own country.

When we look at the citation percentage of knowledge inflows at Korea, it is shown that most of citation comes from US and Japan. That is Korean patents made citation to US patents for about 44 percent and to Japanese patents for about 35 percent. However, when we try to scrutinize in light of biasedness through pre-existing pattern of geographic concentration, we can get different story. That is Korean patents has not been biased toward US, but, mostly biased toward Japan. Korean patents cite less than the proportion of US, based on the distribution of cited patents, but cite more than that of Japan.

Although Korea cites US most frequently, it is because there are much technological activities in US. However this fact does not hold when we consider pre-existing pattern of concentration. Korea does not cite US as high as expected.

From this, it is possible to conjecture on the importance of the localization of knowledge flows in each country and to distinguish between strong and weak localization. Although localization of knowledge flows occur in Korea, its importance is not comparable that of advanced countries or even Taiwan. Rather, knowledge inflows from Japan is more important than own country in Korea. We can define this weak localization that the relative importance of own country is weaker than that of another country.

Whether there is strong or weak localization can be defined in light of the degree of biasedness, with consideration of the pre-existing distribution. Strong localization represents being mostly biased toward innovation of own country. That is, a country has a mostly biased dependence upon own country. Meanwhile, weak localization entails being mostly biased toward another country, although there is still biased dependence toward own country, in consideration of the pre-existing distribution of technological activities. In a country with weak localization, another country emerges as the most important country in their technological innovation. This country is the most influential country, compared to the pre-existing distribution of technological activities.

Overall, it is probable that Korea shows weak localization, whereas Taiwan shows strong localization, although same in terms of nature of catching-up countries.[21]

<Table 11: Country composition of cited patent for catching-up countries>

	Citation percentage (%)(A)	Controls (%)(B)	Degree (%)(A-B)
A. U.S. patents held by Korea			
U.S.	44.38	50.23	-5.85
Japan	35.45	29.27	6.18
Korea	6.78	1.36	5.42
Germany	3.37	5.65	-2.28
U.K.	1.72	2.55	-0.83
France	1.61	2.74	-1.13
Taiwan	1.41	0.93	0.48
Canada	1	1.33	-0.33
B. U.S. patents held by Taiwan			

21 And also although not large, table 4 shows active exchange between Korea and Taiwan.

U.S.	55.84	60.59	-4.75
Japan	15.07	16.66	-1.59
Taiwan	12.64	1.33	11.31
Germany	3.74	6.26	-2.52
Korea	2	0.77	1.23
Canada	1.92	2.14	-0.22
U.K.	1.74	2.65	-0.91
France	1.65	2.68	-1.03
Italy	1.05	1.14	-0.09

Note: For each country, we only show countries within cumulative ratio of 95% in descending order

4.2.2 Knowledge diffusion and nature of geographic localization at pure knowledge flows

Even when we are confined to knowledge flows between innovators, i.e. pure knowledge flows, the previous discussion does not change. As previously mentioned, strong localization of knowledge flows still exist in advanced countries. These are mostly affected by their own patents, in consideration of the pre-existing geographic distribution of patenting activities. Japan and the U.S. comprise the first tier in the degree of the localization of knowledge flows, with Germany, France and the U.K. following.

For Asian catching-up economies, it must be noted that the influence of Japan is larger, when only considering the knowledge flows between innovators rather than all knowledge flows. For Korea, the degree of citing Japanese patents compared to the control dataset becomes larger than when considering all knowledge flows. As previously indicated, the degree of own country decreases. For Taiwan, the impact of own country is still mostly large and thus important, but the affect and importance of Japan is also large and important.

For Taiwan, previous literature asserts that the U.S. had a much more important affect than Japan. Hu and Jaffe (2003) argue that it is much more likely for Korean patents to cite Japanese than U.S. patents, whereas Taiwanese inventors tend to learn evenly from both.[22] But our

[22] Korea is much closer to Japan than it is to the U.S., whereas Taiwan draws on both Japan and the U.S. with similar frequency. Further, the frequency of citation of Taiwan to the U.S. and Japan (after controlling for other effects) is similar to the frequency of citation of Korea to the U.S., making the high frequency of citation of Korea to Japan the ''outlier'' among these four country pairs. This high-citation dependence of Korea on Japan is partly due to their technological proximity. Even after controlling for technological proximity, however, the dependence of Korea on Japanese technology is higher than has been found among any of the G-5 countries. The fact that there is a higher incidence of Taiwan citing U.S. patents than Japanese patents is also consistent with the argument that foreign direct investment from the U.S. and linkage of Taiwanese firms to U.S. firms through returning students and Taiwanese expatriates working in the U.S. play an important role in Taiwan's technological progress, particularly in the electronics industry (Hu and Jaffe, 2003).

results show evidence against this assertion.

<Table 12: Country composition of cited patents for advanced countries in case of excluding self-citations>

	Citation percentage (%)(A)	*Controls (%)(B)*	*Degree (%)(A-B)*
A. U.S. patents held by U.S.			
U.S.	70.88	52.05	18.83
Japan	10.95	20.54	-9.59
Germany	5.29	7.64	-2.35
U.K.	3.15	2.68	0.47
France	2.26	2.91	-0.65
Canada	1.64	2.12	-0.48
Switzerland	1.02	1.63	-0.61
B. U.S. patents held by Germany			
U.S.	53	61.09	-8.09
Germany	15.4	8	7.4
Japan	14.13	13.41	0.72
U.K.	4.14	3.71	0.43
France	3.37	3.18	0.19
Switzerland	2.31	1.64	0.67
Canada	1.26	1.82	-0.56
Italy	1.23	1.2	0.03
Sweden	1.12	1.11	0.01
C. U.S. patents held by France			
U.S.	59.03	61.15	-2.12
Japan	11.23	13.27	-2.04
Germany	8.31	8.22	0.09
France	7.79	3.22	4.57
U.K.	4.26	3.88	0.38
Switzerland	1.65	1.59	0.06
Canada	1.44	1.76	-0.32
Italy	1.21	1.12	0.09
Netherlands	1.04	1.02	0.02
D. U.S. patents held by U.K.			
U.S.	61.6	60.8	0.8
Japan	10.69	14.04	-3.35
U.K.	8.08	3.71	4.37

Germany	7.6	7.97	-0.37
France	3.34	3.31	0.03
Canada	1.53	1.69	-0.16
Switzerland	1.43	1.65	-0.22
Sweden	0.99	1.03	-0.04
E. U.S. patents held by Japan			
U.S.	48.32	63.27	-14.95
Japan	33.34	9.52	23.82
Germany	6.72	8.3	-1.58
U.K.	2.71	3.73	-1.02
France	2.26	3.28	-1.02
Switzerland	1.05	1.79	-0.74
Netherlands	0.96	0.9	0.06

<Table 13: Country composition of cited patents for catching-up countries in case of excluding self-citations>

	Citation percentage (%)(A)	*Controls (%)(B)*	*Degree (%)(A-B)*
A. U.S. patents held by Korea			
U.S.	45.09	49.73	-4.64
Japan	37.98	29.84	8.14
Germany	3.48	5.52	-2.04
Korea	3.33	1.57	1.76
U.K.	1.8	2.51	-0.71
France	1.68	2.74	-1.06
Taiwan	1.33	0.84	0.49
Netherlands	1.05	1.29	-0.24
B. U.S. patents held by Taiwan			
U.S.	54.63	57.85	-3.22
Japan	20.9	19.31	1.59
Taiwan	6.16	1.51	4.65
Germany	4.52	6.53	-2.01
Korea	2.7	0.92	1.78
France	1.98	2.7	-0.72
U.K.	1.98	2.61	-0.63
Canada	1.62	1.92	-0.3
Italy	1.12	1.09	0.03

In sum, in considering the pre-existing pattern, Korea cites Japan most frequently, which signifies that Japan, not Korea, emerges as Korea's most influential country whether we consider all flows or just flows excluding self-citations. Taiwan cites her own country most frequently with consideration of the pre-existing pattern, but when we consider flows excluding self-citations, even though the impact of own country is still mostly large and thus important, the affect and importance of Japan is also large and important.

If strong or weak localization can be defined in light of the degree of biasedness, with consideration of the pre-existing distribution, catching-up countries, especially Korea, can be characterized as having weak localization of knowledge flows. That is, Korea has been mostly biased toward another country, although there is still biased dependence toward own country, in consideration of the pre-existing distribution of technological activities.

4.3 Different pattern of geographic localization in catching-up countries

We now focus mainly on the difference between Korea and Taiwan. It is well-known that the Korean economy and its innovation activities are spear-headed by large diversified business groups, while the Taiwanese economy is dominated by relatively smaller but specialized firms. We are interested in the impact that these differing characteristics have on the nature of the geographic localization of knowledge flows.

4.3.1 The difference between Korea and Taiwan, and self-citation

Table 14 summarizes the degree of geographic localization in Korea and Taiwan, the differences between them, and that in the case excluding self-citations. It is evident that the degree of geographic localization is higher in Taiwan than in Korea. This holds whether we consider all citations or exclude self-citations. Thus even if self-citations are excluded, the degree of geographic localization is higher in Taiwan, hinting at the fact that interaction between innovators is more active in Taiwan.

<Table 14: difference between Korea and Taiwan in terms of degree of localization>

All flows			Pure flows		
Korea	Taiwan	Difference	Korea	Taiwan	Difference
5.43%***	11.31%***	5.89%***	1.76%***	4.65%***	2.89%***

As indicated previously, we can decompose geographic localization into interaction *between* innovators and interaction *within* innovators. We distinguish knowledge flows within innovators and knowledge flows between innovators. We can analyze the localization of knowledge flows by excluding knowledge flows within innovators, i.e. pure knowledge flows between innovators. This will highlight an important element in the localization of knowledge flows, i.e. the differing nature of geographic localization between catching-up economies.

First, we describe the self-citation data and the interactions between innovators in each country. The following comparisons between catching-up and advanced economies can be made. Catching-up economies have a relatively high proportion of self-citations but a relatively low proportion of non-self-citations among citation matching. Advanced economies are the opposite, which suggests that interaction between innovators is more active in advanced countries. However, strict analysis necessitates further consideration of the pre-existing distribution of technological activities that is captured by the control set. It should also be noted that the criteria for citation matching is different from that of self-citation. Nationality is identified by the inventor and self-citation is identified by the assignee; these are not necessarily the same.[23]

<Table 15: Statistics of self-citation>

	Citation matching percentage	Proportion of self-citation
Advanced economies		
U.K.	0.1247795	0.424239
France	0.1318666	0.4754
Germany	0.2304233	0.423828
Japan	0.4178514	0.315015
U.S.	0.7480522	0.233156
Catching-up economies		
Korea	0.0678469	0.543644
Taiwan	0.126425	0.665776

Note: Proportion is only from the citation matching data.

Table 16 represents ratio of self-citation and locality. According to it, Korea has shown larger proportion of locality in case of self-citation but small proportion of locality in case of non-self-citation. However, Taiwan has shown smaller proportion of locality in case of self-citation rather than Korea, but higher in another case.

23 In Korea, the total citation it made reaches 79,193. Among this, those geographically matching with Korea are 5,373 which consist of 2,921 self-citations and 2,452 non-self-citations. But at the same time, there are also 2,676 self-citations and 71,144 non-self-citations that are not geographically matching with Korea.

<Table 16: Ratio of self-citation and locality>

Korea				Taiwan			
self-citation		non-self-citation		self-citation		non-self-citation	
0.0706754		0.9293246		0.3143683		0.6856317	
local	non-local	local	non-local	Local	non-local	local	non-local
52.19	47.81	3.33	96.67	26.77	73.23	6.16	93.84

In following discussion, we try to analyze by periods.

4.3.2 Change in the pattern of geographic localization of knowledge flows by periods

We now measure the time trend of the localization of knowledge flows in catching-up countries by periods. To do this, we group the application years and estimate for five-year intervals. The first period is 1980-1984 application years, the second period is 1985-1989, the third period is 1990-1994 and the final fourth period is 1995-1999.

Table 17 and Table 18 show rising trend of geographic localization in both countries. At the same time, like the annual trend, the degree of Taiwan is higher than that of Korea.

<Table 17: Overall matching fractions by 4 periods in Korea >

	Number of Observations	Citation matching percentage(A)	Controls(B)	Degree of Localization(A-B)
1980-1984	523	0.0172084	0	1.72%***
1985-1989	3831	0.0208823	0.0029924	1.79%***
1990-1994	24469	0.0498181	0.009689	4.01%***
1995-1999	50224	0.0808777	0.0179871	6.29%***

Note: *** represents significance at 0.01, based on t-test

<Table 18: Overall matching fractions by 4 periods in Taiwan>

	Number of Observations	Citation matching percentage(A)	Controls(B)	Degree of Localization(A-B)
1980-1984	1789	0.0313024	0.0037831	2.75%***
1985-1989	8849	0.0524353	0.0053327	4.71%***
1990-1994	31470	0.1051478	0.0106675	9.45%***
1995-1999	51822	0.1567095	0.020713	13.60%***

Note: *** represents significance at 0.01, based on t-test

From what element does the difference between Korea and Taiwan emerge? Again we analyze the degree of the interaction between innovators, distinguished from internalization within innovators. Tables 19 and 20 present overall matching fractions by 4 periods in Korea and Taiwan, excluding self-citations. For Korea, after excluding self-citations, the degree of localization shows a remarkable decrease and only a minor localization of knowledge flows remains. However, for Taiwan, excluding self-citations does not remove the localization of knowledge flows, especially in the 1990s.

<Table 19: Overall matching fractions excluding self-citations by 4 periods in Korea >

	Number of Observations	Citation matching percentage(A)	Controls(B)	Degree of localization(A-B)
1980-1984	334	0.005988	0	0.60%
1985-1989	3386	0.0050207	0.000607718	0.44%***
1990-1994	22630	0.0201502	0.0111205	0.90%***
1995-1999	47172	0.0419105	0.0202053	2.17%***

Note: *** represents significance at 0.01, based on t-test

<Table 20: Overall matching fractions excluding self-citations by 4 periods in Taiwan>

	Number of Observations	Citation matching percentage(A)	Controls(B)	Degree of localization(A-B)
1980-1984	883	0.006795	0	0.68%**
1985-1989	5091	0.0188568	0.0039754	1.49%***
1990-1994	20708	0.0426888	0.0107427	3.19%***
1995-1999	37904	0.0793848	0.0202414	5.91%***

Note: *** and ** represents significance at 0.01 and 0.05 respectively, based on t-test

4.3.3 Change in the nature of knowledge diffusion by periods

We now highlight the nature of geographic localization through the country composition of cited patents. For Korea, in the country composition of cited patents during the four periods, Japan is the biggest influence until the third period 1990-1994, compared to the pre-existing geographic distribution. Until this period, the influence of Japan increases over time, implying that growth in technological capability accompanied a biased dependence on Japan. However, in the last period, the gap between the degree of Japan and that of own country decreases. This indicates that Korea moved from weak to strong localization, and its technological capability growth has recently accompanied less biased dependence on Japan.

<Table 21: Knowledge diffusion and the trend of localization: country composition of cited patent by 4 periods in Korea>

Country	Citation percentage (%)	Controls (%)	Degree (%)	Citation percentage (%)	Controls (%)	Degree (%)
Period	1980-84			1985-1989		
U.S.	66.92	70.27	-3.35	52.99	55.66	-2.67
JAPAN	10.33	7.69	2.64	27.85	22.14	5.71
KOREA	1.72	0	1.72	2.09	0.3	1.79
TAIWAN	0.38	0	0.38	0.63	0.38	0.25
Period	1990-1994			1995-1999		
U.S.	43.49	49.88	-6.39	43.85	49.88	-6.03
JAPAN	37.56	29.48	8.08	35.35	29.96	5.39
KOREA	4.98	0.97	4.01	8.09	1.8	6.29
TAIWAN	0.78	0.44	0.34	1.79	1.16	0.63

Meanwhile, Taiwan shows strong localization throughout all periods in terms of the degree of the localization of knowledge flows, compared to the pre-existing geographic distribution of technological activities. The degree of localization of knowledge flows has increased with time. Compared to Korea, the influence of Japan was not large.

<Table 22: Knowledge diffusion and trend of localization: country composition of cited patent by 4 periods in Taiwan>

Country	*Citation percentage (%)*	*Controls (%)*	*Degree (%)*	*Citation percentage (%)*	*Controls (%)*	*Degree (%)*
Period	1980-84			1985-1989		
U.S.	70.15	71.5	-1.35	65.22	66.53	-1.31
JAPAN	7.43	7.25	0.18	10.96	10.46	0.5
TAIWAN	3.13	0.38	2.75	5.24	0.53	4.71
KOREA	0.11	0.06	0.05	0.20	0.06	0.14
Period	1990-1994			1995-1999		
U.S.	57.76	62.04	-4.28	52.39	58.37	-5.98
JAPAN	14.34	15.68	-1.34	16.61	19.08	-2.47

TAIWAN	10.51	1.07	9.44	15.67	2.07	13.6
KOREA	0.96	0.41	0.55	3.02	1.28	1.74

When exploring the country composition confined to citations excluding self-citations in Korea, three things must be noted. First, the degree of Japan was larger than in the case of all citations. It means that in the interaction between innovators, the impact of Japan was much larger. Second, similar to the case of all citations, the degree of Japan increases until third period 1990-1994. Considering the fact that innovation effort occurred 1-2 years ahead of patent application, innovation that is dependent on outside innovation received much biased impact from Japanese technology in the first period of 1990s. Third, unlike the case of all citations, even in the last period, the degree of Japan and that of own country has not converged. That is, Japan still has the strongest impact on Korea on non-internalized innovation, compared to the pre-existing distribution of technological activities.

<Table 23: Country composition of cited patents excluding self-citations by 4 periods in Korea>

Country	*Citation percentage (%)*	*Controls (%)*	*Degree (%)*	*Citation percentage (%)*	*Controls (%)*	*Degree (%)*
Period	1980-84			1985-1989		
U.S.	61.98	65.72	-3.74	51.59	55.3	-3.71
Japan	14.67	8.49	6.18	31.04	23.12	7.92
Korea	0.6	0	0.6	0.5	0.06	0.44
Taiwan	0.6	0	0.6	0.41	0.43	-0.02
Period	1990-1994			1995-1999		
U.S.	43.57	49.62	-6.05	45.2	49	-3.8
Japan	40.37	30.18	10.19	37.54	30.6	6.94
Korea	2.02	1.11	0.91	4.19	2.02	2.17
Taiwan	0.61	0.43	0.18	1.75	1.05	0.7

For Taiwan, the comparison between the case confined to citations excluding self-citations, and all citations is remarkable. First, when confined to citations excluding self-citations, Japan is the most influential country, compared to the pre-existing distribution. That is, Taiwan shows weak localization until the 1980s. This confirms that Taiwan also received very biased impact from Japanese technology in the case of non-internalized innovation. Second, dependence on Japan tends to decrease and is even negative in the last period 1995-1999. Third, as Japanese impact diminishes, there is an increasing tendency to depend on own country, i.e. localization. Thus innovation in Taiwan has a strengthening trend of localization of knowledge flows, even in the case of interaction between innovators. This process accompanies relative independence from other countries, i.e. Japan.

<Table 24: Country composition of cited patent excluding self-citations by 4 periods in Taiwan>

Country	*Citation percentage (%)*	*Controls (%)*	*Degree (%)*	*Citation percentage (%)*	*Controls (%)*	*Degree (%)*
Period	1980-84			1985-1989		
U.S.	64.55	66.9	-2.35	60.7	63.74	-3.04
JAPAN	12.68	9.52	3.16	16.5	12.25	4.25
TAIWAN	0.68	0	0.68	1.89	0.4	1.49
KOREA	0	0	0	0.14	0.04	0.1
Period	1990-1994			1995-1999		
U.S.	55.86	58.71	-2.85	52.84	55.53	-2.69
JAPAN	20.54	18.3	2.24	21.97	22.42	-0.45
TAIWAN	4.27	1.07	3.2	7.94	2.02	5.92
KOREA	1.2	0.5	0.7	3.96	1.41	2.55

Finally, we now compare Korea and Taiwan. Table 25 summarizes the degree of geographic localization in Korea and Taiwan, the differences between them, and that in the case of pure knowledge, by periods. It is evident that the degree of geographic localization is higher in Taiwan than in Korea by all periods, whether we consider all citations or exclude self-citations. Thus even if self-citations are excluded, the degree of geographic localization is higher in Taiwan, hinting at the fact that interaction between innovators is more active in Taiwan

Table 26 presents the ratio between degree of localization of all flows and that of pure flows. Remarkably, Korea has a rising trend in the share of self-citations, while Taiwan has a falling trend. We may infer that the localization of knowledge flows in Korea is led by the internalization of knowledge flows within innovators. Meanwhile, localization in Taiwan is led by the interaction between innovators. This conforms to the previously mentioned fact that technological development is led by a few large innovators in Korea.

<Table 25: Difference between Korea and Taiwan in terms of geographic localization>

	All flows			Pure flows		
	Korea	Taiwan	Difference	Korea	Taiwan	Difference
1980-1984	1.72%**	2.75%***	1.03%	0.60%	0.68%**	0.08%

1985-1989	1.79%***	4.71%***	2.92%***	0.44%**	1.49%***	1.05%***
1990-1994	4.01%***	9.45%***	5.44%***	0.90%***	3.19%***	2.29%***
1995-1999	6.29%***	13.60%***	7.31%***	2.17%***	5.91%***	3.74%***
Whole period	5.43%***	11.31%***	5.89%***	1.76%***	4.65%***	2.89%***

Note: *** and ** represents significance at 0.01 and 0.05 respectively, based on t-test and F-test

Note: Whole period represents coverage from 1975 to 1999 on registration year base

<Table 26: The ratio between degree of localization of all flows and that of pure flows>

Period	Korea			Taiwan		
	All flows(A)	Pure flows(B)	Ratio ((A-B)/A)	All flows(A)	Pure flows(B)	Ratio ((A-B)/A)
1980-84	1.72%**	0.60%	0.65203	2.75%***	0.68%**	0.75308
1985-89	1.79%***	0.44%**	0.75333	4.71%***	1.49%***	0.68406
1990-94	4.01%***	0.90%***	0.77498	9.45%***	3.19%***	0.66188
1995-99	6.29%***	2.17%***	0.65487	13.60%***	5.91%***	0.56511
Whole period	5.43%***	1.76%***	0.67558	11.31%***	4.65%***	0.588733

Note: It is calculated by (the degree of localization when including self-citation - the degree of localization when excluding self-citation)/the degree of localization when including self-citation.

Note: Whole period represents coverage from 1975 to 1999 on registration year base

4.4 Summary

Localization can be defined as the bias toward the innovation of one's own country. This localization then functions as a knowledge pool for further innovation in the country. This is because acquisition of external knowledge also necessitates the technological capability strengthened by the localization of knowledge flows.

Advanced countries, i.e. the U.S., Japan, Germany, France and U.K., show localization of knowledge flows. They mostly depend on their own country to generate innovation, more than is expected in light of the composition of their technological activities.

Similar to advanced countries, countries that achieved technological catch-up such as Korea and Taiwan have localization of knowledge flows. By detailed observation, one finds that catching-up countries have weak localization; they are biased toward a foreign country. Hence a foreign country emerges as the most important country in its technological innovation. While Korea shows weak localization, however, Taiwan shows strong localization. Korea was mostly biased toward another country, although there is a biased dependence toward its own innovations, in consideration of the pre-existing distribution of technological activities. Taiwan was mostly biased toward its own innovations.

The following findings arise from the analysis of the periodical trend. First, typically, as the level of innovation increases, localization goes from a low level to high and from weak to strong. In other words, the increase in innovation or the growth of technological capability accompanies higher and stronger localization. The growth of technological capability generates independence from the innovation of other countries.[24] Thus it is possible to interpret the geographic localization in Taiwan as illustrating the possibility that, even in catching-up economies, technological development accompanies a strengthening of the localization of knowledge flows, from weak to strong.

Second, factors that influence the localization of knowledge flows can be identified through evidence from catching-up economies such as Korea and Taiwan. The first and most important is the level of technological development, as previously indicated. The second factor influencing the localization of knowledge flows is the level of internalization within innovators, mostly firms, particularly in Asia. Increasingly strong interaction within the same organization increases localization. The third factor that affecting localization of knowledge flows is the interaction between innovators. This can be described as the diffusion of technological knowledge. The two latter factors do not coincide but have their own insight regarding innovating organizations, but in Korean and Taiwanese evidence, it is found that technological development accompanies the strengthening of the last factors.

The relative importance of each factor differs according to the characteristics of the each country. Nonaka's characterization of the types of knowledge creation can be applied to the cases of Korea and Taiwan. Korea, featured by large innovating firms, can be said to have strength in internalization like Japan, whereas Taiwan, featured by small innovating firms, can be said to have strength in externalization involving mainly explicit knowledge. In other words, while Korea's localization of knowledge flows occurred mainly through internalization of knowledge flows within innovators, Taiwan's localization of knowledge flows occurred mainly through interaction between innovators.

5. Summary and conclusion

Technological innovation can be regarded as the generation and exploitation of available knowledge flows. Meanwhile, knowledge flows also affect the level of technological innovation. Regarding knowledge flows, much of literature to date focuses on technology diffusion, mainly through capital goods. However, knowledge flows are not confined to technology diffusion through goods and services. Rather, they tend to be disembodied. Along these lines, an

24 The term 'independence' does not mean that innovation is achieved in isolation. Rather, considering the distribution of technological activities, it means that a country should retain an essential knowledge pool for further innovation.

important finding of some recent literature that analyzes the process of knowledge flows is the geographic localization of knowledge flows.

The geographic localization of knowledge flows is associated with the possibility of exploiting the results of past innovations within the national boundary. Its importance can be summarized as follows. First, for technological innovation to be sustainable, it is necessary to promote the ability to use and preserve knowledge flows in an fully exploitable form. For the sustainability or stability of innovation, the characteristics of knowledge flows, geographic localization within the national boundary in particular, are very important. Second, while direct government intervention has diminished, the function to affect overall knowledge flows and to reap the results of innovations within the country is becoming important. And innovation policy is mostly predicated on the existence of a geographic component to the knowledge spillover mechanism and the localization of knowledge externality.

To measure the degree of geographic localization, we construct cohorts of citing-cited pairs of catching-up economies. A corresponding control sample for each economy is also made. As a reference, we then test the localization of advanced economies. This reference sample can be used for identify whether the degree of geographic localization differs for catching-up economies.

When constructing the control frequency, we consider the sources of systematic variation over time in citation intensities and national technological specialization. We choose a control patent whose technological area and application year is the same as that of each cited patent. For each cited patent, a corresponding control sample of equal size, whose distribution across time and technological areas are identical to that of the cited patent, is constructed. The frequency with which control patents geographically match on the national dimension with the originating patent is an estimate of the frequency with which a randomly drawn patent not belonging to a citation but with the same technological and temporal profile as the citation, geographically matches on the national dimension. A significantly higher citation match frequency implies that citations are localized, even after controlling for timing and technology. And whether there is strong or weak localization can be defined as the degree of bias, in consideration of the pre-existing distribution.

From this study, we can observe the following. First, there is a marked difference between advanced countries and catching-up economies that differ in the stage of technological development, in terms of strong or weak localization of knowledge flows or spillovers. Second, even in catching-up countries, technological development accompanies a strengthening of the localization of knowledge flows, from weak to strong as well as from low to high. However, the characteristics of each country also affect innovation and localization of knowledge flows. Korea with large innovating firms achieved localization of knowledge flows mainly through internalization of knowledge flows; Taiwan featured by small innovating firms achieved localization of knowledge flows mainly through interaction between knowledge flows. And a high level of localization would accompany the latter case.

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