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How "Open" is Innovation in the US and Japan?: Evidence from the RIETI-Georgia Tech inventor survey

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ABSTRACT

While individual inventors are key to technological progress, it is becoming increasingly necessary for inventors and their firms to exploit information and capabilities outside the firm in order to combine one's own resources with resources from the external environment. To better understand the collaborative process in inventions, we collected detailed information on a sample of triadic patents, focusing on the invention process, sources of ideas, and collaboration (the RIETI-Georgia Tech inventor survey), with over 1900 responses from the US and over 3600 responses from Japan. Our results suggest that in both countries, just over 10% of inventions involved an external co-inventor and about 30% involved external (non-co-inventor) collaborators (with the rate of collaboration somewhat higher in Japan). Cross-organizational co-inventions increase as firm size declines, especially in Japan. In both countries, vertical collaborations (both co-inventions and other collaborations) with users and suppliers were the most common. The most important knowledge sources were similar in the two countries: patents, customers, publications, and information from other parts of the firm, although their relative rankings varied somewhat. In particular, patent literature is a relatively more important information source in Japan and scientific literature is relatively more important in the US. Since our evidence suggest that inventors see literature globally, such difference does not seem to be driven by the difference of the disclosed literature (for an example, more early patent disclosure in Japan) as suggested by earlier literature but by that of the incentive and capability of the inventors. While in both countries most R&D funding is provided internally, venture capital and government funding play a greater role in the US than in Japan, with venture capital funds especially important for the smallest US firms. On the other hand, industry funding plays a greater role for university researchers' inventions in Japan. There is some evidence that "open innovation" through collaborations enhances not only the technical significance of the invention, but also the probability of its commercialization through, for an example, vertical collaboration facilitating better matches between the needs of customers or the capabilities of suppliers.

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1. Introduction

While individual inventors are key to technological progress, it is becoming increasingly necessary for inventors and their firms to exploit information and opportunities outside the firm in order to combine one's own capabilities and resources with those from the external environment. While such collaborative innovation strategies have been sometimes considered a hallmark of the Japanese innovation system (Branstetter and Sakakibara, 1998), increasingly, the US system is seen as moving toward an open innovation model (Chesbrough, 2003). Thus, inventing is increasingly seen as a collaborative activity. Furthermore, the conditions under which firms organize their invention process, the extent to which they collaborate with other organizations, and their uses of extramural sources are all expected to differ by country and by technology sector. To better understand the invention process, we collected detailed information on a sample of patented inventions, focusing on the invention process, sources of ideas, and collaboration. The data come from a unique set of matched surveys of US and Japanese inventors of triadic patents (the RIETI-Georgia Tech inventor survey). We have over 1900 responses from the US and over 3600 responses from Japan, stratified over the 2 digit NBER technology classes.

Using these data, we develop a detailed narrative of the invention process in the US and Japan. We focus on the extent to which invention is an open/collaborative activity, similarities and differences across the two countries, and how the process varies by industry and by organization type. Our results suggest that invention draws heavily on outside sources and is often a cooperative activity. In addition, we find that the invention process, and especially, the degree of inter-organizational cooperation, is broadly similar across the two countries, much more similar than we might expect based on bibliometric data such as patent co-assignment for the US (Hagadoorn, 2003, Hicks and Narin, 2001). In addition, we find that collaboration tends to enhance the value of an invention and the chance of commercialization, in particular, through increasing the exploitation of external information.

2. Data and Method

There has been substantial empirical work on inter-organizational cooperation, especially, that on the invention process. Much of this work uses patent document data such as co-inventorship, co-assignee, or citations, as measures of cooperation and uses of outside information (Narin, et al., 1997, Hicks, 1993, Hagedoorn, 2003, Hicks and Narin, 2001, Jaffe, et al., 1993). Another stream of research uses licensing data, joint ventures or formal R&D collaborations or consortia as the measure of cooperative innovation, generally collecting data from government documents, press releases and similar archival sources (Arora, et al., 2001, Branstetter and Sakakibara, 1998, Sakakibara, 2002). While this work has provided important insights into the relations between collaboration and innovation, these data sources have important limitations, the most important of which is that they depend on a formalized codification of the cooperation and information flows. However, informal cooperation may be an important component of cooperative R&D and of uses of outside information (von Hippel, 1988, Sattler, 2003). In addition, firms may generate codified information that only weakly reflect the underlying activities. For example, inventions that involve inventors from multiple organizations might be assigned to a single organization in order to simplify the property right (Hagedoorn, 2003, Fontana and Guena, 2008).

In order to capture this broader notion of cooperative R&D and information flows in a comprehensive manner, we make use of a recently conducted inventor survey in the US and in Japan. These survey data allow us to collect information on information flows and on R&D cooperation that does not depend on the existence of a publicly accessible formal agreement or codified information (such as a co-assigned patent, publicly announced cooperative R&D project or citation to a prior patent or publication). The design of our survey questionnaire, while depending on the recently implemented European inventor survey (PatVal survey, see Giuri, et al. (2007)), adds new dimensions such as distinguishing vertical and horizontal collaborations, which allows us to analyze the collaboration in R&D from new perspectives (see the Appendix 1 for the key aspects of the survey method). The data come from a survey of inventors on triadic patents (patents filed in Japan and the EPO and granted by the USPTO), We received data on over 3600 Japanese inventions (21% response rate, 27% after adjusting for ineligible, undeliverable, etc.). We also received responses from over 1900 US inventors (24% response rate, 32% adjusted).[2] For details of the survey, see Appendix 1. Because of differences in the technology sector composition in each country, when we report overall

[2] For the US data, comparing respondents and non-respondents based on bibliometric indicators found few differences that were either statistically or substantively significant. In particular, measures of collaboration (solo inventions: 27% for respondents, 26% for non-respondents; average number of inventors: 2.71 for respondents, 2.80 for non-respondents), links to universities (citations to non-patent literature: 2.4 for respondents v. 2.7 for non-respondents) and measures of patent value (forward citations: 2.2 for respondents and 2.4 for non-respondents) are all similar (none are significantly different, $p<.05$ [though some significant at .10], N=7933). The only significant differences are that inventors for which we only had a company address are less likely to respond (4% of respondents had a company address v. 6% for non-respondents, $p<.001$) and those inventors with more patents are more likely to respond, although the absolute difference is quite small (an average of 1.18 triadic patents for respondents, 1.13 for non-respondents, $p<.001$).

averages, we weight each country's responses by the (inverse) of the relative common frequency (the average of the US and Japanese frequencies) of that NBER technology class, so that that differences in the overall averages are net of the composition difference. However, when we do detailed breakdowns within country (for example, comparisons across firm size classes, or types of projects), we use the unweighted averages, since here the focus is on within country differences.

We asked respondents to tell us about a specific patented invention (named on the cover of the survey). For the target invention, we asked the surveyed inventor how many inventors are on the patent, and which type organization each of the inventors works for (supplier, customer, university, etc.). These were recoded as a set of dummy variables with a value of one if there was an external co-inventor from that type of organization, and zero otherwise. We also asked if, in addition to co-inventors, there were any formal or informal collaborations and what types of organization these collaborators represent. Again, these were recoded as a set of dummy variables representing types of external collaborators. We also asked how important various sources of information (published data, patents, information from customers, suppliers, universities, etc.) were for suggesting the project and for contributing to completion of the project. We asked the sources of finance for the R&D projects yielding the invention. We also asked the inventor for an estimate of the economic value and (for the US survey) the technological significance of the patent. We also asked whether the invention is commercialized either through internal use, license or startups. We will use these measures to analyze the collaborations in the creation of inventions in each country and across different sectors and their effects.

Table 1 gives basic descriptive statistics for our sample. We see that about 80% of the inventors are employed in large firms (over 500 employees), with somewhat more large firm inventors in Japan (84% v. 77%). The US sample contains more inventors from very small firms (less than 100 employees), with about 12% of the US inventors (versus 5% of Japanese inventors) from very small firms. Only 2% of the inventors on triadic patents are from universities, with little difference between the US and Japan. We also find that about 90% of the inventors in each country have at least a college degree, with 45% of the US inventors having a doctorate (12% for Japan). The average age of inventors in Japan is just under 40, while in the US, the average age is 47 years old. Five percent of the US sample is female, compared to less than 2% in Japan.

3. Co-invention, Co-assignee and Collaboration

Cooperative R&D can take many forms, including co-inventing (which has a legal meaning and can affect the validity of a patent), co-assignment (which involves sharing the property right in the invention) (Fontana and Geuna, 2008) and informal or formal collaboration but less than co-invention and co- assignment,. Bibliometric measures of co-assignment capture only one of these forms (Hicks and Narin, 2001, Hagedoorn, 2003). We can use our inventor data to estimate the relative incidence of different types of cooperative R&D.

Co-invention and Co-assignee

First, we compare the size of the research teams in each country. We find that the average Japanese patent has 2.78 inventors and the average American patent has 2.71. Thus, we see very little difference in the size of inventor teams in each country. Figure 1 gives the percent of solo inventions overall and by firm size. Again, we see that these are very similar across the two countries, with about 30% of the inventions having a single inventor, and the rates of solo inventions being very similar across firm sizes, except for the very small firms, which have higher rates of solo invention in both countries (about 40%).

Figure 2 gives the percent of external co-inventions (that is, co-invention with a inventor affiliated with an external organization), by country, and broken out by the organizational affiliation of the co-inventors. We see that, in both the US and Japan, about 13% of triadic patents have an external co-inventor. However, when we examine the patent documents, we find that while about 10% of these patents (10.3%) have co-assignees in Japan, less than 2% of US patents (1.8%) have co-assignees (consistent with prior work on US patents by Hagedoorn, 2003 and Hicks and Narin, 2001, and on European patents by Giuri, Mariani, et al., 2007). For the US data, we find that co-assignment is higher (in the range of 5-6% of patents) in drugs, biotech[3] and semiconductors. In Japan, co-assignment in these technology classes is close to the overall average. On the other hand, in Japan, co-assignment is highest in earth moving equipment, agriculture/food/textiles, measuring/testing instruments, receptacles, and surgical/medical devices, all of which have no co-assigned patents in the US sample. A closer examinations of the ownership structure shows that in Japan one third of the co-assigned patents are jointly owned by the parent and subsidiary firms, partially accounting for its high frequency of co-assignment. In addition, in the US, a coassignee can freely license his right to use the invention to a third party, while in Japan a co-assigned patent can be licensed only if all co-assignees agree. These findings suggest that

[3] Consistent with the findings of Hicks and Narin (2001).

there may be important country-level institutional differences in the drivers of co-assignment of patents, such as more diffused ownership of patents within a group of related firms in Japan. This finding requires additional research to uncover what aspects of invention lead to a co-assigned patent.

Figure 2 also shows that, in both countries, vertical links (to suppliers and customers) are most common among all types of co-inventors. If we add the co-inventions either with suppliers or with the users, they amount to more than 7% (9%) in Japan (the US). In the US, these vertical links (with both customers and suppliers) are most common in materials handling and measuring/testing patents, while in Japan, resins patents tend to have above average vertical linkages. Materials processing patents in the US also tend to have above average rates of collaboration with competitors, non-competitors in the same industry, and with universities, suggesting that this industry, in particular, has embraced open innovation. Co-inventions with university inventors represent about 2.5% in each country. Co-invention with competitors or others in the same industry is rare, each accounting for about 1% of patents.

Figure 3 gives the rates of having any external co-inventor, by firm size with which the inventor is affiliated. We see that it decreases with firm size, which is consistent with a view that the efficiency gain for combining internal and external resources is larger for a smaller firm, given its more limited internal resource. The rate of external co-invention is much higher for Japanese SMEs than for American[4], even though the rate of multi-inventor patents is very similar. The most important driving force for high incidence of external co-inventor is vertical linkage as shown in Figure 4. Here we see that, in Japan,

[4] Even if we focus on the sample without co-applications between parent and subsidiaries in Japan, the incidence of external co-inventions is substantial for SMEs in Japan.

co-inventions with suppliers and customers are most common for small firms. In the US, however, the rate of co-invention with suppliers or customers is largely the same across firm size. Since co-invention in SMEs is only slightly more common in Japan (see Figure 1), what this fact suggests is that if they co-invent, the invention is more likely to be with an external inventor (compared either to large firms in Japan or to similar sized US firms). On the other hand, there is only a small cross-national difference in the rates of multi-inventor patents and in the rates of external co-invention for large firms. In fact, external co-invention is slightly more frequent in the US than in Japan (see Figure 3).

Collaboration other than co-inventions

If we expand our definition of cooperative R&D to include formal and informal collaborations other than co-invention, we find even more cross-organizational cooperation. As shown in Figure 5, overall, 23% of US patents and 28% of Japanese patents involved collaboration with members of outside organizations. Since there are no significant overlaps between co-inventions and the formal and informal collaborations other than co-invention, almost 40 % of the inventions involve external capabilities on the average (somewhat higher in Japan than in the US). Thus, invention is a very open process and co-inventions data significantly underestimate the actual R&D collaborations. Again, most of these formal and informal collaborations are with suppliers (10-15%) and customers (about 7-9%). In both countries universities were involved in about 4% of inventions. And, again, firms report very little horizontal cooperation in both countries. Even if we add co-inventions and formal or informal collaborations, the sum adds up only to 1-2% of the inventions, which is a very small share. Difficulty of managing R&D collaboration among competitors may account for very low incidence of horizontal collaboration (See Nelson and Winter (1986) for the difficulty of monitoring the activities of competitors and prevent free-riding, especially in R&D). It is also possible that concerns about anti-trust regulations may have dampened either the activity or the reporting of the activity, or both. Interestingly, while Japan is often viewed as engaging in substantial amounts of cooperative R&D (through consortia and other such mechanisms), there is virtually no difference across the two countries in the amount of collaboration with competitors (coinvention or the other collaboration) or non-competitors in the same industry.

Co-inventions and collaborations with university researchers by sectors and by firm size

Universities and government labs are seen as playing a key role in facilitating innovation, especially in the US context (although recent reforms in Japan have focused on encouraging Japanese universities to play a more active role in technology transfer, see Walsh, et al., 2008). Figure 6 gives the detailed breakdown of the incidence of university co-invention by technology for 12 major sectors. The level and the pattern is very similar between the two countries. We see that in both Japan and the US, biotech is the most active in terms of university co-invention, with 19% of biotech patents having a university co-inventor in Japan and 14% in the US. Drug patents are also especially likely to have university co-inventors (9% in Japan, 7% in the US). Note that in both cases, Japan and the US have approximately the same rate of university-industry links. Besides these two, in Japan, organic compounds has an above average rate of university co-invention (6%), while in the US, material handing patents are above average with about 6% of patents having university co-inventors.

Figure 7 gives the results for cross-organization inventions between firms and universities, by firm size. While we might expect large firms to have closer links to universities, we find, on a per-invention basis, university co-inventors tends to increase as firm size declines, except for very small firms and are most common in small firms (100-250 employees) in both countries. In the US, the rate of university co-inventors for startups (less than 100 employees and less than 5 years old) is 2.3% (about the same as overall average). If we compare formal or informal collaboration other than co-invention, we get a similar picture. Collaboration tends to increase as firm size declines, as shown in Figure 8. It is the SMEs, especially the smallest Japanese firms, that are most likely to collaborate with universities (on a per-invention basis). Thus, although the US is well-known for its university-industry links, and the strength of its small firm sector, our data shows that very small firms are more likely to co-invent or collaborate formally or informally with university researchers in Japan than in the US, although startups based on university inventions are far more active in the US (see Nagaoka and Walsh (2009b)).

4. Sources of Information

In addition to cooperative R&D and external funding, we are also interested in the extent to which inventions draw on outside sources of information, the role this information plays in the invention process, and whether the information is coming from published sources or through personal channels. We asked our respondents to tell us how important were each of several sources of information for suggesting the research that led to the patented invention. In addition, we asked how important these sources were for contributing to the completion of the research (cf., Cohen, Nelson and Walsh, 2002). The information sources were scientific and technical literature, patent literature, fairs or exhibitions, technical conferences and workshops, standards documents for literature sources, and your own firm (excluding co-inventors), universities, government research organizations, customers or product users, suppliers, competitors (for example, by reverse engineering) for non-literature sources. Each source was rated on a 0 to 5 scale, from "did not use" to "very important". Figures 9A and 9B summarize the results, showing the percent of respondents that rated each source as important (4 or 5) for suggesting the project and then for contributing to project completion.[5] While Japanese inventors seem to make much more use of outside sources than do American inventors, we should be cautious in interpreting these results in this way, since there are significant country differences in the distribution of the responses of the US and Japanese inventors over the choices on a Likert Scale.[6] In order to avoid the risk of mis-interpretation, we will do cross country comparisons of the relative rankings of the different sources of information.

We find that the patent literature is more important than the scientific literature in Japan, where the importance is reversed in the US, and that this is true for both suggesting new projects and contributing to project completion. These results are consistent with prior work (Cohen, et al., 2002a) that finds that the Japanese firms rely more heavily on the patent literature than do American firms. The question is why. While Cohen, et al., 2002a emphasize the difference of the usefulness of disclosed patent literature due to the difference of patent system between the two countries, such as first to file in Japan vs. first to invent in the US, the automatic disclosure in 18 months in Japan vs. disclosure upon grant in the US, our research suggest that the main explanation would

[5] Note that these percentages include "did not use" in the denominator.
[6] As shown in the appendix 2, the Japanese inventors choose 4 significantly more often than the US inventors.

be found more in the difference of the capability or the incentive of the inventors to use patent and scientific literature than in the difference of the disclosed literature between the two countries. The Japanese inventors appreciate foreign scientific or patent literature significantly more than domestic science and patent literature, as shown in Figure 10. Our survey does not limit the scope of the literature to domestic literature and the Japanese survey specifically asked the relative evaluation of the domestic and foreign science literature, finding that 49% of the inventors regard them equally important and 34% regard foreign literature more important and 17% regard domestic literature more important. The corresponding shares for patent literature are 53%, 30% and 17%[7]. Thus, we have some evidence that inventors in both countries are looking at the same scientific literature (US patents and US/international publications), suggesting that the differences in the uses of this information may be due to the incentives and capabilities of inventors in each country.

One credible explanation for higher appreciation of scientific literature relative to patent literature in the US than in Japan is the greater share of PhDs among US inventors, and hence a greater familiarity and absorptive capacity for scientific literature. Figure 11 shows the uses of patents and of scientific literature, by country, broken out by education level of the inventor. We find that those with PhDs, in both countries, are more likely to use the scientific literature, supporting the above interpretation. However, we also find that, within education classes, Japanese respondents rely more (or, at least as much) on patents than publications, for all education levels except PhDs. In the US, we find the opposite, with inventors of all education classes relying more (or, at least as much) on

[7] If we focus on the inventors who see patent or science literature very important (the highest score in the Likert Scale), the difference in favor foreign literature is much larger.

publications than patents for all education classes except for those with only a high school education. Thus, the difference in the relative uses of patents versus publications does not seem to be solely due to the differences in education levels across countries.

Another related explanation is that the Japanese R&D focuses relatively more on improvement of existing inventions than on "pioneer" patents. Such R&D would make inventors study more closely the existing patents. Consistent with this view, scientific literature is more used in the R&D projects for seeds creation and for new business than those for existing business both in Japan and the US.[8] In addition its usefulness is more closely related to the high performance of the R&D project in terms of the value of the invention and the number of patents from the project than that of patent literature is in Japan.[9] That is, there are not many high value patents when patent literature is very important for the conception of the inventions. One additional explanation might be the US penalties against "willful infringement" (treble damages), which might discourage inventors from examining rivals' patents lest they be accused of knowingly infringing. There is also some evidence that Japanese authors of science and technical literature are more likely to withhold important competitive information from their publications than are American authors (Walsh and Huang, 2007), although the Japanese inventors appreciate foreign science literature more than domestic science literature as pointed out above.

In both countries, the scientific literature is more important for drug, biotech, and organic compounds inventions. Again, this result is consistent with prior work that has shown that these industries are especially close to science (Cohen, et al., 2002b). In both

[8] See Nagaoka and Walsh (2009).
[9] See Nagaoka and Walsh (2009).

countries, compared to patents and publications, other public sources (conferences, standards documents and trade fairs) are relatively less important. However, trade fairs are relatively more important in Japan, on par with technical conferences, while in the US, technical conferences are much more important than trade fairs. Standards documents are relatively more important in the US (ranking above trade fairs), while in Japan, they are the least important of the public sources.

When we turn to non-literature information source by kind of organization, we find that the most important source of information, in terms of percent giving a "high" score to that source (4 or 5),[10] both for suggesting projects and contributing to completion, is the inventor's own firm. In both countries, the second most important source is customers/users. Again, these results are consistent with prior surveys of R&D managers (Cohen, et al., 2002a). In Japan, information from competitors (for example, from reverse engineering) is almost as important as information from customers, while US inventors report less use of this knowledge source (note that collaboration with universities is not different across countries). Universities are relatively more important in the US, ranked at about the level of suppliers or competitors (for suggest), while in Japan, these industry sources are ranked much more highly than university research. In both countries, however, drug and biotech inventions tend to rely most heavily on information from universities (while customers are considered a less important source in these sectors). Thus, while university inventors, university co-inventors and university collaborators are about equally likely in both countries, the US relies (relatively) more on

[10] If we focus on the response of the highest score, patent literature and users are more important than own firm in Japan and science literature is more important than own firm in the US.

universities as sources of information (beyond the published literature). In both countries, customers or competitors are relatively more important for suggesting projects than for contributing to completion, while for suppliers the reverse is true. This suggests an innovation process where research problems come from contact with customers or observations of competitors, while solutions come from interacting with suppliers, which is consistent with the view of how an open innovation model works (Chesbrough, 2003, von Hippel, 1988). Competitors are especially important (for both suggesting projects and contributing to solutions) in motors and material handling machines in Japan, but not in the US. On the other hand, in the US, the inventors in drugs and medical devices rate competitors as especially important, but this is not true in Japan. In the US, we find a modest correlation at the technology class level between the use of the patent literature and the importance of competitors as the sources of information, r=.39. In Japan, there is little correlation (r=.06), in part because patents and competitors are both so widely used.

5. External Funding of R&D

Another form of inter-organizational cooperation in the innovation process is through external funding of research projects. A firm may raise external funds that are specifically tied to an R&D project. We asked our respondents to give the breakdown, in percentage terms, of the project funding across sources, including own firm, government, other companies, customers, suppliers, and venture capital/angel funding. Figure 12 gives the results (with percentages of funding from different sources, weighted by the size of the project, measured in man-months). While the vast majority of funds come from the firm (about 90% in each country), we find that US inventions get slightly more funding from the government (5.2% v. 2.4%) and also more from venture capital (3.3% v.

0.2%). Government funding is most common in the biotech sector, with over 15% of funding for biotech projects coming from government funding, both in Japan and the US. Other sectors in the US with significant (10% plus) of the funds coming from government funding are semiconductors, drugs and power systems. In the US, venture capital funding is most common in medical devices (11%). Communications and software get about 4% of their funding from venture capital. Biotech and drugs in the US get only about 2-3% of their funds from venture capital. In Japan, even these sectors get 1% or less of their funds from venture capital.

（Figure12）

Table 2 gives a more detailed breakdown of funding, by organization type (again, weighted by project man-months). Here we see that venture capital funding is most common in the US very small firm sector, with 18% of the funding for firms with less than 100 employees coming from venture capital. University-based projects in the US received about 6% of their funds from venture capital. Outside these sectors, there is very little VC money even in the US. In Japan, almost no sector gets significant (even 1%) amounts of its funding from VC sources. We also see greater government funding in the US. SMEs in the US get 4-6% of their funding from the government, with the money distributed across all three classes of SMEs. Even the largest firms in the US get about 3% of their funding from the government. In Japan, on the other hand, government funding is more likely in the smallest firms.

We can also use these data to examine industry funding of university research (which is another aspect of open innovation, see Chesbrough, 2003). Here, we find that industry funding of university inventions accounts for 9% of US university invention funding (roughly comparable to the 6-7% funding coming from industry money that NSF reports during this period, NSF, 2008). In Japan, about 22% of funding comes from firms, including those from users and suppliers. If we compare the incidence of getting any money from industry, we find that about 10% of US university-based projects got some industry money, while 39% of inventions by Japanese university-researchers got some industry money. Thus, industry sponsorship of university invention-oriented research is about twice as much in Japan in terms of the share of university funding, but four times more frequent in Japan. In Japan, much of this might have taken the form of donations or other informal or semi-formal sponsorship of research projects which are not well counted in the official statistics of industry funding of university research (Kneller, 1999, Walsh, et al., 2008). Note that (in both countries) the number of university researchers includes faculty who are participating in industry projects (for example, as a consultant or in collaborative research) that resulted in an invention that the included the professor. We also find that 83% of these university researchers' inventions in Japan are not assigned to the university, consistent with this system of industry sponsorship leading to professors (or seconded researchers) transferring their inventions to firms before the recent incorporation of Japanese universities[11]. Even in the US (which has long had a system of professors' inventions being assigned to their universities), we find that 36% of professor inventions are not assigned to their university (cf. Thursby, et al., 2009, where they find that 26% of professor patents were not assigned to the university). Thus, studies of university-industry linkages based on university-originated licenses are likely

[11] The incorporation of the Japanese national universities in 2004 has increased the share of patents assigned to Japanese universities.

to significantly under-estimate the amount of collaboration between university personnel and firms, especially in Japan.

6. Collaboration, Patent Value and Commercialization

Our results suggest substantial collaboration in producing these triadically patented inventions. Much current work on innovation strategy emphasizes collaboration among firms as a key to successful innovation (Chesbrough, 2003, Arora, et al., 2001). Collaborative inventions draw on a wider knowledge base and so should be of higher value. They should also be more commercializable since collaboration enables a better match between available technology opportunities and the user needs for the invention. And yet, multiparty collaboration creates significant barriers to success (Walsh and Maloney, 2007, Cummings and Kiesler, 2007), including higher coordination costs, communication barriers (distance and cultural barriers, lack of shared understanding), information asymmetry and free rider problem (Nelson and Winter, 1982) and disagreements over invention and innovation strategy. Thus, we have offsetting predictions about the likely outcome of collaborative inventions. Using our survey data, we will examine the relation between collaboration, patent value and commercialization.

We envisage the following simple model accounting for these relationships. Here q is the technical significance of the invention, θ is the level of matching of the invention for market requirements, *Pr* is the probability of commercializing the invention either through internal use, license or startups, *EV* the (expected) value of the patent and v for the value of the invention once commercialized.

$$q = f(Collaboration, Information, Controls) \qquad (1)$$

$$\Pr = g(q, \theta(Collaboration, Information), Controls) \qquad (2)$$

$$EV = \Pr(q,\theta) \times v(q,\theta) = h(Collaboration, Information, Controls) \quad (3)$$

Thus, collaboration can affect the (expected) patent value though affecting the technical significance of the invention (q) as well as the commercialization probability, which depends both on the technical significance of the invention and on the level of matching of the invention for market requirements (θ). We evaluate these channels by estimating the above equations: the technical significance equation, the commercialization probability equation and the (expected) economic value equation in a reduced form. We control for technology class (6 broad classes), firm size (three classes), inventor human capital (PhD or not), and project size and type (whether it is an upstream invention from the project dedicated only to basic or applied research, not development).

Collaboration and technical Significance of the invention

We begin with models predicting the technical significance of the invention, where we expect that collaboration is associated with higher technical significance. We measure the technical significance of patents, using the survey item that asked the inventor, compared to other inventions in his field during the same year as the patented invention, how he rated the technical significance of the invention, compared to other technical developments in his field in his home country that year (this item was not included in the Japan survey).[12] We asked the inventor to rank his invention as being either in the top 10%, top 25% but not top 10%, top half but not top 25%, or bottom half.

[12] For Japan, we estimated an equation, for which technical significance was measured by the number of forward citations received from the references by the inventors in the technical description of the inventions. However, most explanatory variables, except for man-months, are found to be insignificantly related to this measure of technical significance.

We focus on the collaboration in terms of the heterogeneity of those with whom the inventor (or the team of inventors) had a formal or informal (non-co-inventor) collaboration for the research, where heterogeneity in this case is an index of the types of external organizations with which the inventor collaborated (supplier, customer, university, competitor, etc.). In Japan, almost 30% of the inventions made by the inventors affiliated with firms involve such collaborations, 80% of which involve a single type of collaborating organization (see Table 3) and the rest involve more heterogeneous sets of organizations. In the US, 23% involve some collaboration, with 34% involving multiple external partners. Thus, while collaboration is somewhat more common in Japan, multiple collaborators are more common in the US.[13] This measure reflects the importance of bounded rationality in research, constrained search model of information access (Simon, 1947, Nelson and Winter, 1982, Cohen and Levinthal, 1990), where, in this case, the search space is structured by the position of an organization in an organizational field (DiMaggio and Powell, 1983). Each type of organization (focal firm, suppliers, customers, universities, etc.) has better access to certain types of information and more difficulty getting unmediated access to other types of information (due to its localization, its tacit nature, or the limited absorptive capacity of the focal firm for that type of information). Therefore, collaboration with other kinds of organizations for research can increase the richness of the search space, and therefore the probability of a high-value discovery (Nelson and Winter, 1982). In order to identify the effects of two main sources of collaborations (vertical collaborations and collaborations with

[13] For co-invention, only 10% of patents with external co-inventors involved more than one external partner, while in the US, 25% of external co-invention involved multiple partners.

universities), we also tested models using the dummy variables for these two types of collaborations. We also test for co-inventor collaborations (any external co-inventor and a heterogeneity index). Since our argument depends in part on the information access provided through collaboration, we also measure the effects of the use of external information to suggest projects to see if that explains some of the effects of collaboration. Based on a factor analysis of our information sources, we create three indices, one measuring information flows from other firms (customers, suppliers, competitors); one for patents and publications; and one for universities, government labs and standards documents. We also control for the inventor having a PhD or not, as well as number of man-months used by the project, firm size (large and very small, with medium/small as the excluded category), technology class (one digit NBER classes).

Table 4 shows the results of an ordered logit regression predicting the technical significance of the patent for the US We find that inventions that were based on a more heterogeneous collaboration (more kinds of organizations represented) are of significantly higher technical significance (1% significance), on average (controlling for technology class, firm size, inventor human capital, and project size and type). This result is robust to our other measures of collaboration (any collaborator, any external co-inventor, heterogeneity of co-inventors). When we add the use of outside information, we find that the effect of collaboration decreases, and that information from universities and government labs has a significant effect on the technical significance, while information from spillovers from other firms (customers, suppliers, competitor) does not have a significant effect on technical significance, controlling for other predictors. Finally, inventors with PhDs are associated with inventions with greater technical significance.

Part of the influence of published literature is picked up by the PhD dummy variable. Dropping this variable increases the effect of publications/patents. Also, the average invention for very small firms is of higher significance, while for large firms, the average is of lower significance.

"Open v. Closed" Innovation for Commercializing the Invention

Open innovation implies both openness in the invention process and in the commercialization process. In another paper, we examine the incidence of in-licensing and out-licensing of inventions (Nagaoka and Walsh, 2008). We find that the overall level of commercialization is quite similar between Japan and US, although the licensing is more active in Japan and the startups are more active in the US.

As noted above, we have offsetting predictions on the effects of collaboration on commercialization, net of the higher value such patents are likely to have. On the one hand, they may benefit from more customization of the invention process due to better match between technological opportunities and the user needs and fine-grained information transfer that can facilitate commercialization. On the other hand, coordination costs, transaction costs and disagreements about how best to develop a technology may retard commercialization. Thus, we are left with the empirical question of how open innovation in the invention process relates to commercialization of that invention.

If we look at the predictors of whether or not the invention was commercialized as function of the level of collaboration (Table 5), we find that, in both the US and Japan, controlling for the technical significance of the invention (the level of inventor citation for the Japanese patents), vertical collaboration has a positive effect. This effect is attenuated somewhat when we add information flows, although still there is a significant positive relationship between vertical collaboration and the likelihood of the invention being commercialized for the US. In Japan, it is not significant. For commercialization, inter-firm spillovers have a strong positive effect, while the use of published literature and patent information has a negative effect on commercialization. These results suggest that vertical collaboration increases the chance of commercialization through customizing the type of invention as well as the other collaborative mechanism , net of the technical significance of the invention. This may be due to the links between, for example, customers and suppliers allowing a ready market for the technology.

Technical significance has a significantly positive effect on the probability of commercialization as expected. The dummy of the upstream invention (which is pure basic, pure applied research or the combination of the two, i.e., no development) has a significantly negative coefficient, which is not surprising since such research likely requires additional R&D before commercialization. Phd has a negative coefficient (probably due to a selection effect due to Phds working on project that are more upstream even net of the upstream dummy). Man-months has a positive coefficient on the commercialization possibility.

Collaboration and value of the patent

We then test models using self-reported economic value as the measure of patent value, which would reflect the effects of collaboration both on the technical significance and the commercialization probability. We use the survey item that asked the inventor, compared to other inventions in his field in his home country during the same year as the patented invention, how did his patent rate in terms of economic value. We asked the inventor to rank his invention as being either in the top 10%, top 25% but not top 10%, top half but not top 25%, or bottom half.

Table 6 shows the results of an ordered logit regression predicting the economic value of the patent for the US and Japan.[14] We find that inventions that were based on a more heterogeneous collaboration (more kinds of organizations represented) are on average of higher value (1% significance for Japan and not quite significant (p<11%) for the US), controlling for technology class, firm size, inventor human capital, and project size and type). This result is robust to our other measures of collaboration (any collaborator, any external co-inventor, heterogeneity of co-inventors). When we introduce separate dummies for vertical collaborations and for collaborations with universities, we find that in Japan the coefficient of university collaboration is twice as large as that for vertical collaboration. In the US, we find a similar difference (although neither coefficient is significant). When we add the use of outside information, we find that the effect of collaboration decreases, and that information from universities and government labs has a significant effect on the economic value of the patent, consistent with the above findings, while information from spillovers from other firms (customers, suppliers, competitor) does not have a significant effect on economic value, controlling for other predictors. We do see that the information spillovers from other firms have a positive correlation with the economic value in the US, consistent with the effects on commercialization probability (but not in Japan). Use of information from patents and

[14] We would expect the measure of economic value to be less closely related to information sources (heterogeneity and uses of outside information), since economic value is likely a combination of the technical significance of the invention and also such factors as demand characteristics, competitive conditions, complementary capabilities, strength of patents, and other factors that influence the ability of a firm to generate rents from its inventions.

publications is also not associated with higher value patents. Finally, inventors with PhDs are associated with inventions with greater economic value. Part of the influence of published literature may be picked up by the PhD dummy variable. Dropping this variable increases the effect of publications/patents somewhat. Also, the average invention for very small firms is of higher economic value, while for large firms, the average is of lower economic value (although the differences are not significant in the US). In Japan, the dummy for upstream invention has a significantly positive coefficient on economic value only if the information sources are not included, indicating that the upstream invention of a firm has a premium value only if it has a significant information input from university in its conception. In the US, the upstream dummy has little effect on economic value, controlling for other factors.

Thus, we have some evidence that collaboratively produced inventions are more likely to be of greater technical significance value, and, furthermore, that this effect is partly due to better access to outside information from public sources (but not from other firms). Vertical collaboration tends to increase the probability of commercialization while collaboration with a university tends to enhance the technical significance of the invention. These results are consistent with predictions from the open innovation perspective, which suggests that firms can benefit by cooperating in technology development (Chesborough, 2003).

7. Conclusions

Adding to the debate on open innovation, our results suggest several important similarities across the two countries, as well as some interesting differences. First, we find that just over 10% of patents have external co-inventors in both countries, despite the significantly larger incidence of co-assignment in Japan. These results suggest that co-assignee data is not a good predictor of cooperative R&D and understate that in the US and in Europe (cf. Giuri, et al., 2007). The results also show that most co-invention is with vertically related firms (suppliers or customers/users); co-invention with competitors is very rare in the two countries. However, if we break out the results by firm size, we see that external co-invention increases as firm size declines significantly more in Japan, so that Japanese SMEs engage in significantly more external co-inventions than do either American SMEs or larger firms in Japan or the US.

We also find that in both countries about 30% involved external (non-co-inventor) collaborators (with the rate of collaboration somewhat higher in Japan). In both countries, vertical collaborations with users and suppliers are the most common. On the other hand, co-invention or collaboration with university personal was quite uncommon in both countries, though such links were at least as common in Japan as in the US. They tend to increase as firm size declines. Venture capital and government funding play a greater role in the US than in Japan, especially for the smallest firms. Industry funding is more broadly distributed among university inventions in Japan, although the overall level is about the same in the two countries. These results suggest that, while the bulk of funding for R&D comes from the firm itself, there are a few segments of the innovation system that are involved in more externally funded research. In the US, very small firms get a significant portion of their funding from venture capital, and this is largely the only sector that gets substantial VC funding, in either country. Government funding, on other hand, is more concentrated in the smallest firms in Japan, while in the US government money is spread more evenly across firm size classes. University research is funded by industry at about the same level in both countries, but in the US it seems to be concentrated in larger projects, while in Japan the funding is spread across many smaller projects.

The most important knowledge sources were similar in the two countries: patents, customers, publications, and information from other parts of the firm, although their relative rankings varied somewhat. In particular, patents were a relatively more important information source in Japan and scientific literature was relatively more important in the US. Since our evidence suggests that inventors see literature globally, such difference does not seem to be driven by the difference of the disclosed literature (for an example, more early patent disclosure in Japan) as suggested by earlier literature but by that of the incentive and capability of the inventors.

"Open innovation" through more collaborations seems to enhance the value of the invention by enhancing the technical significance of the invention as well as its commercialization possibilities, controlling the research man-months input and education of the inventor. Collaboration with a university is important for the technical significance of the invention and vertical collaboration is especially important for commercialization. One important advantage of collaboration is more information from external organizations leading to higher value inventions, but there seem to be the other advantages too. For example, this collaboration may provide information that is useful for guiding the development of the invention into a commercial product (so that it better matches the needs of customers or the capabilities of suppliers).

Future research will examine the mechanism and the predictors of these differences in the uses of external information and collaboration, and also the impact of these on patent value and commercialization. Our initial findings suggest that collaboratively produced inventions have greater technical significance and that this higher technical significance is due to greater use of outside information. We also find that non-co-invention collaboration is associated with higher rates of commercialization, net of value. We will also examine the predictors of the forms of cooperation to better understand the open innovation process (cf., Fontanta and Geuna, 2008).

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Appendix 1.

Japan and US Inventor Surveys

A.1 Basics of the survey

The survey in Japan was conducted by RIETI (Research Institute of Economy, Trade and Industry) between January and May in 2007. It collected 3,658 triadic patents[15], with priority years from 1995 to 2001. The survey in the US was conducted by Georgina Tech between June and November 2007, in collaboration with RIETI, and collected 1,919 patents, with 2000-2003 priority years. The survey used both mail and web (post-mail out and response by post or web) and the response rate was 20.6% (27.1% adjusted for undelivered, ineligible, etc.) in Japan and 24.2% (31.8% adjusted for the deceased, undeliverable, etc.) in the US.

A.2. The questionnaire

The questionnaire consists of the following six sections: (1) Inventor's Personal Information; (2) Inventor's Education; (3) Inventor's Employment and Mobility; (4) Objective and Scope of R&D and the Invention Process; (5) Inventor's Motivations; (6) Use of invention and the patent. The questionnaire is downloadable at www.rieti.go.jp for Japan and at www.prism.gatech.edu/~jwalsh6/ for the US.

A.3 The sampling strategy and procedure

The sampling frame used for the survey is the OECD's Triadic Patent Families (TPF patents) database (OECD, 2006) which includes only those patents whose applications are filed in both the Japanese Patent Office and the European Patent Office and granted in the United States Patent and Trademark Office. There are both practical and theoretical advantages to using the TPF patents. Practically, we could utilize the enormous databases provided by all three patent offices. Particularly, we could extract from the EPO database the addresses of the U.S. inventors, which are not available from the USPTO. We could use the extensive citation information available from the USPTO, to assess the backward and forward citation structure of the Japanese inventions. Also, the reduced home country bias and relatively homogenized value distribution of patents enhances the comparability of patented inventions between patents as well as among nations (Criscuolo, 2006; Dernis

[15] The survey also covers 1501 non-triadic patents as well as a small number of important patents.

and Khan, 2004). Furthermore, focusing on triadic patents can avoid sending most questionnaires to economically unimportant patents, given the highly skewed nature of the value of patents, since filing in multiple jurisdictions works as a threshold. The number of basic patents (first priority patent) of TPFs account for only 3% of the domestic applications in Japan. One caveat here is that this characteristic of TPF may favor large and multinational firms.[16]

The survey population of Japan is the TPF patents filed between 1995 and 2001 (first priority application) and having at least one applicant with a Japanese address and at least one inventor with a non-alphabetical name (i.e. the name consists of Chinese characters and hiragana), given that the Japanese survey questionnaire was in Japanese. The population satisfying these requirements amounted to 65,000 patents. We randomly selected 17,643 patents for the final mail out, stratified by 2-digit NBER technology class[17] (Hall, Jaffe, and Trajtenberg, 2001), with oversampling for the technology sectors such as biotechnology with a relatively small number of patent applications[18]. In order to increase the response rate by reducing the respondent burden, we sent a maximum of two questionnaires to the same inventor of triadic patents and a maximum of 150 questionnaires to one establishment. We updated the inventor address based on the patent documents information of the JPO, to take into account the mobility of inventors across the establishments within a firm. The survey population for the U.S. is the TPF patents filed between 2000 and 2003 inclusive (first priority application) and having at least one U.S.-addressed inventor. We sampled 9,060 patents, stratified by NBER technology class (Hall, Jaffe, and Trajtenberg, 2001). Then, for the first U.S. inventor of each patent we collected U.S. street addresses, mostly from the EPO database but supplemented by other sources such as the USPTO application database or phone directories. If no address was available, we take the next U.S. inventor. After removing 18 patents that are either withdrawn or for which we could not find any U.S. inventor address, we had 9,042 patents in our sample. Taking the first available U.S. inventor as a representative inventor

[16] Since the Japanese survey also covered non-triadic patents, we could compare the characteristics of triadic and non-triadic patents (See Nagaoka and Tsukada (2007)). The differences in terms of applicant structure are often small. For an example, the share of small firms (with 250 employment or less) account for 10.2% of non-triadic patents and 8.7% of triadic patents.
[17] We separated computer hardware and software.
[18] The simple averages and the averages reflecting the sampling weight give essentially identical results.

of each patent, we have 7,933 unique inventors. In order to increase response rate and reduce respondent burden, we only surveyed one (randomly chosen) patent from each inventor. The final mail out sample was, thus, a set of 7,933 unique U.S. patents/inventors.

Using the patent-based indicators for all patents in the sample, we tested response bias, in terms of application year, the number of assignees, the number of inventors, the number of claims, and the number of different International Patent Classes. There are some differences in application year in both countries (the responses have newer application dates by 1 month in Japan and by 0.3 months in the US on average, both significant at 5%), the number of claims in Japan (the responses have smaller number of claims by 0.37, significant at 5%) and the number of inventors in the US (the responses have smaller number of co-inventors by 0.07 persons on average, significant at 10%). These test results show that there do not exist very significant response biases.

Because the distribution of patents by technology class varies significantly between the US and Japan, we constructed a set of weights to represent the observed distribution relative to the population distribution across the two countries, and applied these weights when calculated country-level means for comparisons (for example, the mean percent of patents that were commercialized). However, weighted and unweighted means produced essentially the same results.

Appendix 2 Distribution of Likert Scale Responses in the US and Japan

The following figure compares the distribution of the responses of the US and Japanese inventors over 49 common questions with the choices according to a Likert Scale (1= not important, 5=very important). The US responses are more evenly distributed over the five choices (20% for each choice), while the Japanese responses are more centered on 4 (36% of the inventors choose 4). As a result, on average across all items, more that 50% of the inventors in Japan chose 4 or 5 while less than 40% of the inventors in the US choose 4 or 5.

Appendix Figure 1

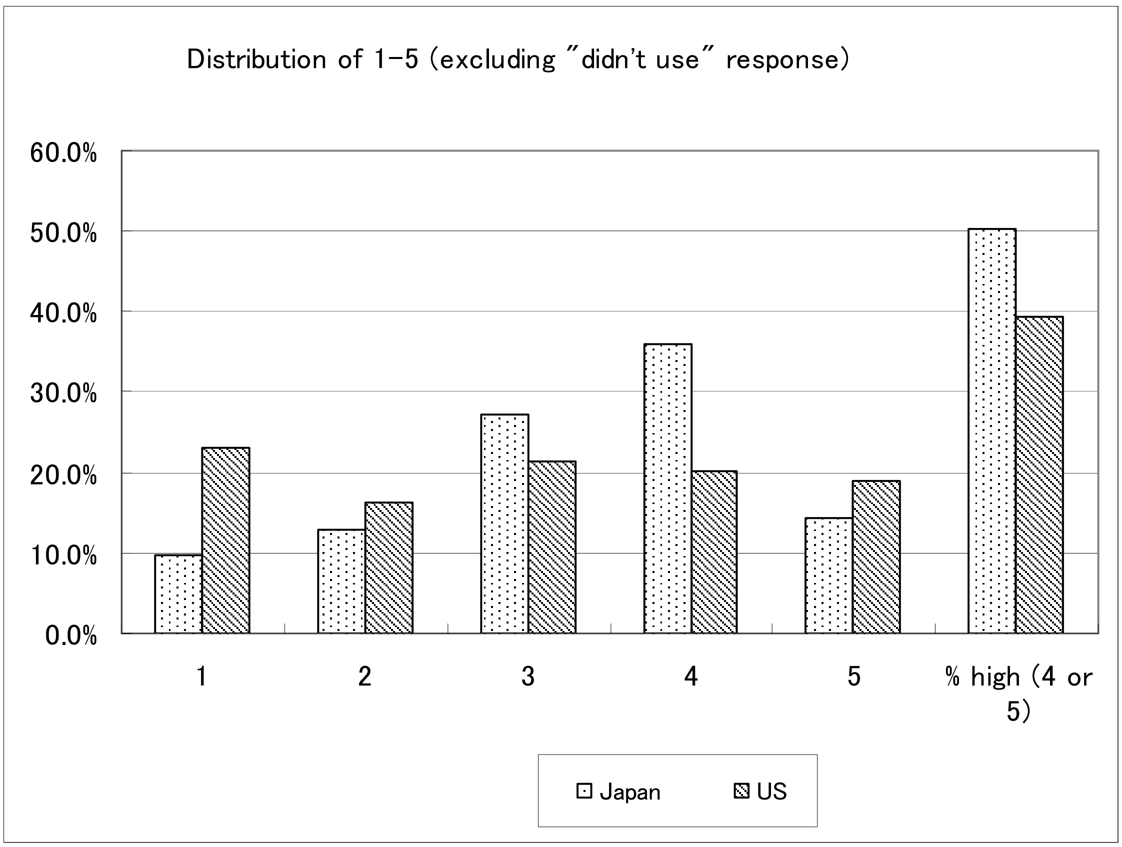


Table 1. Basic Profile of Inventors, Japan, and US, triadic patents
(Common NBER Technology Class weighted)

		Japan	US
	Sample size	3658	1919
Academic Background	University graduate (%)	87.6	93.6
	Doctorate (%)	12.9	45.2
Demographics	Female (%)	1.7	5.2
	Age (mean years, std. dev.)	39.5 (9.1)	47.2 (9.9)
Organizational Affiliation	Large firm (500+ employees)(%)	83.6	77.1
	Medium firm (250-500)(%)	5.0	4.2
	Small firm (100-250)(%)	3.1	3.3
	Very small firm (lt 100)(%)	4.7	12.1
	University (%)	2.5	2.3
	Other	1.0	1.0

Figure 1. Solo inventions, by firm size, US and Japan

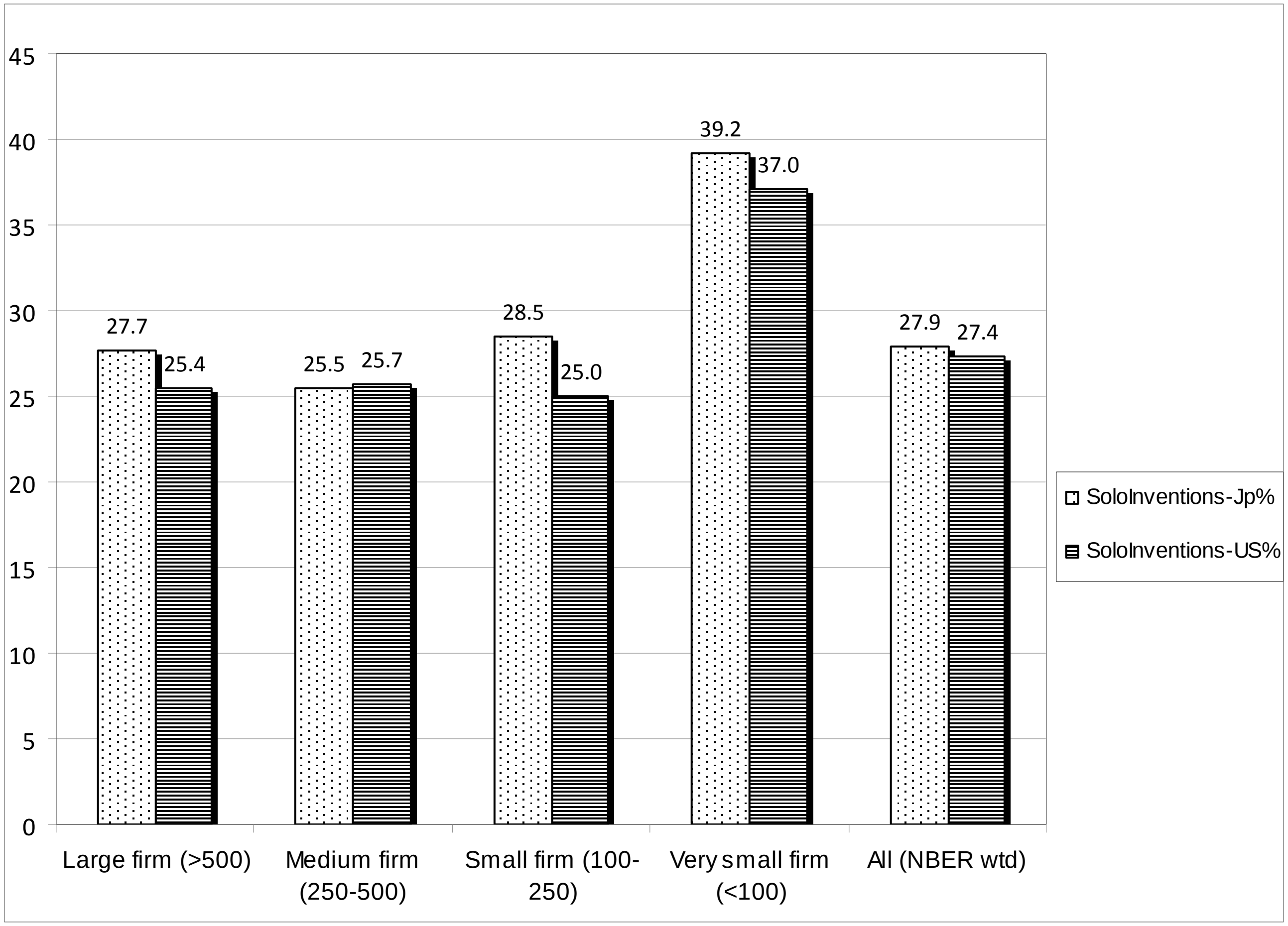
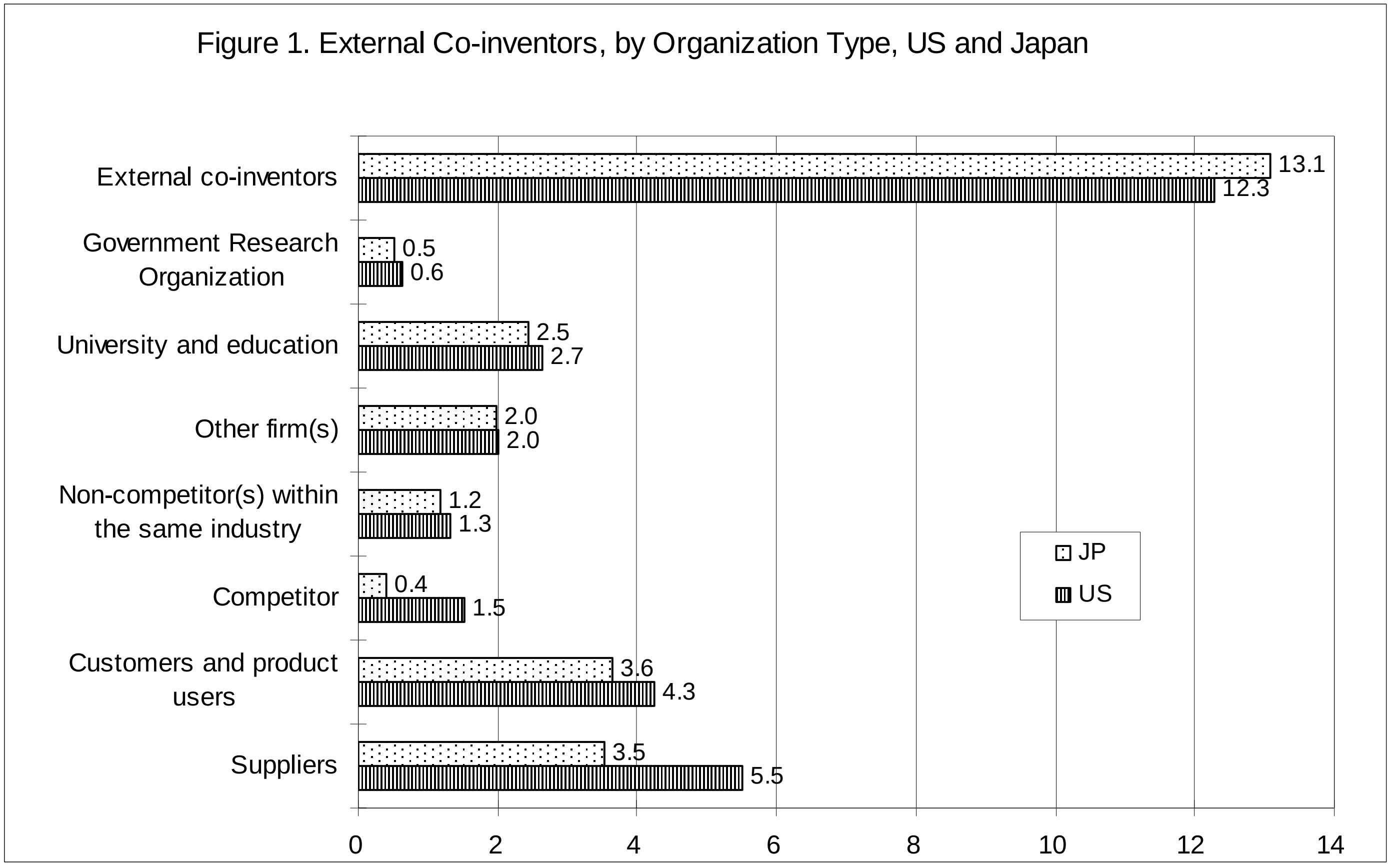


Figure 2. External Co-inventors, by Organization Type, US and Japan (Common structure)



Note. This table adjusts fully the technology composition difference between the two countries, based on the common technology structure. It does not display some minor sources of external co-inventions and other category.

Figure 3. Any external co-inventor, by firm size, US and Japan.

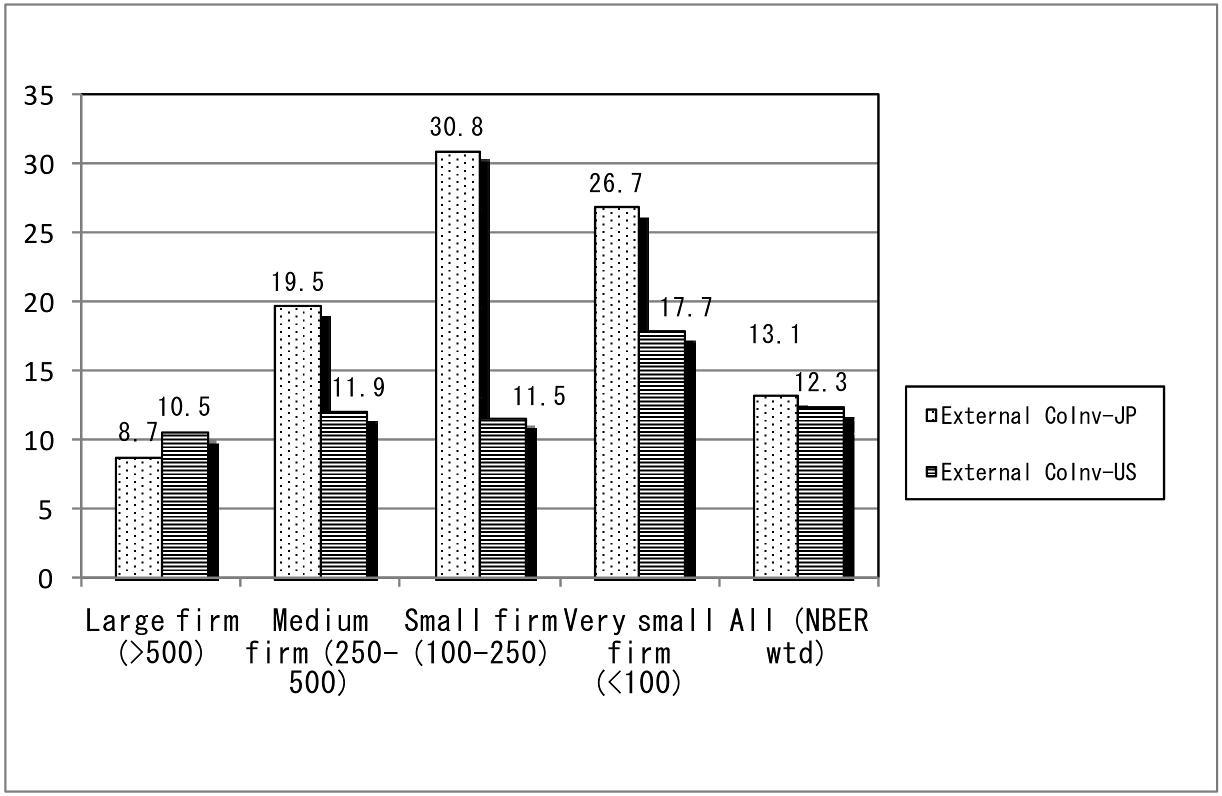


Figure 4. Co-invention with Customers and Suppliers, by Firm Size, US and Japan.

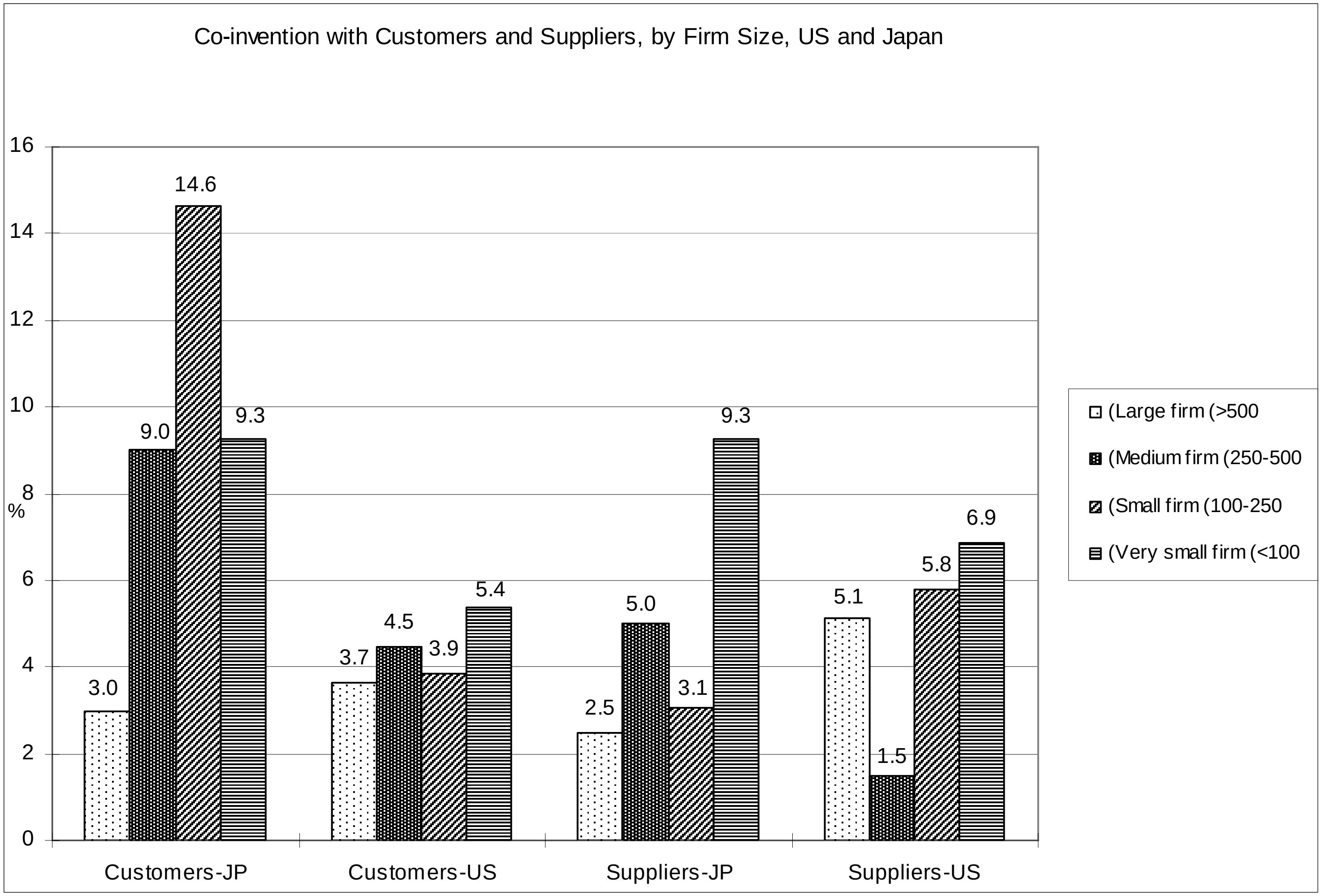


Figure 5. Formal or Informal Collaboration with Outside Organizations, by Organization Type, US and Japan (NBER weight).

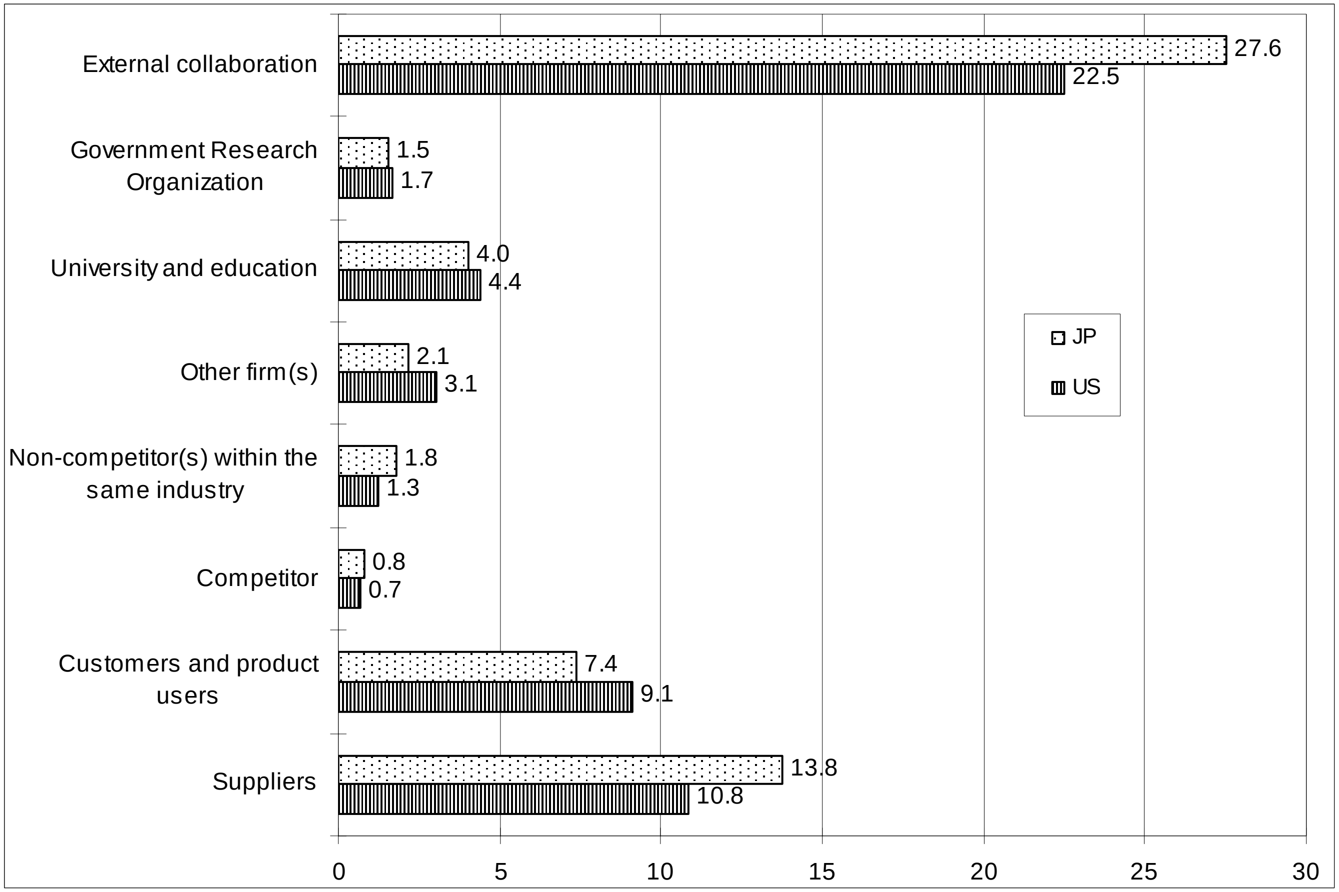


Figure 6. Co-invention with University Personnel, by Sector, US and Japan.

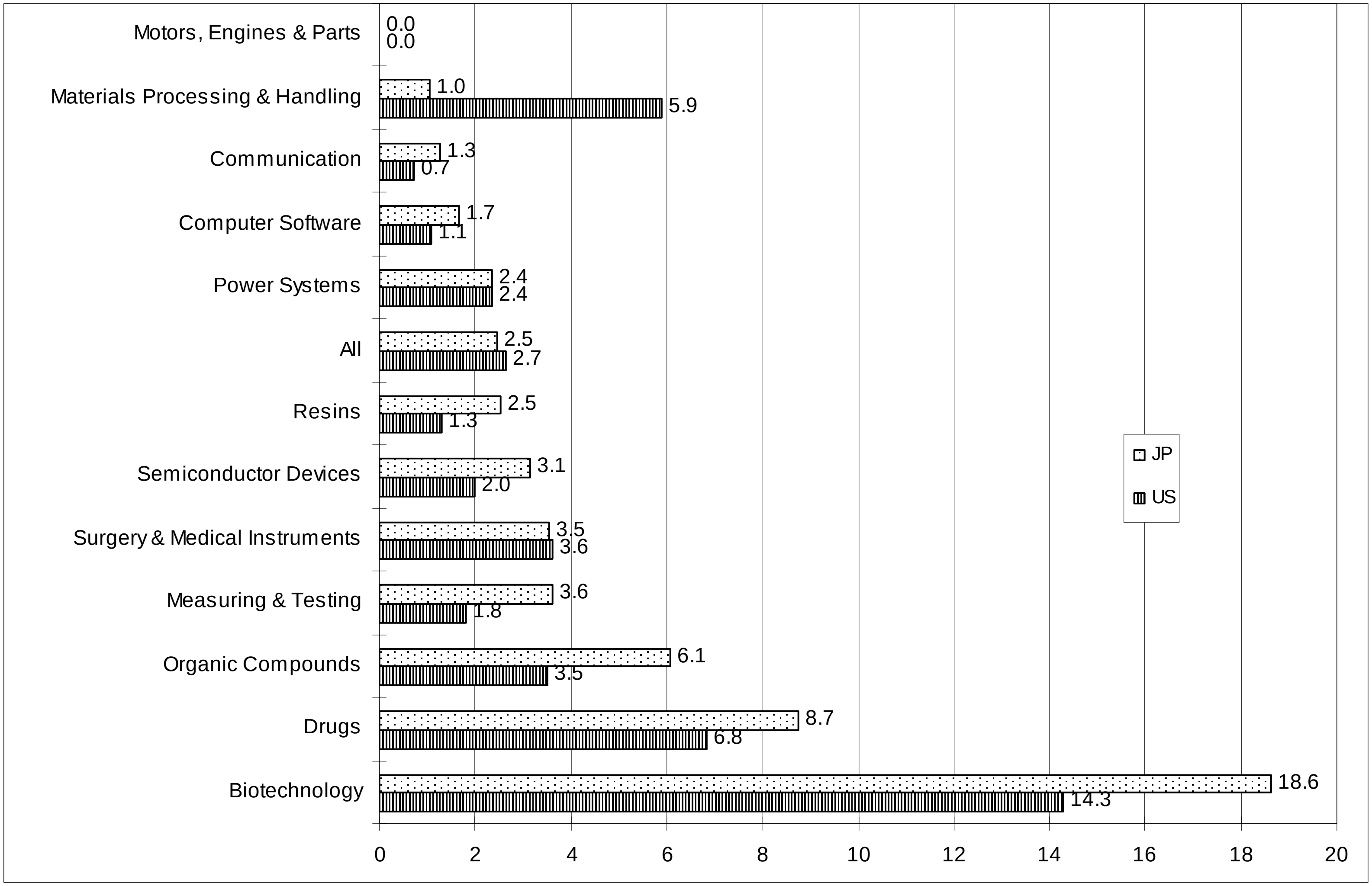


Figure 7. Co-inventions with universities, by firms size, US and Japan.

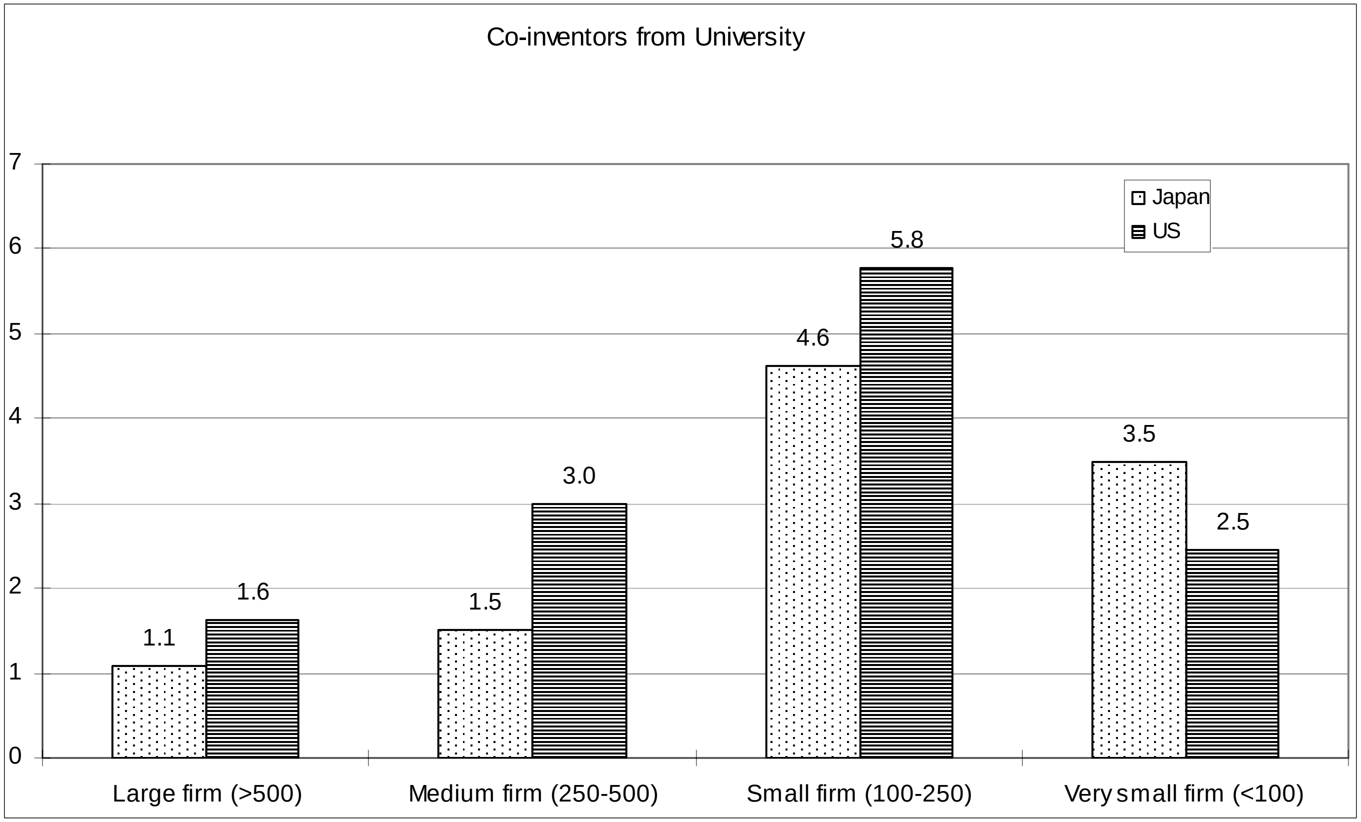


Figure 8. Non-co-invention collaboration with universities, by firm size, US and Japan

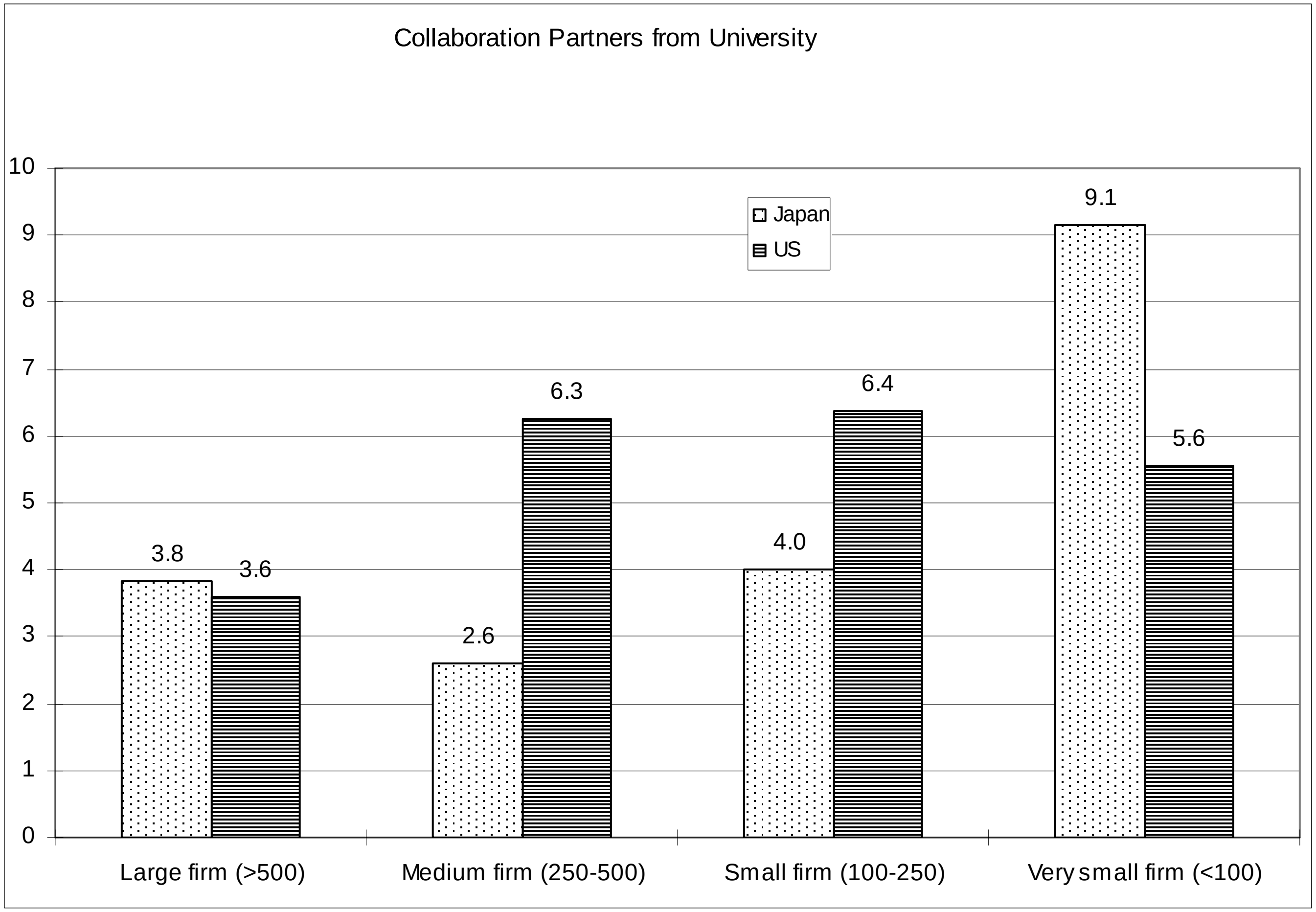


Figure 9A. Sources of Information-Suggestion New Project, US and Japan (US-JP common weight).

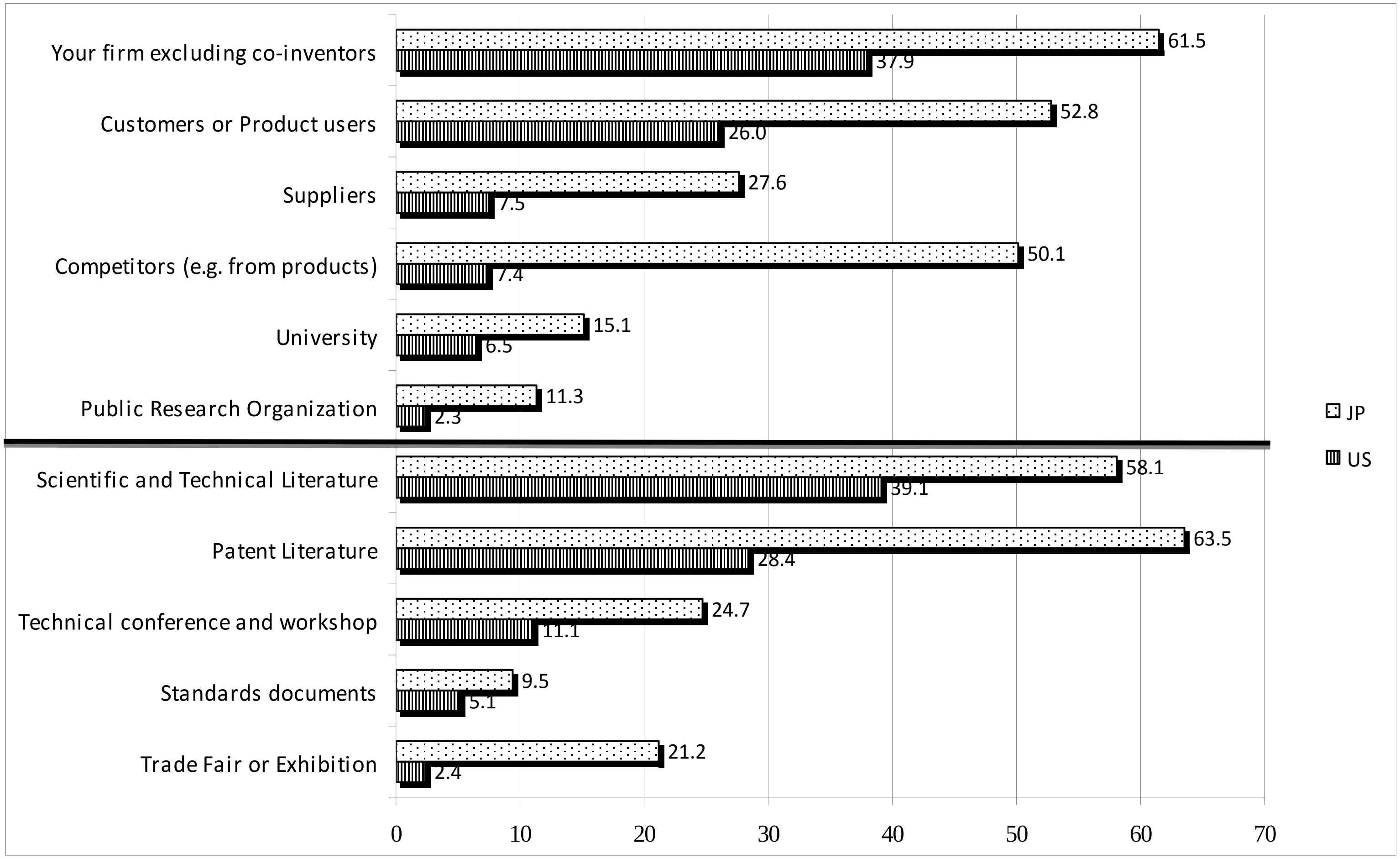


Figure 9B. Sources of Information-Contribution to Completion of Project, US and Japan (US-JP common weight).

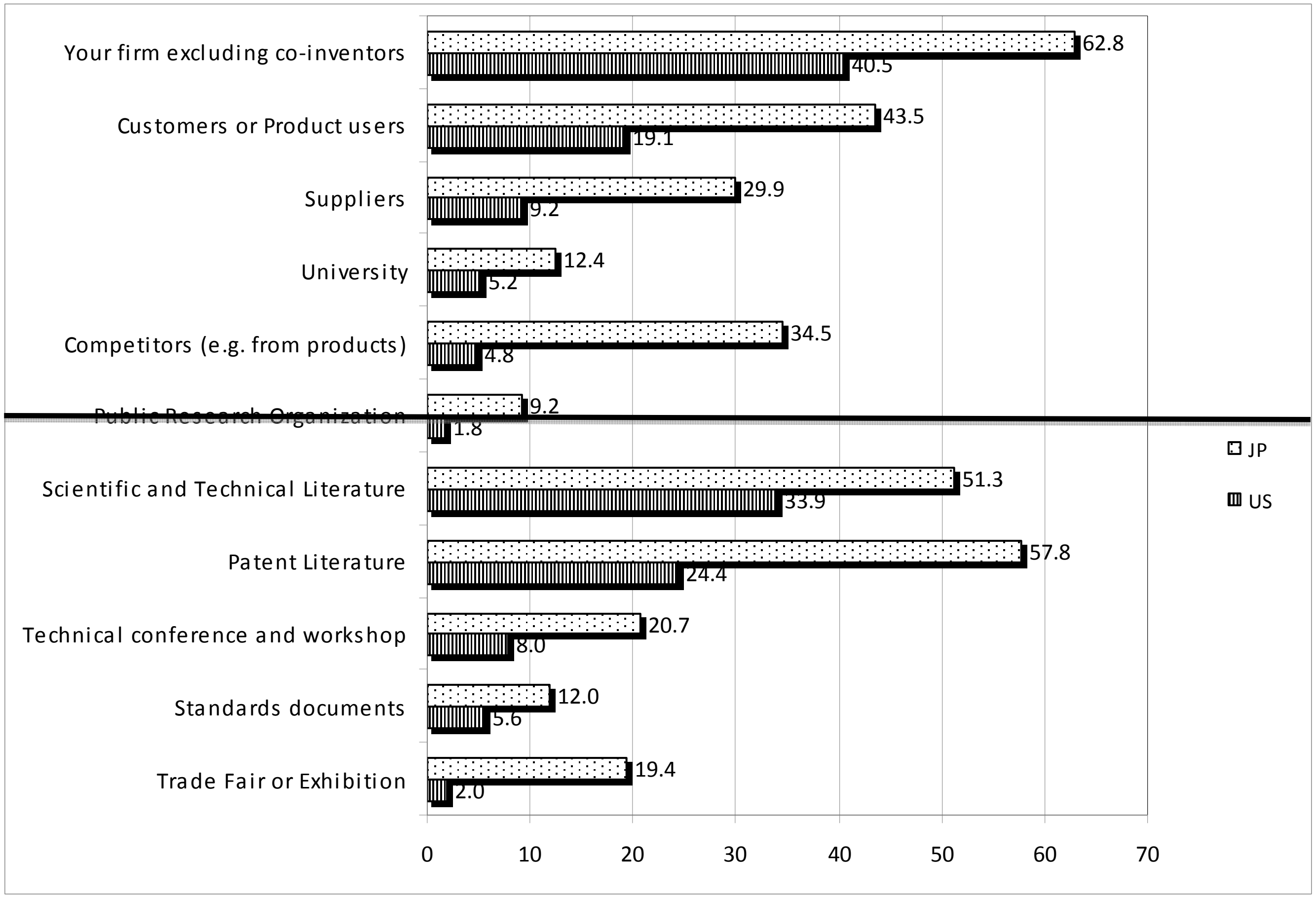


Figure 10. Relative importance of domestic and foreign literature in Japan

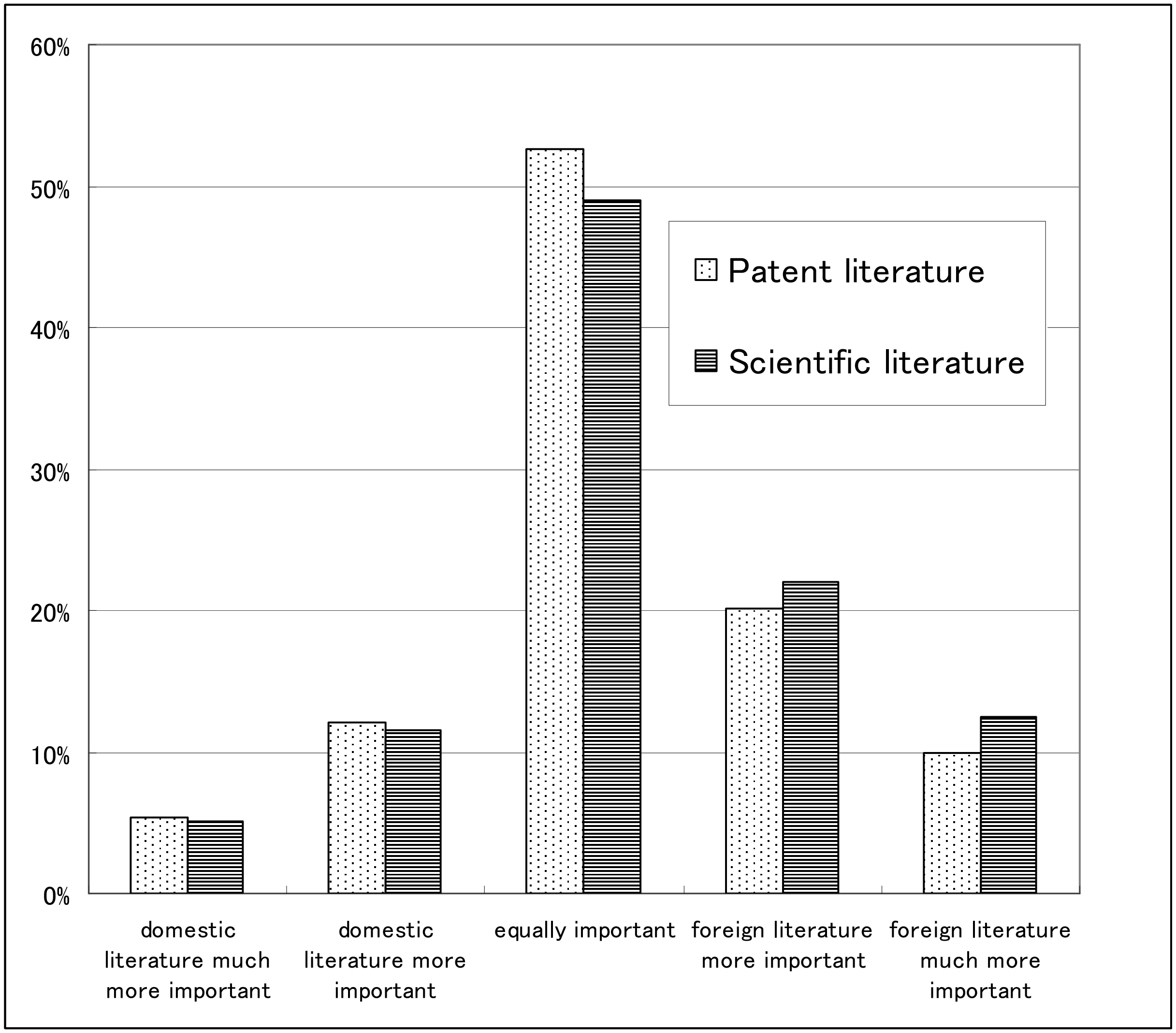


Figure 11. Use of Scientific Literature and Patents to Suggest Projects, by Inventor Education, US and Japan.

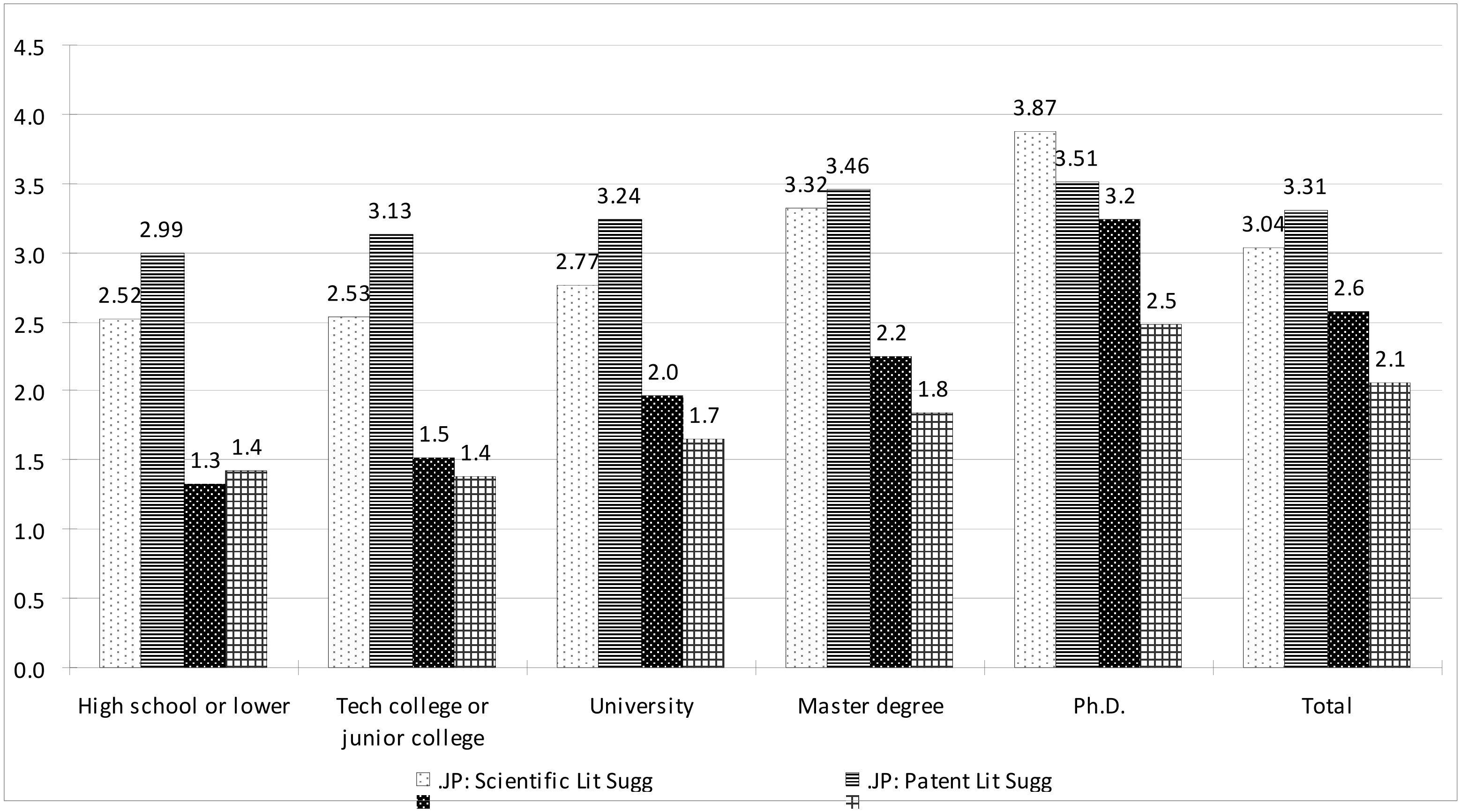


Figure 12. Finance Shares of R&D Projects, weighted by man-months, US and Japan (US-JP common weight).

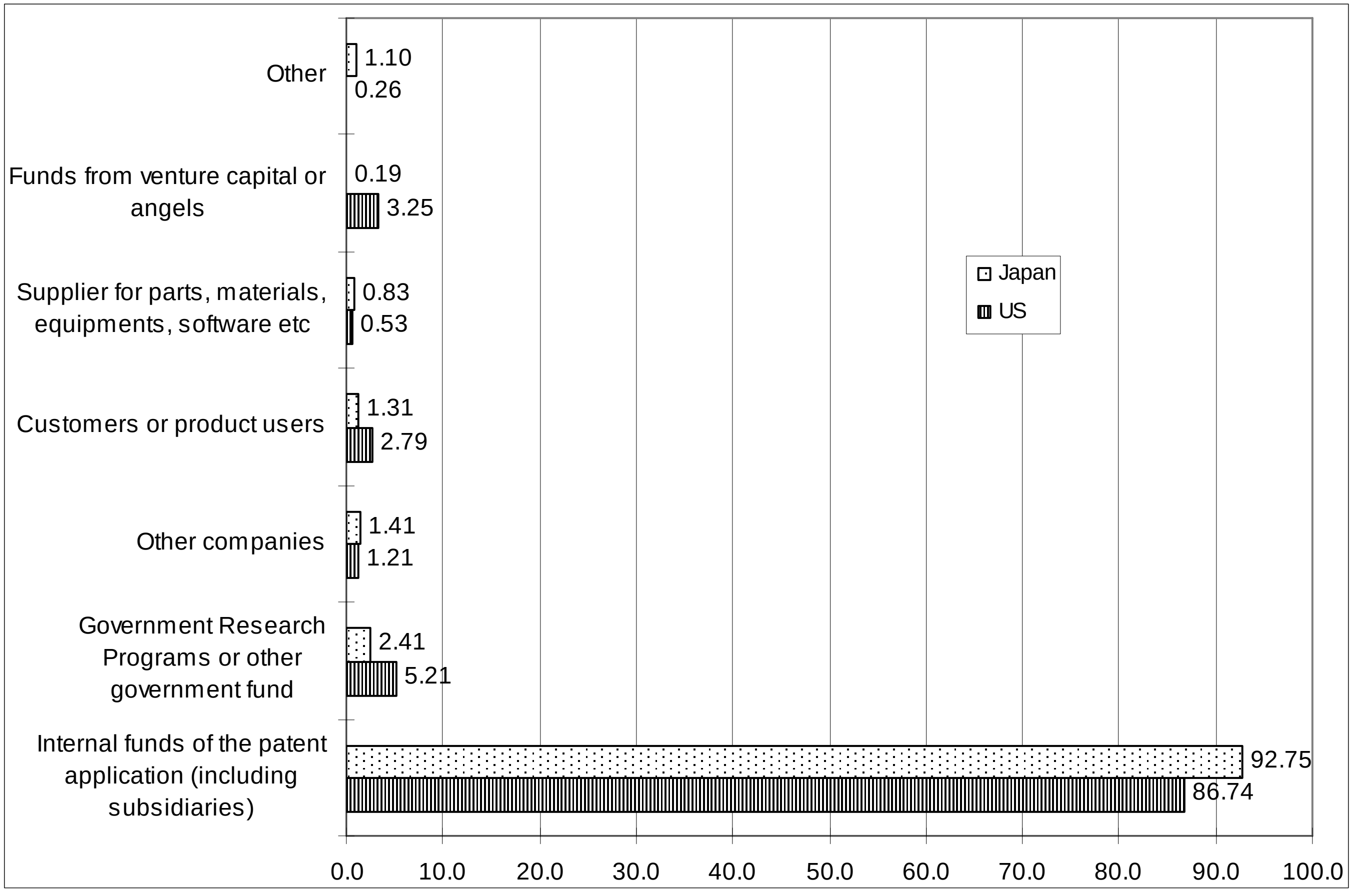


Table 2. Mean share (%) of funding by source, by organization type, US and Japan (weighted by man-months).

	Own (including debt)		Government		User		Supplier		Other firms		Venture Capital and Angels	
	JP	US	JP	US	JP	US	JP	US	JP	US	JP	US
Large firm	95.5	93.9	1.3	2.9	1.2	1.8	0.8	0.5	0.6	0.5	0.1	0.3
Medium firm	96.2	90.8	0.8	4.7	2.1	4.5	0.6	0	0.2	0	0	0
Small firm	87.6	88.5	2.5	5.9	8.9	3.6	0.4	0	0.6	0.8	0.1	1.1
Smallest firm	87.2	64.9	4	4.8	2.2	6.1	0.4	0.9	1.4	4.7	0.9	18.2
University or college	47.8	30.1	23.6	54.5	0.3	0.6	3.3	0	18.9	8.8	0	6
Other	49.9	67.9	27.6	13.2	3.3	16.7	0	0	3.6	0	0	0
All	92.8	86.2	2.5	5.5	1.5	2.9	0.8	0.5	1.2	1.4	0.2	3.3

Table 3. Distribution of the heterogeneity of the collaborating organizations

Number of types of external collaborators	Japan	US	Number of types of external co-inventors	Japan	US
0	71.0%	77.2%	0	88.1%	88.5%
1	24.1%	15.1%	1	10.8%	8.6%
2	4.1%	5.7%	2	1.0%	1.7%
3	0.6%	1.5%	3	0.1%	.6%
4+	0.1%	0.6%	4+	0.1%	.6%
Total (N=)	100% (3364)	100% (1587)		100% (3395)	100% (1611)

Table 4. Ordered-logit regressions of technical significance on collaboration and information sources, US .

Ordered Logit	US (Tech. Sig.)		US (Econ. Val.)		JP (Econ. Val.)	
Collaborator heterogeneity	0.186** (0.070)	0.079 (0.077)	0.125† (0.072)	-0.010 (0.079)	0.163*** (0.058)	0.142** (0.061)
Info-firms		0.020 (0.017)		0.068** (0.018)		−0.013 (0.011)
Info-Pubs/patents		0.021 (0.020)		-0.008 (0.020)		0.015 (0.017)
Info-Univ./Gov. Lab/Standards		0.071** (0.025)		0.061* (0.026)		0.031** (0.013)
PhD degree	0.454*** (0.106)	0.355** (0.114)	0.437*** (0.110)	0.437** (0.118)	0.503*** (0.115)	0.411*** (0.122)
Man-months	0.016*** (0.002)	0.014*** (0.002)	0.012*** (0.002)	0.011*** (0.002)	0.008*** (0.001)	0.008*** (0.001)
Big firm (> 500)	-0.144 (0.214)	-0.189 (0.216)	-0.242 (0.216)	-0.239 (0.218)	−0.074 (0.131)	−0.005 (0.141)
Small firm (< 100)	0.712** (0.249)	0.675** (0.252)	0.327 (0.251)	0.315 (0.255)	0.901*** (0.217)	0.798*** (0.244)
LR Chi-SQ	118.90***	131.43***	67.53***	92.05***	127.5***	
(df)	10	13	10	13	10	
N	1287	1240	1248	1206	2443	

Standard errors in parentheses ***p<.001 ** p<0.01, * p<0.05 †p<.10
Includes controls for 1-digit NBER

Table 5. Logistic regression of commercialization of patents, US and Japan

Logistic	US		JP	
Vertical collaboration	0.6801*** (0.1854)	0.4670* (0.1942)	0.196* (0.096)	0.160 (0.101)
University Collaboration	-0.1703 (0.3336)	0.0736 (0.3667)	-0.288 (0.201)	-0.333 (0.214)
Info-firms		0.0816*** (0.0242)		0.057*** (0.011)
Info-Pubs/patents		-0.0672** (0.0257)		0.118*** (0.016)
Info-Univ./Gov. Lab/Standards		-0.0475 (0.0343)		0.025† (0.013)
PhD degree	-0.4203** (0.1435)	-0.3057* (0.1515)	-0.164 (0.132)	-0.094 (0.138)
Man-months	0.00228 (0.00318)	0.00281 (0.00328)	0.002† (0.001)	0.003* (0.001)
Big firm (> 500)	-0.7894*** (0.2977)	-0.7598* (0.3032)	-0.325* (0.140)	-0.278† (0.148)
Small firm (< 100)	-0.3494 (0.3482)	-0.3184 (0.3549)	0.479* (0.232)	0.409† (0.247)
Upstream	-0.6991*** (0.1915)	-0.6567*** (0.1973)	-0.699*** (0.086)	-0.630*** (0.090)
Technical Significance	0.4388*** (0.0682)	0.4660*** (0.0706)	0.273*** (0.056)	0.278*** (0.244)
Wald Chi-SQ	106.38***	116.77***	164.76***	220.83
(df)	17	20	20	23
N	1068	1040	3162	3000

Table 6 Ordered-logit regressions of economic value on collaboration and information sources, US and Japan.

Ordered Logit	US (Econ. Val.)		JP (Econ. Val.)	
Collaborator heterogeneity	0.1204 (0.0735)	-0.0117 (0.0799)	0.147* (0.060)	0.142* (0.061)
Info-firms		0.0707*** (0.0183)		−0.015 (0.011)
Info-Pubs/patents		-0.0115 (0.0207)		0.016 (0.017)
Info-Univ./Gov. Lab/Standards		0.0621* (0.0259)		0.033* (0.013)
PhD degree	0.4819*** (0.1141)	0.4844*** (0.1214)	0.472*** (0.122)	0.442*** (0.124)
Man-months	0.0121*** (0.0024)	0.0106*** (0.00246)	0.007*** (0.001)	0.008*** (0.001)
Big firm (> 500)	-0.2687 (0.2195)	-0.2611 (0.2222)	−0.078 (0.131)	−0.006 (0.141)
Small firm (< 100)	0.3038 (0.2561)	0.3152 (0.2594)	0.879*** (0.219)	0.802** (0.243)
Upstream	-0.0708 (0.1540)	0.0425 (0.1575)	0.334** (0.098)	−0.117 (0.086)
LR Chi-SQ	67.62***	92.51***	127.5***	117.84***
(df)	11	14	10	13
N	1248	1206	2443	2308

Standard errors in parentheses ***p<.001 ** p<0.01, * p<0.05 †p<.10

Includes controls for 1-digit NBER