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Who Invents?: Evidence from the Japan-US Inventor Survey

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SUMMARY

Human resources are increasingly seen as a key to innovation competitiveness, and there is a need for detailed, systematic data on the demographics of inventors, their motivations, and their careers. To gain systematic data on who invents, we collected detailed information on a sample of inventors in the US and Japan (the RIETI-Georgia Tech inventor survey). The data come from a unique set of matched surveys of US and Japanese inventors of triadic patents, i.e., patents from patent families with granted patents in the US and applications filed in Japan and in the EPO, with data from over 1900 responses from the US and over 3600 responses from Japan. Based on these survey data, we compare the profiles, motivations, mobility and performance of inventors in the US and Japan. Overall, we find some important similarities between inventors in the US and Japan. The distribution across functional affiliations within the firm, by gender, by

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educational fields and their motivations, are all quite similar. In particular, in both countries we find inventors emphasizing task motivations over pecuniary motivations. Firm-centered motivation (e.g., generating value for my firm) is also an important reason for inventing and this reason is relatively more important in the US than Japan. Their distribution across types of organizations is quite similar. The percent of university inventors is nearly the same in the two countries, and the distribution of these inventors across technology classes is also quite similar. However, the percent from very small firms is significantly higher in the US. There are a few important differences. American inventors are much more likely to have a PhD. American inventors are older (even controlling for differences in the share of the inventors with PhDs). The modal Japanese inventor has his first invention in his 20s, while for the US, the mode is the early 30s, and we also find many more American inventors over age 55 at the time of their triadic patent invention. In both countries, older inventors tend to produce higher value patents. American inventors are also much more mobile (although Japanese inventors with PhDs also have high rates of mobility, mainly in the form of secondments). In the US, mobility tends to decline with age, while in Japan, mobility is higher for older inventors (likely due to the differences in retirement ages in the two countries). In both countries, mobility is associated with greater access to outside information. Finally, we find that foreign-born inventors are very important in the US (we did not collect data on country of origin for Japan). Overall, these results suggest that inventor characteristics may be important for firm performance, and that institutional differences may affect the profile of inventors in each country, although the inventors of the two countries are very similar in many respects. Future work will examine how these cross-national differences in inventor profiles affect innovation in each country.

1. Introduction

There are significant concerns in the advanced countries over how to maximize the science and technology capabilities of the workforce (Council on Competitiveness 2005; National Academy of Sciences 2006). Also, firms have concerns about what individual characteristics of S&T workers contribute to firm innovative performance (Zucker and Darby 1996). Recently, there has been significant debate in the strategy literature on the micro-foundations of firm capabilities, including those that derive from skilled S&T personnel (Rothaermel and Hess, Forthcoming). Similarly, there has been concern over what motivates scientific and technical workers and the implications for firm innovations (Sauermann and Cohen 2008). Thus, human capital is increasingly being seen as a key contributor to strategic advantage.

These concerns raise questions on who invents, why they invent, and how these characteristics are associated with the value of their inventions. We use data from a survey of inventors in Japan and the US to answer these questions with respect to inventor background (age, sex, educations, experience). We also focus on inventor mobility, which is seen as a key conduit for information flows. Furthermore, we explore the organization of R&D in firms, focusing on what parts of the organization contribute to an invention. We are especially interested in inventions by those outside of R&D units. While firms often have specialized R&D units, invention can come from throughout the firm and can result from either planned activity or as part of the routine activity of the organization (such as manufacturing) inspiring creative solutions to observed problems (Smith 1776).

Finally, we address the question of what motivates inventors to invent. While there has been significant work on the scientific ethos among academic scientists (Merton 1973) and on the motivations of workers generally, going back to the Hawthorne studies, (Mayo 1930), there is less research on what inspires S&E workers to invent, especially those outside of the R&D function (Sauermann and Cohen 2008).

Data

To address these questions, we use the RIETI-Georgia Tech Inventor Survey data to compare the background, mobility, workplace organization and motivations of inventors on triadic patents. The data come from a survey of inventors on triadic patents (patents filed in Japan and the EPO and granted by the USPTO). We surveyed inventors in the US and in Japan. 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). There is a methodological appendix attached to this report giving the details of the survey (Appendix 1).

2. Inventor and Firm Characteristics

2.1 Organizational Affiliation

Table 1 gives basic descriptive statistics for our sample. We see that about 80% of the inventors in each country are employed in large firms (with the percentage somewhat higher in Japan). Twenty percent of the US sample and 13% of the Japanese sample are in SMEs. Most of this difference is in the smallest firms, with 12% of US inventors coming from very small firms (less than 100 employees), compared to only 5% in Japan. Figure 1 shows the percent of inventions by those in very small firms by technology class. In both countries, medical instruments have above average levels of very small firm inventors. There is a large difference between the two countries in the rates of very small firm inventors in software, with 18% of US inventors in this technology class belonging to very small firms, while only 6% of the Japanese inventions in software belong to very small firms. We also see a large gap in communications devices, with the US having a relatively high percent of very small firm (13%) and Japan having a relatively low rate (3%).

Table 1 also gives the percent of inventors affiliated with universities. Only about 2-3% of the inventors on triadic patents are from universities, with little difference between the US and Japan. In both countries, university inventors are most common in biotechnology, with over 12% of the biotech inventions in each country coming from universities (Figure 2). We also see that, not only is the rate of university inventors the same overall in both countries, but that these rates are very similar for each sector.[2] In particular, in biotech, drugs and software (where US universities are seen as being particularly strong in terms of commercial activity), the US and Japan have very similar rates of university inventions.

2.2 Education

Inventors on triadic patents are, on average, highly educated (see Table 1). We find that 88% of the Japanese inventors and 94% of the US inventors have college degrees, with 46% of the US inventors having a doctorate (13% for Japan). In both countries, the percent of inventors with PhDs is highest in drugs, biotech and chemicals technologies (Figure 3). In the US, semiconductors also have above average percentages of PhDs (65%), although in Japan the rate of PhDs in this sector is about average (15%). On the other hand, 8% of Japanese inventors on triadic patents have only a high school education

[2] Some of these university inventors are seconded from firms in Japan.

or less, compared to 2% in the US. In Japan, inventors without a college education are most common (more than 16% of inventors) in apparel/textiles, earth working, and material processing equipment sectors. Apparel/textiles and material processing also have many high school educated inventors in the US.[3]

In both countries, we find a very high correlation between the percent of PhDs in a technology class and the degree to which inventors in that technology class make use of published scientific literature, on the order of .80 in each country. However, when we look at the correlation between informal or formal collaboration with universities and the percent of PhDs in a technology class, we find significant cross-national differences. In Japan, these are highly correlated (r=.75). However, in the US, these are largely uncorrelated (r=.06). Figures 4A and 4B show the scatter plots. We find a similar result if we measure university cooperation based on our question of the importance of universities as a source of information for suggesting projects (Japan correlation is .89 and US correlation is .08). Thus, while use of scientific literature tracks closely with presence of PhDs in both countries (see Walsh and Nagaoka, 2009), university-industry cooperation is much more closely linked to the rate of PhDs in Japan than in the US.

Field of Degree

[3] The number of earth working inventions in the US is too small for comparison.

We also asked inventors for the academic field of their highest degree. The results are in Table 2. In general, the two countries have similar distributions of inventors across fields, except for Chemistry (where the US has significantly more) and Engineering (where Japan has significantly more). Much of this difference is due to a relatively higher rate of chemical engineers in Japan compared to the US (15% in Japan v. 8 percent in the US). We do not know if this difference represents an actual difference in training, or a difference in the classification of fields of study. There is some argument that firms benefit from access to R&D personnel trained in basic science rather than engineering, because they are better able to integrate scientific findings into the invention process and because their broader training makes them more flexible. To explore this thesis, we compared, for each country, the respondents trained in chemistry and chemical engineering. We checked to see if they differ in their likelihood to engage in basic research, to work on technology seeds or new lines of business (compared to existing lines of business), to produce high value patents, and to have their patents commercialized. We limited our comparison to those without a PhD, since even chemical engineering PhDs are likely to be more science focused. Table 3 gives the results: In both countries, we find that those with chemistry backgrounds engage in more basic research than those with chemical engineering backgrounds. However, in both countries, the percentage of inventors working on technology seeds is about the same in the two fields. In Japan, we see that chemists are somewhat more likely to work on new lines of business, while in the US, it is the chemical engineers who are somewhat more focused on new lines of business (although the difference is small). We see little difference by field in the likelihood of a high value patent, in either country. In the US, the commercialization rate is higher for chemists than for chemical engineers, while in Japan it is the opposite. These results suggest that there is not a clear advantage of those trained in chemistry over chemical engineering, although there is a consistent finding that those with a chemistry background (even with a PhD) are more likely to engage in basic research.

2.3 Gender

There is substantial concern about the under-representation of women in the S&E labor force. In our samples of inventors on triadic patents, five percent of the US sample is female, and less than 2% in Japan (Table 1). These percentages are low even compared to the under-representation of women in the S&E workforce, consistent with prior work on gender differences in patenting (Bunker Whittington 2006; Ding, Murray et al. 2006). Published statistics suggest that about 25% of the US S&E workforce is female and about 10% of the Japanese S&E workforce is female. The gender gap between the US and

Japan is especially large for university inventors. In the US, university inventors have an above average rate of female inventors (9.5% of all university inventors), while in Japan, about 1% of university inventors are women, similar to the overall average. Thus, we have in both countries, an opportunity for increased participation of women as inventors. Policy makers and firms might consider what changes in policies and practices might increase the participation of women in the inventive activity of firms.

2.4 Age

The average age of inventors in Japan is just under 40, while in the US, the average age is 47 years old (Table 1). As shown in Figure 5A, there are relatively few young American inventors compared to the Japanese inventors. Only 20% of the US inventors were in their 30s, while in Japan, 45% of the inventors were in their 30s. On the other hand, there are many more older inventors in the US. Over 20% were in their 50s and more than 10% were 60 or older. In Japan, just over 10% of inventors were in their 50s, and only 2% were 60 or older.[4] The standard deviation in the US is 9.9 years, while in Japan the standard deviation is 9.1. Thus, it seems that in both countries, the spread of

[4] While there are a larger number of PhDs in the US sample, the mean age for those without PhDs is also about 47 years old, suggesting that the difference is not limited to PhD scientists. When we compare the age distributions for only those with a bachelor's degree, we see a similar gap (Figure 5B).

ages is about the same. While these are cross-sectional numbers, we can think of this graph as reflecting the careers of inventors in the two countries. Thus, while inventors seems to be active for about the same period, the US inventors start later than their Japanese peers. In order to confirm this, we asked respondents for the year of their first patent applications. Subtracting their year of birth from their first patent year gives us their age at first patent. Figure 6 shows the age distribution for first patent application by country. We can see that over 75% of Japanese inventors in our sample had filed their first patent before their 30th birthday. In fact, almost 20% filed their first application before they turned 25, which suggests they started filing soon after graduating college and joining firms as company engineers. In the US, less than 30% had applied for a patent before turning 30 and only 5% had applied before age 25.

As we can see from Figure 6, the average age of American inventors is higher in large part because they start inventing later (and also because there are more older inventors in the US). To make sure that this is not a cohort effect (i.e., that this result is not due to a big influx of inventors in Japan in recent years), we compared the age at first invention across age cohorts in the two country (limiting to those without a PhD as a further control). Figure 7 shows the results. We see that for every cohort, except the youngest (which is artificially constrained by the current age), and the very oldest cohort (which seems to contain a lot of late bloomers in both countries), Americans made their first invention significantly later (by around 5 years for 35-44 age group) than did Japanese born in the same years. Thus, we have substantial evidence that Japanese inventors start inventing at a younger age than do American inventors. One interpretation of these results is that Americans tend to take longer to finish university, and to find their first regular job, and also retire later than Japanese workers. In both countries, we see a significant drop-off in the number of inventors after the peak of about 10 years' span (during their 30s in Japan, 40s in the US). We suspect that company promotion policies may be related to this sharp drop-off in older inventors. In many firms, engineers get promoted to managers after about 10 years, and at that point, may devote less of their efforts to inventing. Another possibility is that older engineers are less inventive, and so drop out of the population of inventors.

We now look at the relations between inventor age and productivity to see if we find evidence that those older inventors who are still inventing are more productive than their younger colleagues. Of course, we should be careful about the potential selection bias involved in this analysis, since we are selecting those older engineers who are still producing triadic patents. We looked at three measures of the type of patents. First, we looked at the goals of the project, to see if older or younger inventors are more likely to work on technology seed development versus new lines of business or existing lines of business. We then looked at the value of patents, using self-reported rates of inventions in the top 10% of value compared to other technologies in the field (Nagaoka and Walsh 2009). Finally, we looked at the rates of commercialization of inventions (as another measure of the value of the inventions). For this analysis, we grouped the inventors into the following age categories: less than 30, 30-34, 35-39, 40-44, 45-49, 50-54 and 55 plus. In terms of project focus (Figures 8A & 8B), we see an interesting difference in the two countries. In Japan, we see the percentage of inventors working on existing business is highest for younger inventors and declines with age. In contrast, the percentage working on technology seeds increases with age. Inventions related to new business are about equally likely across the age categories. In the US, in contrast, younger workers are more likely to work on new business, and older workers on existing business, with seeds development about equally likely. Note that in both cases, the peak in the rate of existing business inventions is also the age cohort with the greatest representation. In other words, in both countries, at the point when most R&D personnel are most active, the bulk of their activity is focused on existing business. But, in Japan, this peak comes at a younger chronological age. We also see evidence of a division of labor in Japanese firms, with younger workers concentrating on existing business (beginning almost as soon as they join the firm), and older workers spending somewhat more time on technology seeds development, although even among this group of older engineers, the vast majority of their inventions are geared toward existing business. This may be related to promotion practices and management of R&D personnel, with older workers getting the chance to do more fundamental research, after spending some time gaining familiarity with the existing technology base and product lines of the firm. In the US, we see that younger workers are more likely to concentrate on new lines of business and older workers on existing lines of business, suggesting a kind of maturation effect in the US. Further work is needed to explore the implications of these differences for firm performance.

In Figure 9 we show the relation between age and the self-reported value of the patents.[5] We see that, in general, older inventors have more high-ranked inventions than do younger inventors, in both countries. This could be due to greater experience leading to more important inventions. It may also be a result of a selection process whereby the less promising inventors stop inventing and only those with higher than average

[5] Note that overall, 10.8% of Japanese inventors self-rated their patents as being in the top 10%, as did 12% of the US inventors, which suggests that inventors may be reasonably good at estimating the relative rank of their inventions. We also find that this measure is highly correlated with other expected measure of value, such as effort in the project and whether the invention was commercialized (Nagaoka and Walsh, 2009). There is also a positive relation between this measure and forward citations.

capabilities continue to invent. If we look at the commercialization rate (the percentage of patents that were used either in-house, or licensed or used for a startup), we see very little difference across age categories, although the highest commercialization rate in Japan is for those inventors in their early 50s (see Figure 10). Thus, we have some evidence that older inventors produce more valuable patents, although we do not know how robust this result is to various controls, nor do we yet know the exact reasons for such a relationship. However, these results raise some concerns for Japanese large firms, since requiring early retirement suggests that these firms may be losing these potentially high performing inventors (see below on mobility among older inventors). Of course, keeping these very senior inventors in the firm can create problems for the internal labor market and seniority-based salary system common in large Japanese firms. American large firms seem to be better able to keep their more senior inventors. However, these senior inventors are less likely to work on new lines of business, suggesting that perhaps they may be less creative than more junior inventors.

2.5 Country of Origin

In the US survey, we also asked about country of origin. There is a heated policy debate in the US about the role of foreign workers in the American economy, and especially the role of foreign born S&T workers (Levin and Stephan. 1999). When we analyzed the responses, we found that almost 30% of the inventors in the US were foreign-born (Figure 11). Regression analyses suggest that inventions by foreign-born inventors have higher value, and that the gap is even larger when comparing the most educated foreign-born and native-born inventors, suggesting that the high number of foreign-born inventors is a source of strength in the US innovation system (No and Walsh 2008). It is not surprising that foreign-born inventors perform better than average, since they face a double-selection process. First, such inventors self-select, with the expectation that only the talented (i.e., those with high expected returns from their inventive activities) are likely to take on the expense and effort of moving to a new country. Secondly, the host country (the US in this case) screens potential entrants, both through immigration procedures and, perhaps more relevant, by schools and firms choosing which applicants to sponsor for visas. Thus, this double screening process likely produces a group of immigrant scientists and engineers with above average ability and motivation. Currently, there is concern that stricter immigration policies (which may select on characteristics orthogonal to or even negatively related to inventive capabilities) might be weakening the pool of foreign-born scientists in the US (NAS, 2006). There have been calls for a more rational immigration policy that would better support the mission of promoting innovation.

3. Inventor Mobility

Figure 12 shows the mobility of inventors in the two countries. We see that in the US, about a quarter of inventors have moved during the last five years. In Japan, the percentage is only about 10%, and more than half of these were temporary secondments to another organization. Among the large firms in Japan, 70% of moves were secondments (See Figure 13). The difference in mobility rates between the two countries is especially large in biotechnology, medical instruments, semiconductors and computer software, all of which are sectors where the US is seen as having a vibrant, high-tech industry and where inventor mobility is seen as playing a key role in that success (Saxenian 1994; Zucker and Darby 1996). In Figure 13, we also see that, in the US, the probability of an inventor having recently joined a firm increases as firm size decreases, with almost half of those in the smallest firms having joined in the last 5 years. In Japan, there is a similar pattern, but only for the smallest firms (less than 100 employees). In both countries, inventors in these smallest firms are almost twice as likely to have moved in the last 5 years as the overall average. When we examine the sources of inventors, universities are one of the most important sources of the mobility in the two countries, especially in Japan, due to their central role for receiving secondments. We also find that

Japanese firms are more likely to get inventors who move vertically (from customers or suppliers), while US inventors are more likely to move horizontally, across competitors or others in the same industry (Figures 14A and 14B). For example, in the US, 45% of moves to large firms were from competitors or others in the same industry, while in Japan, 16% of moves to large firms are horizontal. In contrast, in the US, for large firms and SMEs, about 6% of moves are vertical, while in Japan, about 20% are vertical. Thus, we have evidence that the labor mobility in the US is more lateral, while in Japan it is more vertical.

We see important differences in mobility by type of inventor. Figure 15 shows the rates of mobility by education (PhD or not) for each country. In both countries, we find that PhDs have a higher rate of mobility than non-PhDs. However, in Japan, we find a major difference in mobility between PhDs and non-PhDs, with PhDs 2.5 times more likely to move than non-PhDs. Although the majority of these moves are secondments, the moves which are not secondments are also significantly more frequent for PhDs than non-PhDs in Japan. Many of these secondments are likely to be to universities (often for the purpose of completing the work for getting the PhD). Thus, to the extent that mobility is important for facilitating information flows (see below), PhDs may be especially important in Japan, since they are much more mobile. The rate of mobility of PhDs in

Japan is close to the overall US rate. We also see an interesting pattern when we compare mobility rates by age across the two countries (Figure 16). In the US, mobility is highest among those in their 30s and declines significantly in the later years. However, in Japan, we see an increase in moving to another firm in the later years (as people retire from the big companies and move to the small firms). We also see that, in Japan, secondment is most common among those in their 30s or early 40s, during the peak of their careers as inventors. Thus, in both countries, those in their 30s are most likely to change organizations, but in Japan most of this mid-career movement is through secondment. Figure 17 shows the percent of inventors age 55 and above, by organizational affiliation. We see that in Japan the large firms have very few older inventors, while the smallest firms, and, especially, universities, have the bulk of older inventors. In the US, the percentage of older inventors in large and medium firms is much higher, although we again see the pattern of more older inventors in very small firms and universities. As noted above, the older workers in our sample are those with the most valuable patents. However, in both countries, but especially in Japan, these older inventors are more likely to move to small firms.

Saxenian (1994) suggests that this mobility of inventors is a key source of information flows across firms and an important contributor to the dynamic innovative vitality of a region. Figures 18A and 18B compare the uses of information sources (for suggesting new projects) for mobile (movers) and non-mobile (stayers) in the Japan and the US. The Japanese results also split the movers into those who changed companies (movers) and those who were on temporary loan to another firm (secondment). We find that, in both countries, mobile inventors generally make greater use of external information sources, especially information from universities and from competitors (although only for secondments in Japan). Interestingly, in the US, we find that these mobile inventors also make less use of internal information sources, suggesting that there is some tradeoff at the level of the individual in his ability to access internal versus external sources if he moves. The Japanese data show a similar pattern, with the added finding that those who have been on secondment also benefit from external information sources similarly to those who have changed companies. On the other hand, those who have been on secondment also make more use of internal information from other parts of the firm, likely due to having ties within the firm, as well as ties to those in other organizations due to the secondment. Future work will examine the relations between inventor mobility and patent value and commercialization.

4. Location of Inventors in the Organization

Figure 19 gives the functional affiliation of the inventors. Most inventions come from stand-alone R&D units, although significant numbers come from R&D units attached to other functions, and from other parts of the organization such as manufacturing or software. We also see that Japanese inventors are somewhat more likely to come from stand-alone R&D labs (70% v. 64%), while American inventors are somewhat more likely to be part of a manufacturing unit (8.5% v. 5%). This difference, however, is mostly due to the larger share of very small firms in the US, as we will see later. In the US, inventors from the manufacturing unit (who may be R&D personnel attached to the unit) are especially likely in motors, and in power equipment, while in Japan, manufacturing unit inventions in these sectors are much less common. Of course, in Japanese firms, at least some of the R&D personnel are likely to have rotated from manufacturing, and so might have direct experience with manufacturing processes, even if they are currently located in a stand-alone lab. Figure 20 gives the work unit of the inventor by firm size. In both countries, large and medium sized firms are more likely to have inventors from R&D labs, while in small firms, inventors from outside R&D (and even outside of manufacturing) are more common. The composition of functional affiliations is quite similar between the two countries for each category of firm.

5. Inventor Motivations

Finally, we address the inventors motivations for inventing. We are especially interested in the relative importance of pecuniary, task (intrinsic) and social motivators (Amabile 1993; Walsh and Tseng 1998; Sauermann and Cohen 2008) We asked our inventors "During the research leading to the focal patent, how important to you were the following reasons to work on inventing?", with the answers on a 5-point scale. We report the percent of respondents who rate each reason as at least moderately important (4 or 5 on the 5-point scale). Figure 21 shows the results[6]. In both countries, the most widely cited motivation is satisfaction from solving technical problems, what we might call task motivation (i.e., the task itself generates utility). Satisfaction from contributing to the progress of science also scores high in both countries. Progress of science is an especially important motivation in biotech and drugs, as we can see in Figure 22. Even the order of sectors in the importance of this motivation is quite similar in both Japan and the US. Figure 23 shows the differences in motivation by science across firm sizes. Here we see that SME inventors in the US are somewhat more motivated by science than those of large firms, compared to their Japanese peers (although this is not true for the smallest

[6] Since the distributions of the importance by a 5-point scale are likely to vary across countries, we focus only on the relative ranking of the motivations.

firms). Finally, generating value for one's firm is a highly cited motivation of the US inventors, second to the satisfaction from solving technical problems, but not so much by the Japanese inventors. Also, US inventors rate prestige/reputation (social motivations) relatively highly among all motivations, while this motivation ranks relatively low among Japanese inventors (fourth most important motivation in the US vs. the least important motivation in Japan). Compared to these task or social motivations, (self-reported) pecuniary motivations such as career advancement, beneficial working conditions and monetary rewards all score much lower than the task or reputation motivations, in both the US and Japan.

We might expect that labor market conditions (and payment practices, such as the use of stock options) may also condition motivations. If the inventor is better able to capitalize on his invention capability by changing firms, he might be more motivated by reputation, since this reputation may be traded for job opportunities and higher pay in another firm. Similarly, if inventors are given stock options, they may be more motivated by enhancing the value of the firm (because they will share in the value, either directly through stock options or indirectly through being able to garner job offers based on being associated with a successful firm). Controlling the level of mobility, these effects should be stronger in smaller firms, since the impact of one inventor on the firm's performance is greater and it is easier to show one's individual contribution. On the other hand, since the level of mobility is higher for smaller firms, an incentive payment related to firm performance may be less effective for inventors in small firms. Compared to Japan, both mid-career mobility and use of stock options are more common in the US (See Nagaoka (2005) for the use of stock options in Japan). Thus, we would expect closer links between firm size or mobility and motivations such as firm value or inventor reputation in the US than in Japan. Figure 24 gives the results comparing the importance of "creating value for my firm", by firm size. We see that, in the US, the motivation of enhancing the value of the firm is not very different across firm sizes. This may be due to the offsetting effects of firm size: more use of incentive payment linked with firm performance and its stronger effect for a given mobility in a smaller firm vs. higher mobility of inventors and a larger risk in a smaller firm. In Japan, we find that concerns about firm performance are highest in the largest firms, perhaps due to more extensive use of long-term employment practices in such firms in Japan and infrequent use of stock options in smaller firms. We also find that the concern with firm performance, relative to the other motivations, seems to be greater in the US than in Japan, despite higher mobility in the US. One potential explanation is higher contribution of the invention to the firm value in the US, perhaps due to stronger patent enforcement there. Figures 25A and 25B shows the motivations by mobility. We see very little difference in motivations between mobile (including secondment) and not mobile inventors in Japan. In the US, we also find that recently mobile inventors are similarly motivated by generating value for the firm as the other inventors. Mobile inventors are somewhat more likely to be motivated by career advance (36% v. 32%). One possible reason for this small difference is that, given the high rates of mobility in the US, even non-mobile inventors in the US are potentially mobile.

If we compare those who are in the R&D units (whose job it is to invent) versus those who are not, we find, in both countries, that those in R&D are more motivated by task (contributing to science), and also by career advance, reputation and beneficial working conditions (Figures 26A and 26B), although the differences are not larger. All of these might be related to the fact that invention is their job, so they expect invention performance related benefits (either within the firm or through mobility). On the other hand, in both countries, non-R&D inventors are more likely motivated by money, perhaps because these inventions generate special bonuses, while they have less chances to be promoted on the basis of inventions. Further research into HR practices would help clarify this difference. Interestingly, in both countries, satisfaction from solving technical problems is about equally important as a motivation for those both outside and inside

R&D (and is the most important motivation), again highlighting the importance of task motivation.

These results are consistent with prior work that suggests that scientists and researchers are motivated primarily by the task, and by recognition from their peers, and only secondarily by pecuniary concerns. However, we should be cautious about interpreting these responses in light of a likely socially desirable response effect that would lead respondents to emphasize their task motivations and under-report their pecuniary motivations (Rynes, Gerhart et al. 2004). We also see that US inventors seem to be more motivated by adding value to the firm (a motivation not explored in the prior literature on inventor motivations). This firm-focused motivation does not track closely with firm size in the US (although it is greater in larger firms in Japan). Thus, we need more detailed information on the correlates of motivations to understand what drives these firm-focused motivations.

6. Conclusions

Overall, we are struck by how similar inventors are in the US and Japan. The distribution across organization type, across functional locations within the firm, by gender, by educational fields and their motivations, are all quite similar. In particular, the percent of university inventors is nearly the same in the two countries, and the distribution of these inventors across technology classes is also quite similar. While this suggests that American and Japanese universities are contributing similarly to the inventions in terms of the relative number of triadic patents, it does not imply that their contributions are similar, since the quality of university researchers' inventions seems to be higher in the US than in Japan and they are more used in the US than in Japan (see Nagaoka and Walsh, 2009). We are also struck by the similarities in motivations in the two countries, and, in particular, the importance of task motivations (solving technical problems, contributing to science) in each country. These results suggest that, in order to increase innovation, R&D managers should ensure that their engineers have opportunities to satisfy these motives in their work (Amabile 1993; Walsh and Tseng 1998; Sauermann and Cohen 2008; Owan and Nagaoka 2009). Future work will explore the effects of motivation on performance, and how that varies by country, firm size and type of invention. This work is likely to have important implications for firm HR strategy and performance. We also find only a small number of women among inventors in both countries, consistent with prior work (Ding, Murray et al. 2006; Giuri, M et al. 2007). In both the US and Japan, there is a concern about a shortage of S&T workers, and these results suggest that women may be a potential resource that countries can tap. This raises the question of what steps can firms and national governments take to increase the rate at which women scientists and engineers generate patents. For example, Bunker Wittington (2006) finds that women bio-medical researchers have higher rates of patenting in small biotech firms than in either universities or large pharmaceutical firms. This suggests that there may be important organizational factors that contribute to the greater or lesser participation of women. Future work will explore the factors that are associated with greater or lesser rates of women S&T personnel patenting.

There are a few important differences. Inventions by very small firms (less than 100 employees) are more common in the US. PhDs are much more common in the US. Also, American inventors are older, on average, and this difference seems to be due to American inventors taking longer to begin inventing, while Japanese inventors tend to start inventing right after graduating college. In addition, American inventors are still inventing into their old age, while there are very few Japanese inventors above age 55, especially in large firms. American inventors are also much more mobile (although Japanese inventors with PhDs also have high rates of mobility, mainly in the form of secondments). In the US, mobility tends to decline with age, while in Japan, mobility is higher for older inventors (likely due to the differences in retirement ages in the two countries). In both countries, mobility is associated with greater access to outside information. Finally, we find that foreign-born inventors are very important in the US (we did not collect data on country of origin for Japan, although the rates are likely to be much lower). We also find that American inventors are more likely to report contributing to firm performance as a reason to invent. This motivation has not been studied extensively in prior work and it is worth considering what factors might affect this motivation. There are also important sector differences too, such as more small firms in communications equipment and drugs in the US. Further work will examine the effects of these higher rates of mobility, and also the relative importance of small firms in particular sectors.

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,[7] with priority years from 1995 to 2001. The survey in the US was conducted by Georgia 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/inventors/InventorQuestionnaire.pdf 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

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

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 (Dernis and Khan 2004; Criscuolo 2006). 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.[8]

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[9] (Hall, Jaffe et al. 2001), with oversampling for the technology sectors such as

[8] 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.

[9] We separated computer hardware and software.

biotechnology with a relatively small number of patent applications.[10] 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 et al. 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 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

[10] The simple averages and the averages reflecting the sampling weight give essentially identical results.

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 un-weighted means produced essentially the same results.

Table 1. Inventor Background, Japan and US, triadic patents (common technology weights).

		Japan	US
	Sample Size	3658	1919
Academic	University graduate(%)	87.6	93.6
Background	Doctorate (%)	12.9	45.2
	Female (%)	1.7	5.2
	Age (mean and s.d.)	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. Inventors Affiliated with Very Small Firms (less than 100 employees), by Sector, US and Japan.

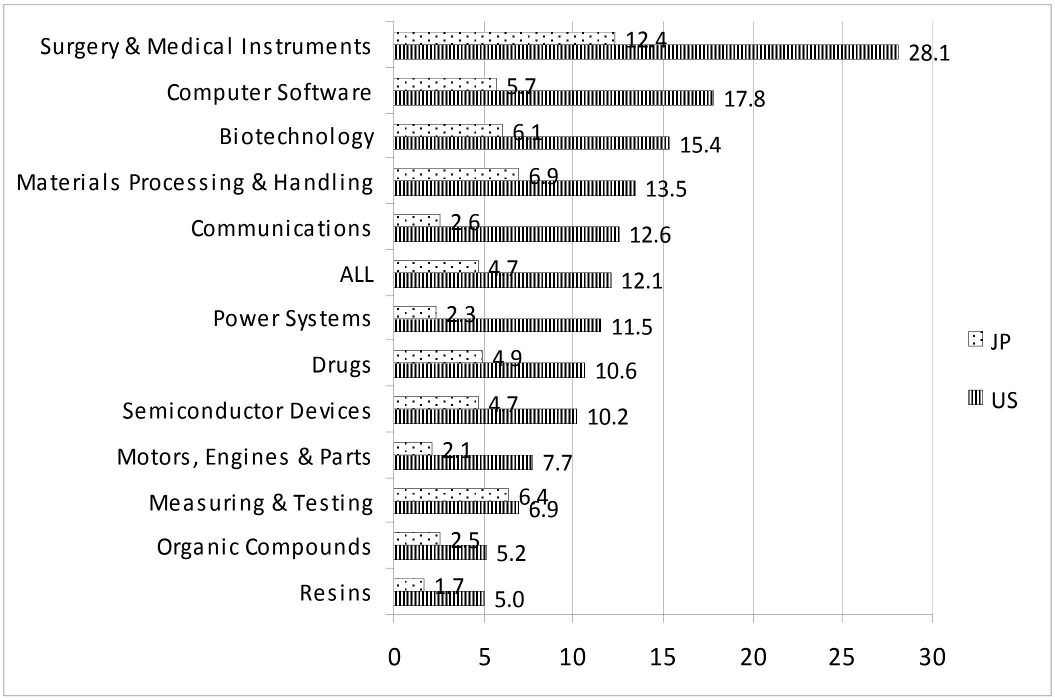


Figure 2. University Inventors, by Sector, US and Japan.

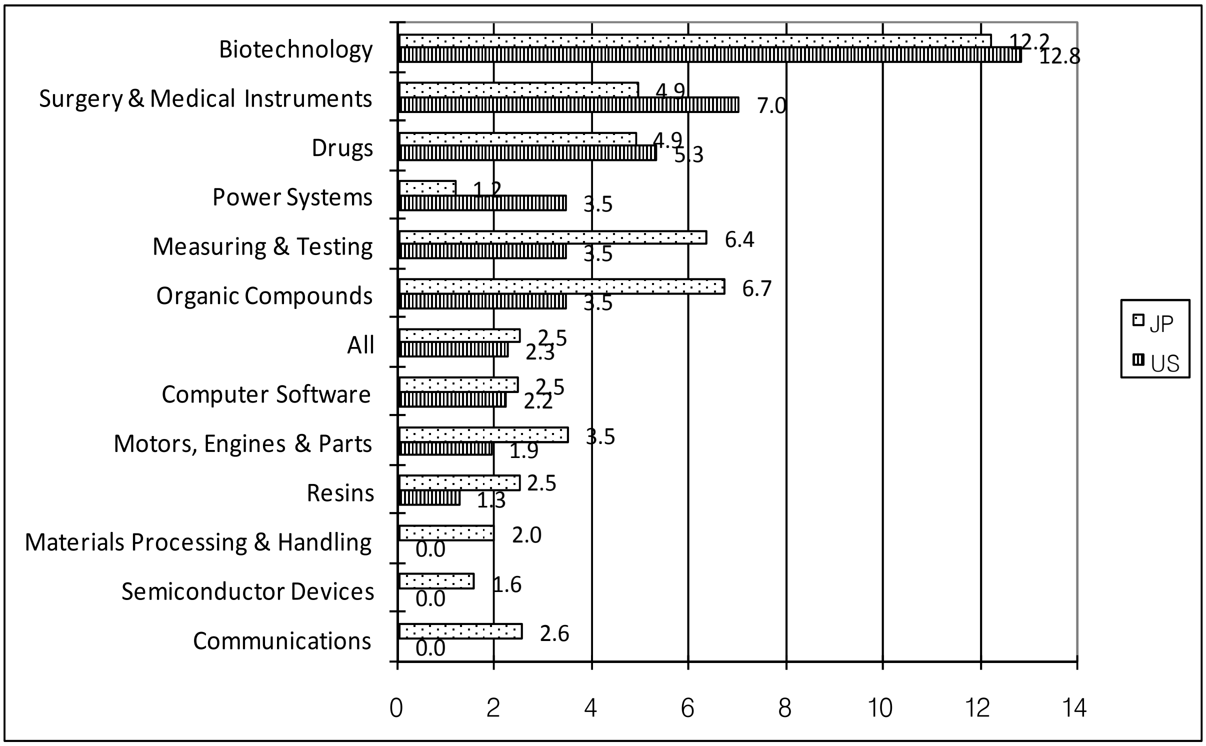
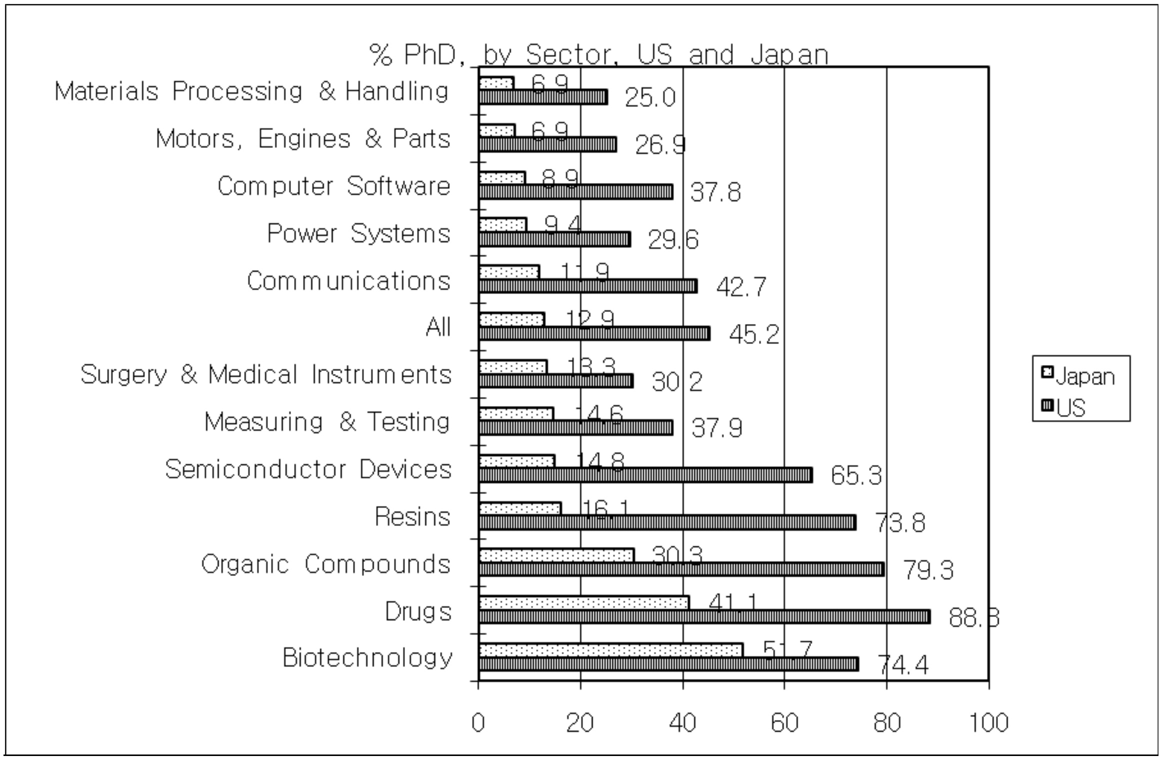


Figure 3. PhD-Level Inventors, US and Japan.



Note: "All" includes common technology weights.

Figure 4A. Percent of inventions in collaboration with universities by percent PhDs in each technology class, Japan.

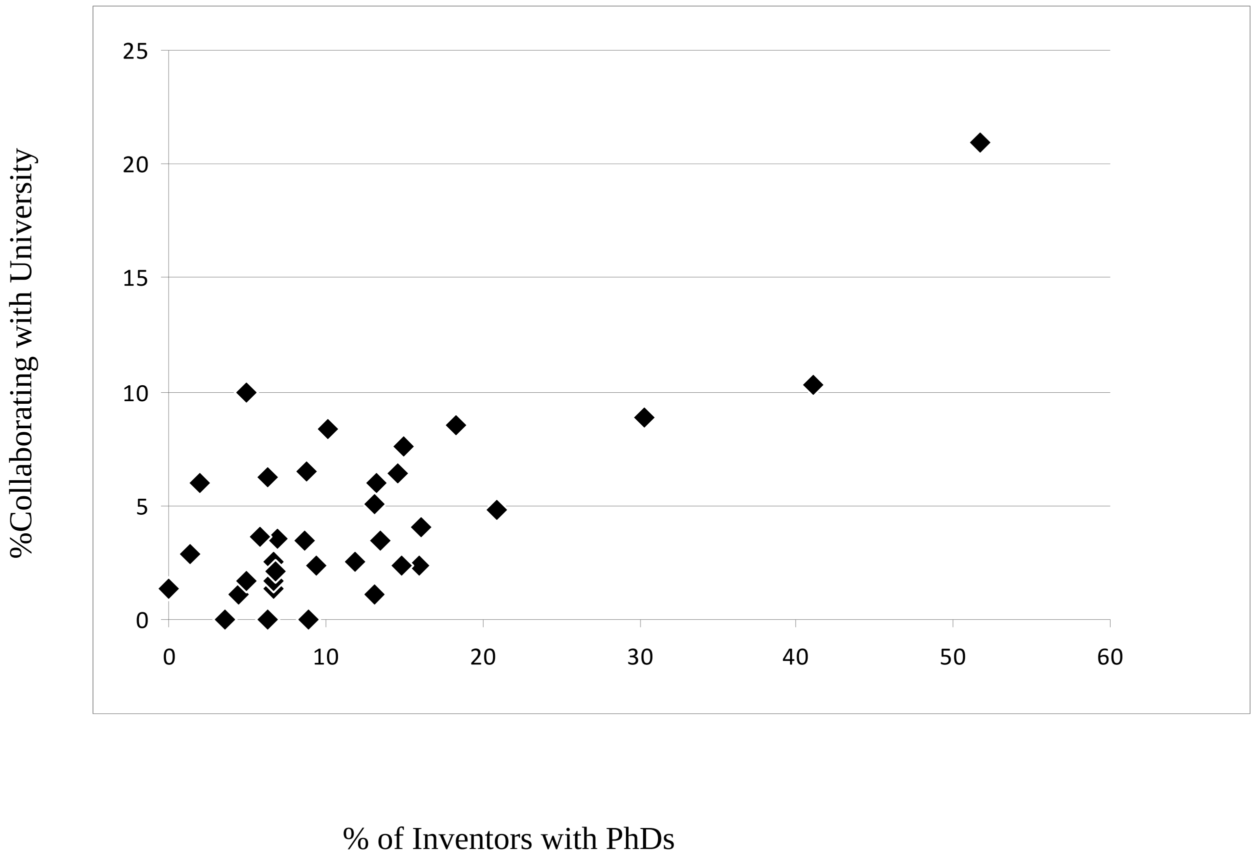


Figure 4B. Percent of inventions in collaboration with universities by percent PhDs in each technology class, US.

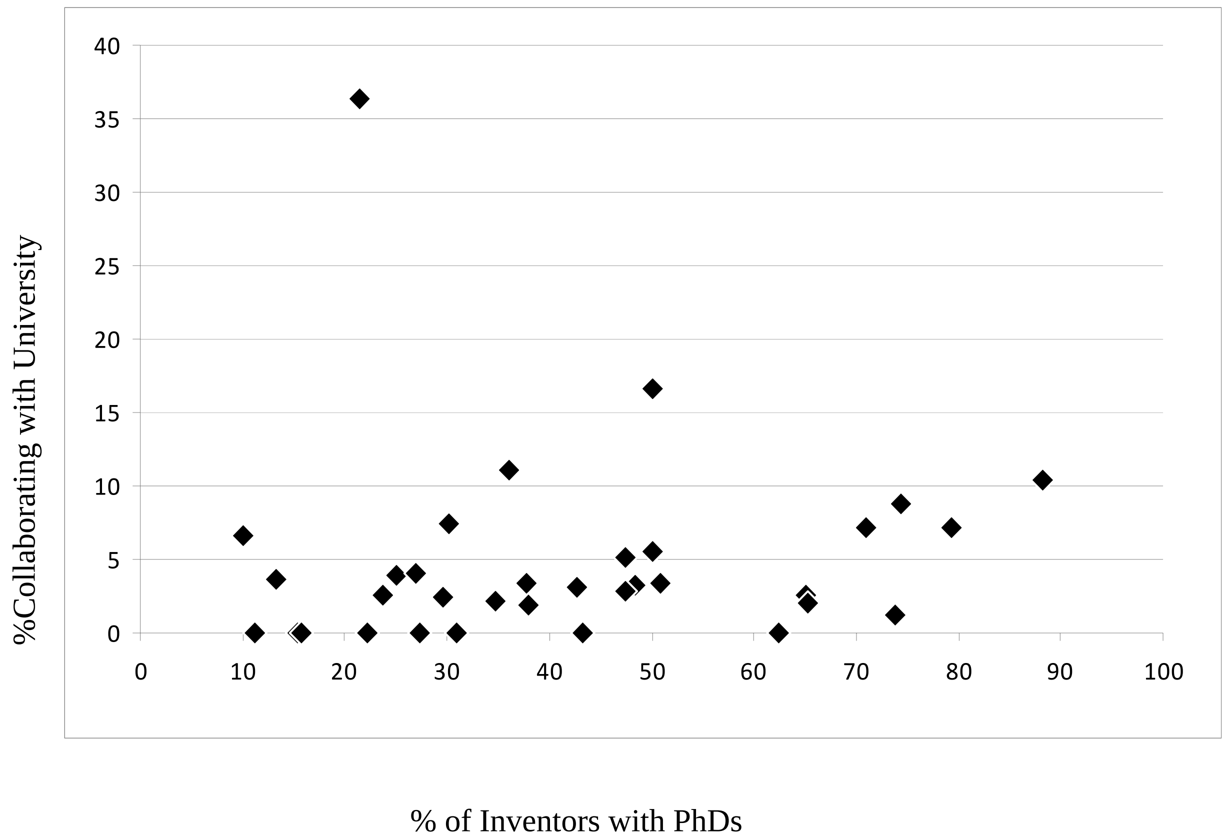


Table 2. Field of highest degree, US and Japan (common technology weights).

Field	Japan	US
Physics/Astronomy	5.8%	8.6%
Math/Computer Science	3.0%	3.7%
Chemistry	7.5%	20.5%
Engineering	74.5%	55.6%
Life Sciences	7.7%	6.1%
Social Sc/Humanities	1.5%	5.4%
Total	100%	100%

Table 3. Research goal and outcomes, Chemists v. Chemical Engineers, US and Japan.

	Japan		US	
	Chemistry	Chem. Engineering	Chemistry	Chem. Engineering
Basic (%Yes)	34	25	35	24
Goal: New	33	24	22	27
Goal: Existing	60	69	46	45
Goal: Seeds	6	6	26	28
Top10 Econ Val (Domestic)	7	7	9	11
Commercialized	55	62	71	55

Note: BA/MA level inventors only, unweighted means

Figure 5A. Age Profile, US and Japan (common technology weights).

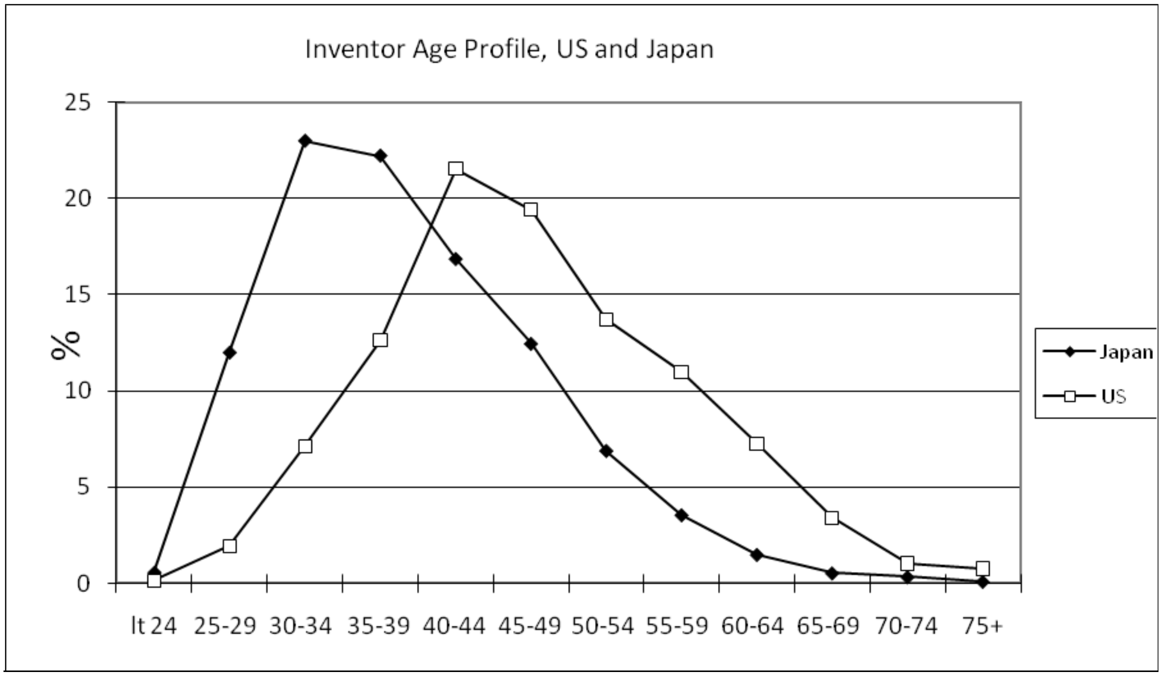


Figure 5B. Age Profile, US and Japan, BS-degree holders only (common technology weights).

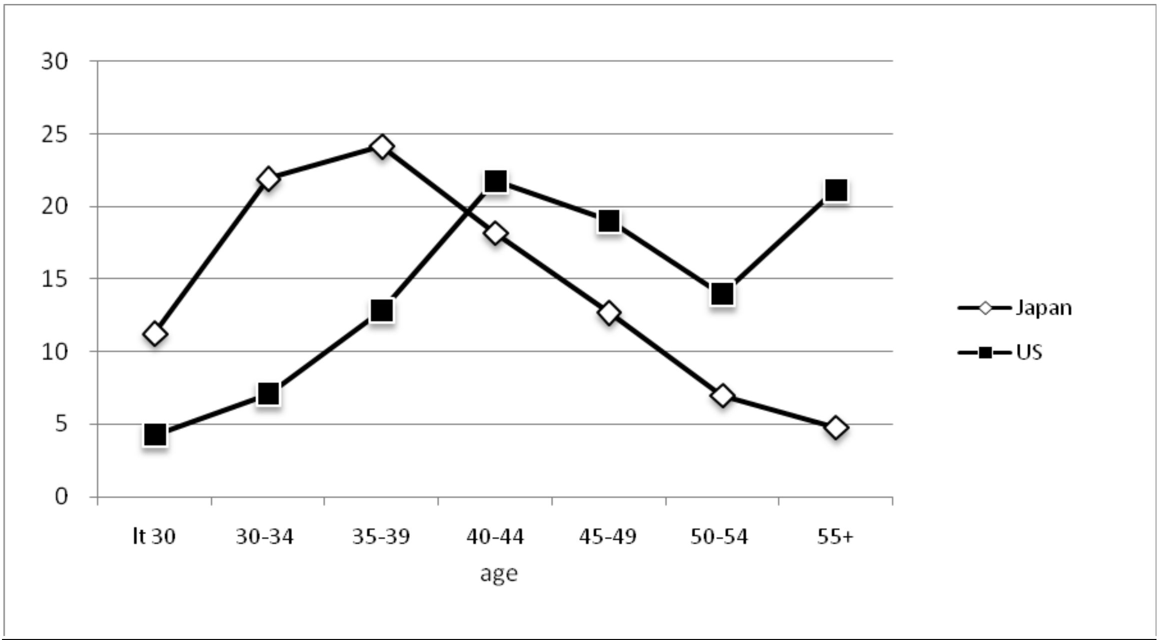


Figure 6. Age at first patent application, US and Japan (common technology weights).

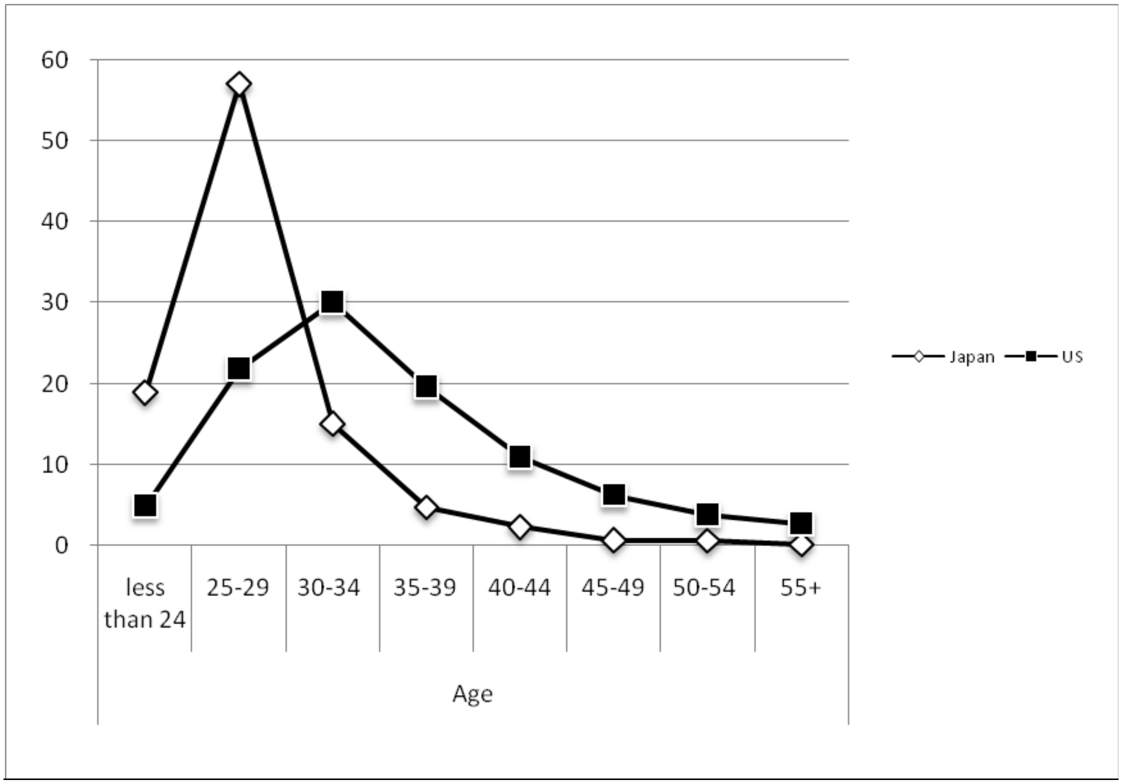


Figure 7. Mean age at first invention, by age cohorts, US and Japan, non-PhDs, common technology weights.

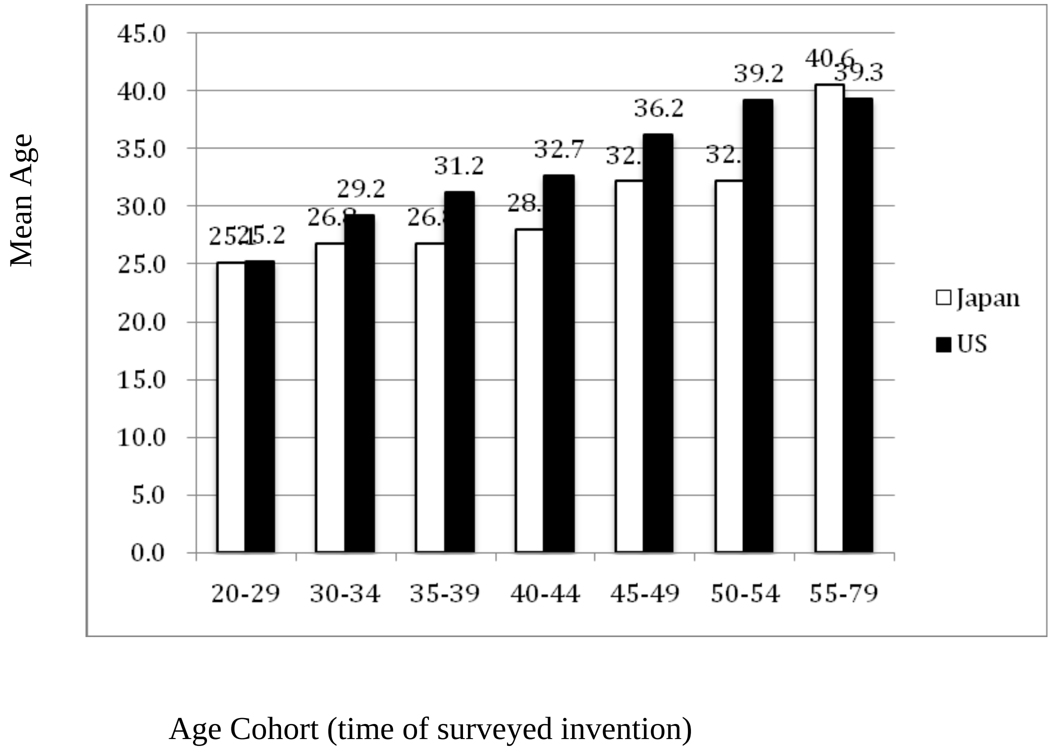


Figure 8A. Goals of the research project leading to the invention, by age of inventor, Japan.

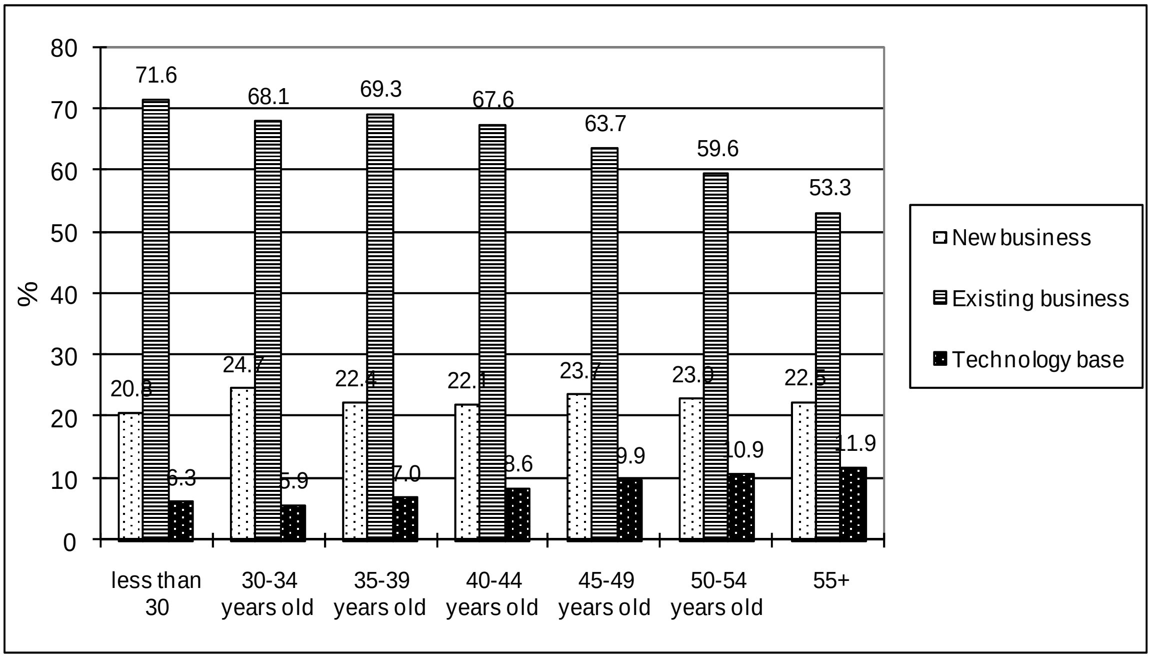


Figure 8B. Goals of the research project leading to the invention, by age of inventor, US.

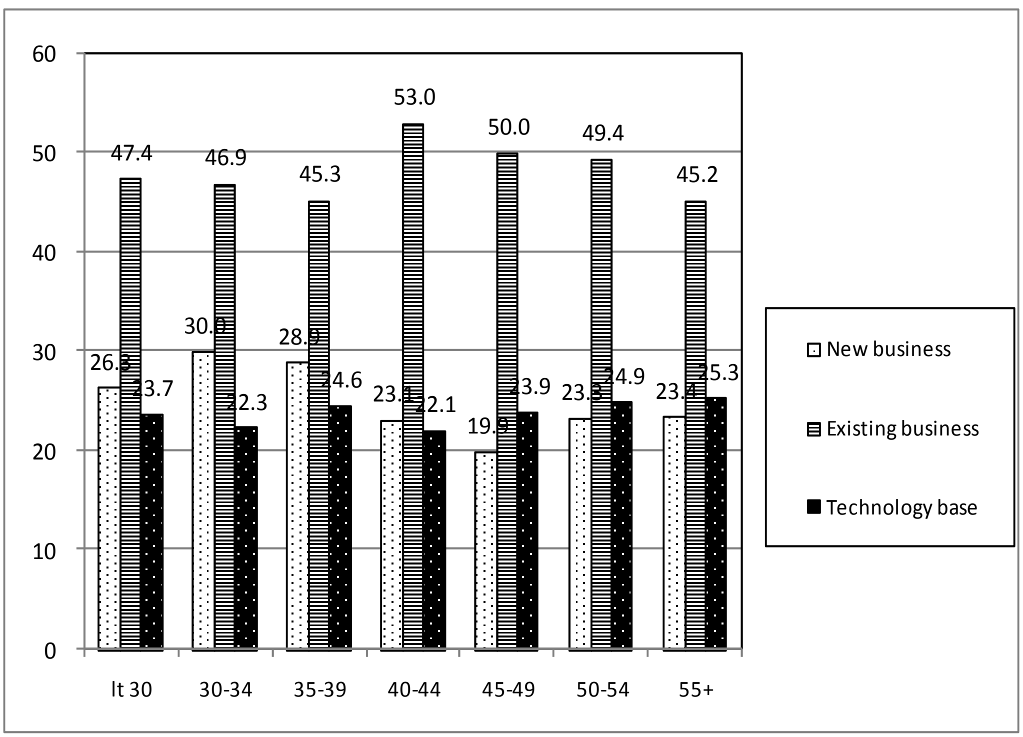


Figure 9. Percent of patents rated in the top 10% (domestic economic value), by age, Japan and US, common technology weights.

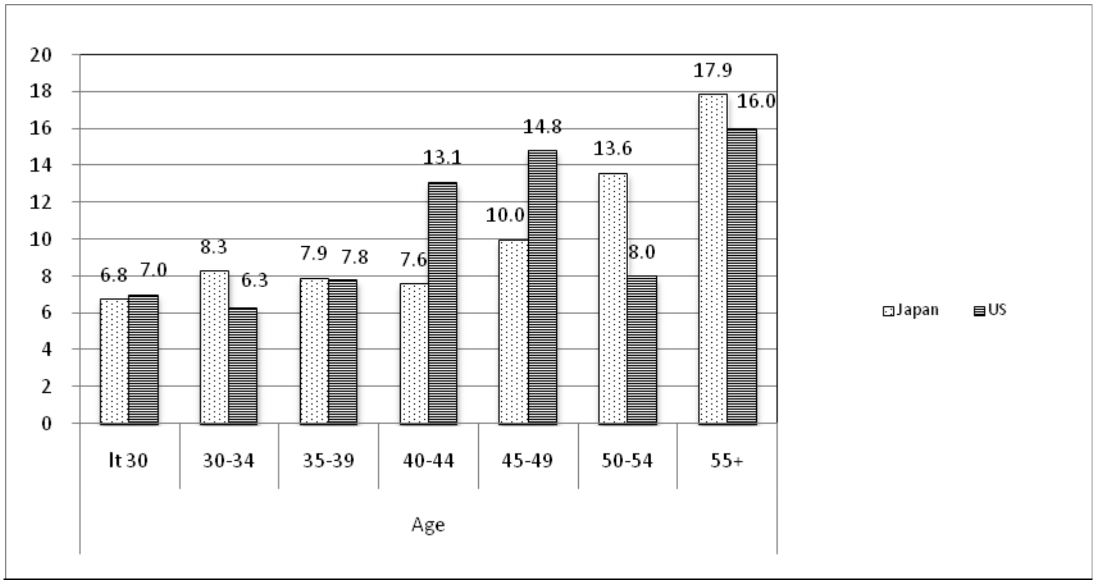


Table 10. Percent of patents commercialized, by age, US and Japan, common technology weights.

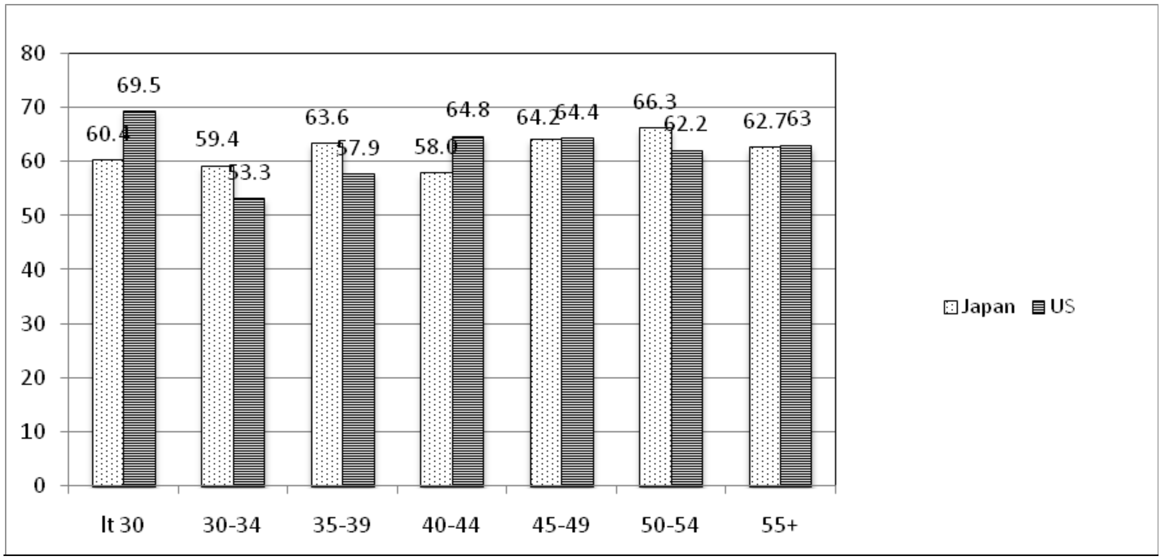


Figure 11. Country of Birth for US inventors

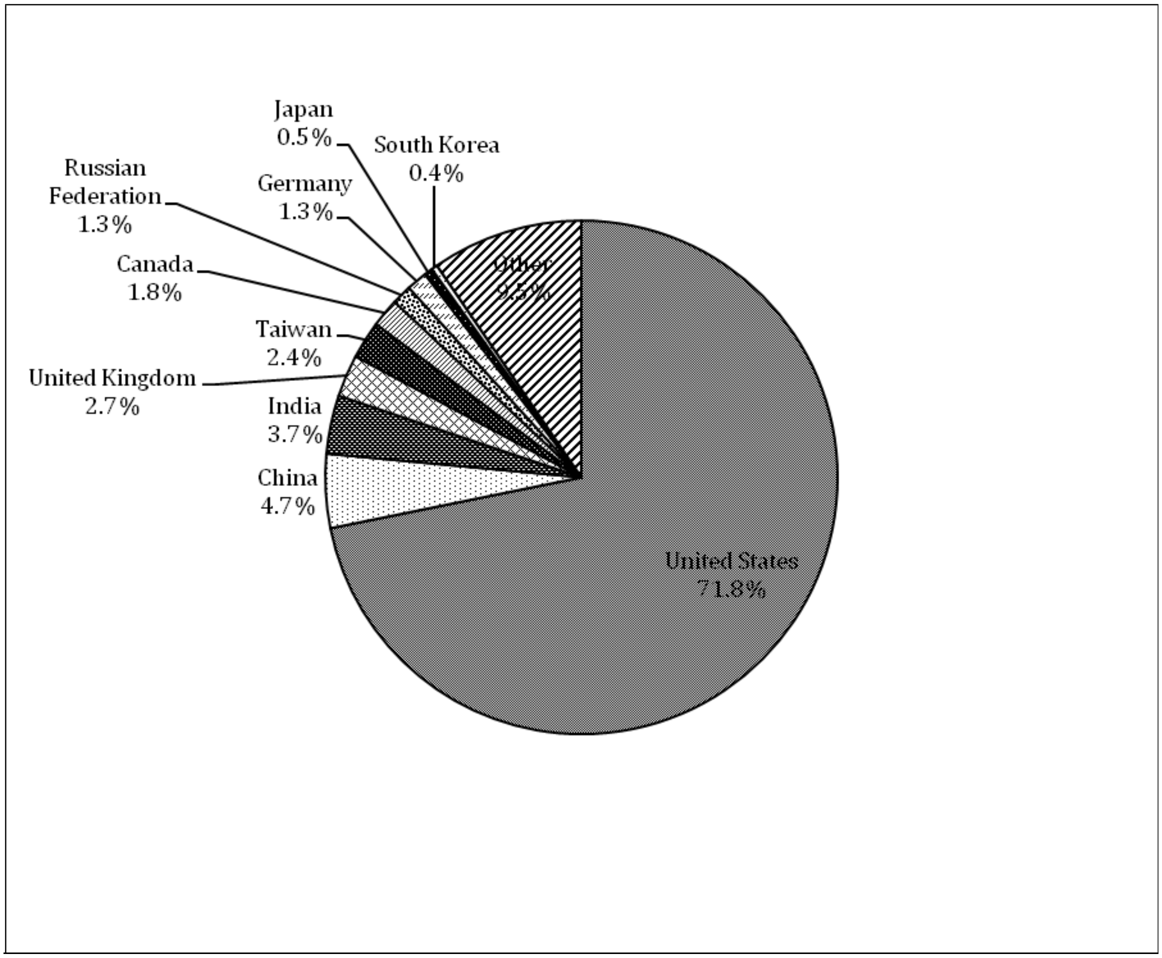


Figure 12. Inventor Mobility, US and Japan, common technology weights.

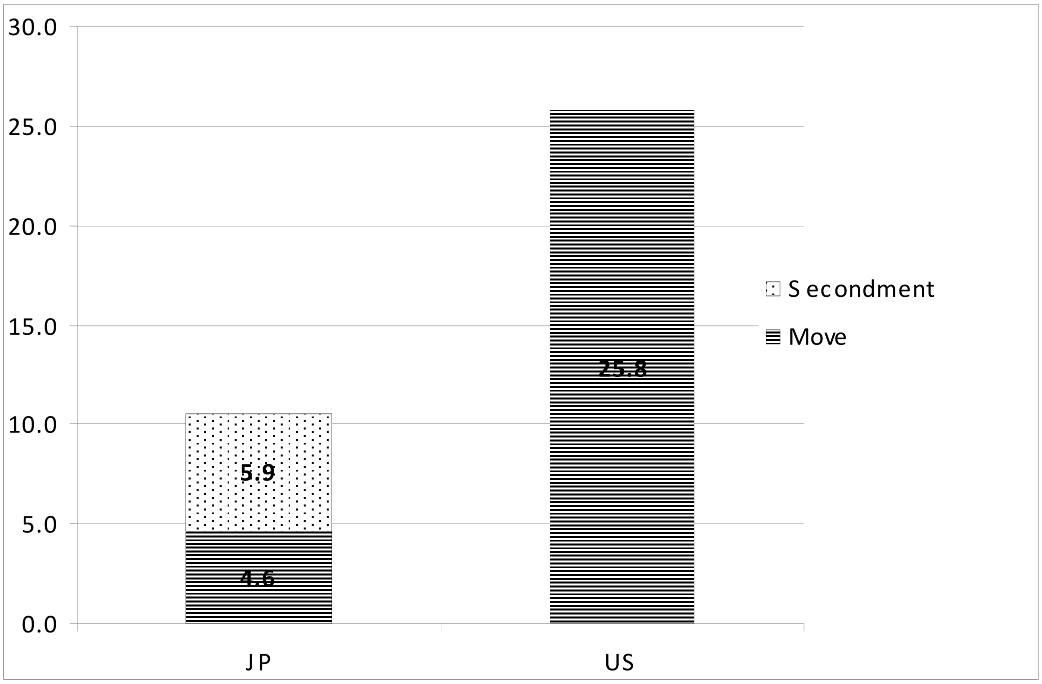


Figure 13. Inventor Mobility, by firm size, US and Japan.

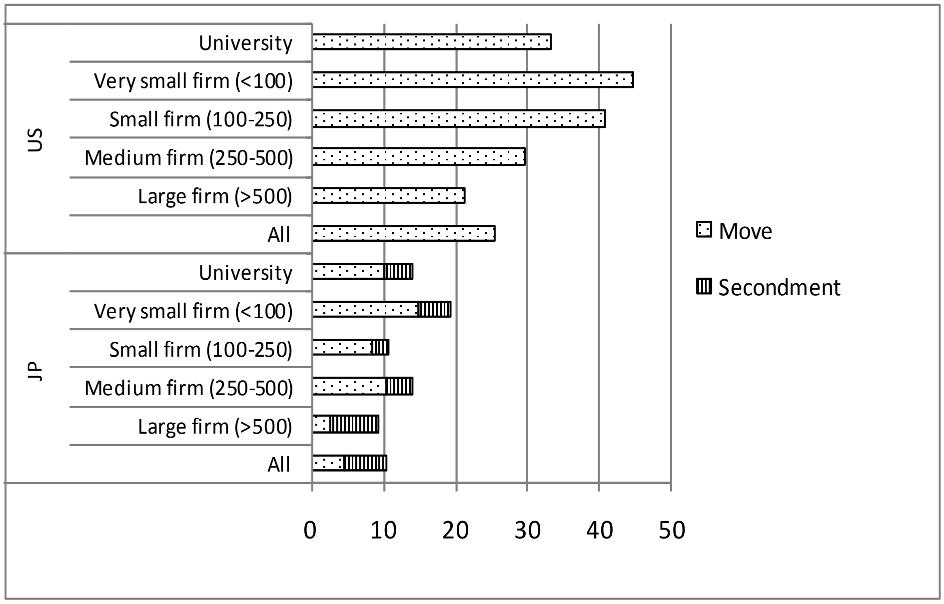
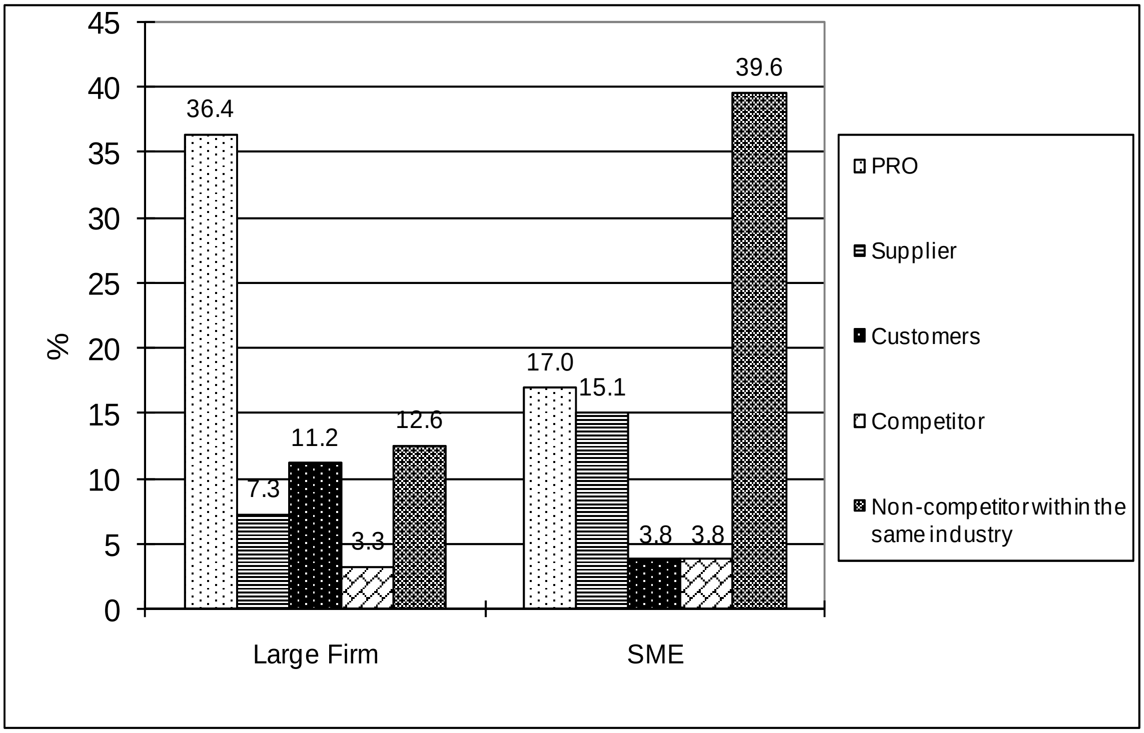
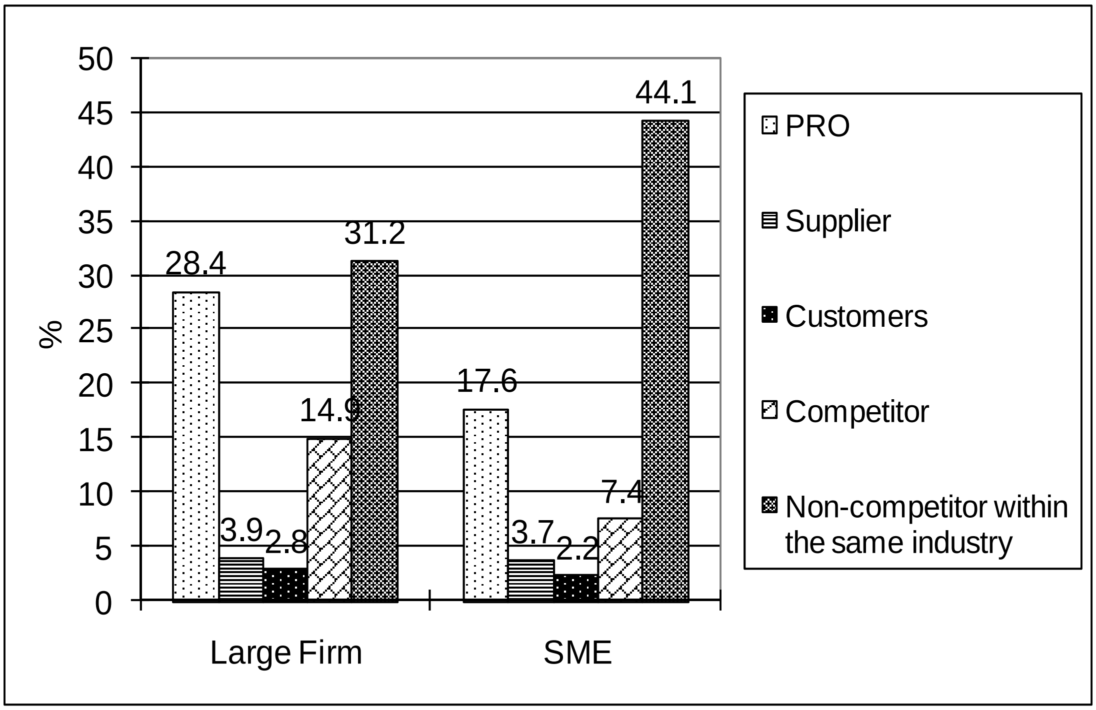


Figure 14A. Mobility from-to, Japan.



Note: “Other” excluded. Others include the secondment to related firms in Japan.

Figure 14B. Mobility from-to, US



Note: "Other" excluded.

Figure 15. Inventor Mobility, PhD v. not, US and Japan, common technology weights.

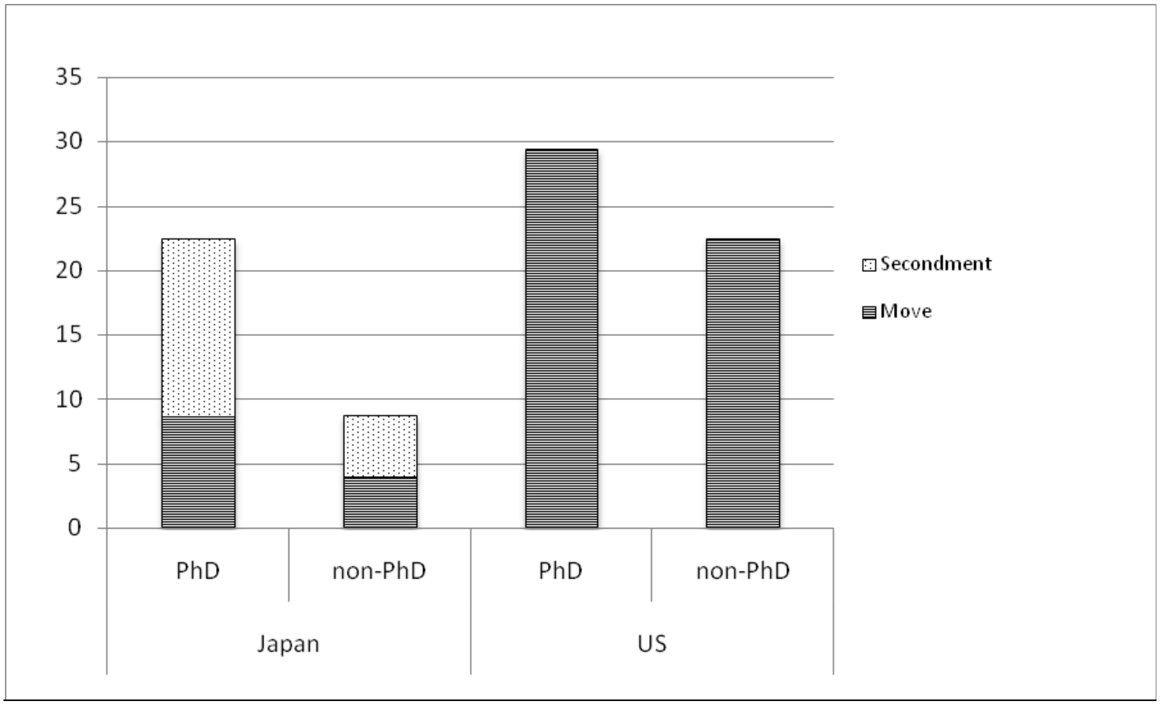


Figure 16. Mobility by age, Japan and US, common technology weights.

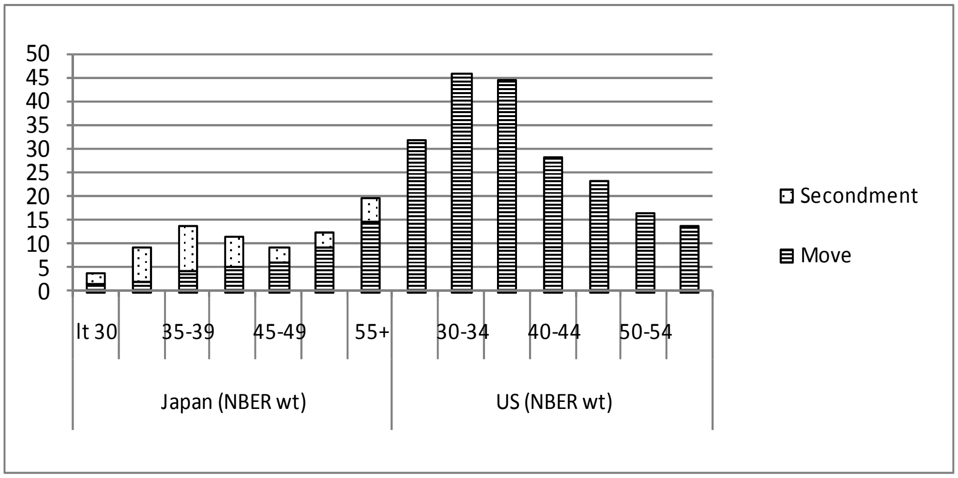


Figure 17. Percent of inventors over age 55, by organizational affiliation, US and Japan.

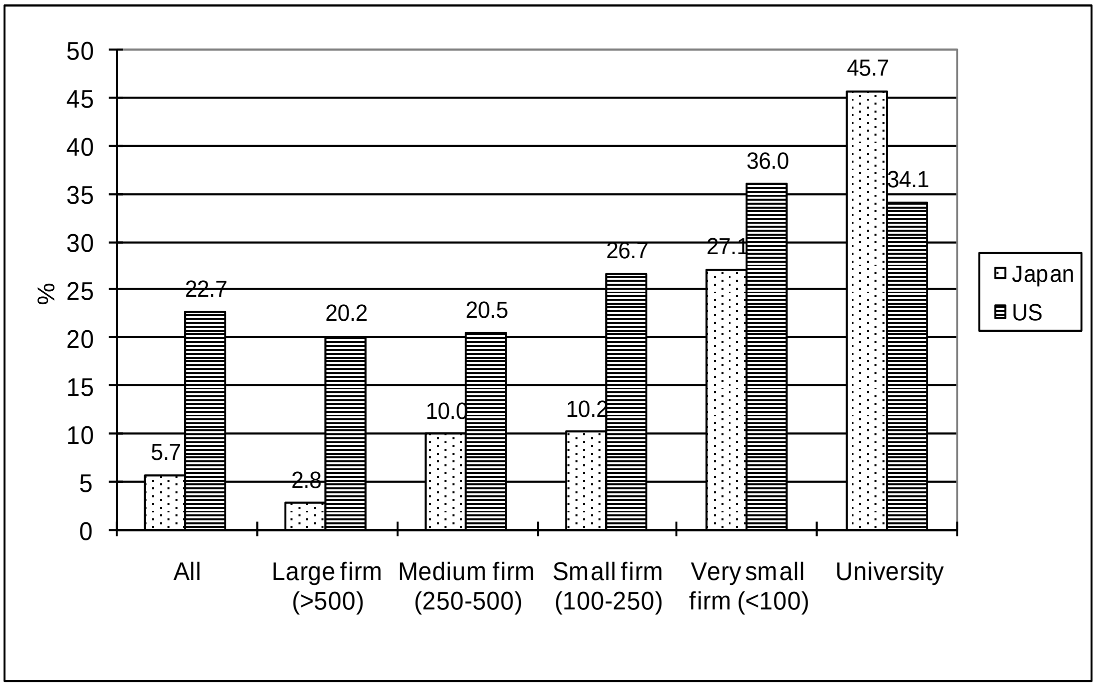


Figure 18A. Mobility and Information Flows (suggest new projects), Japanese Respondents.

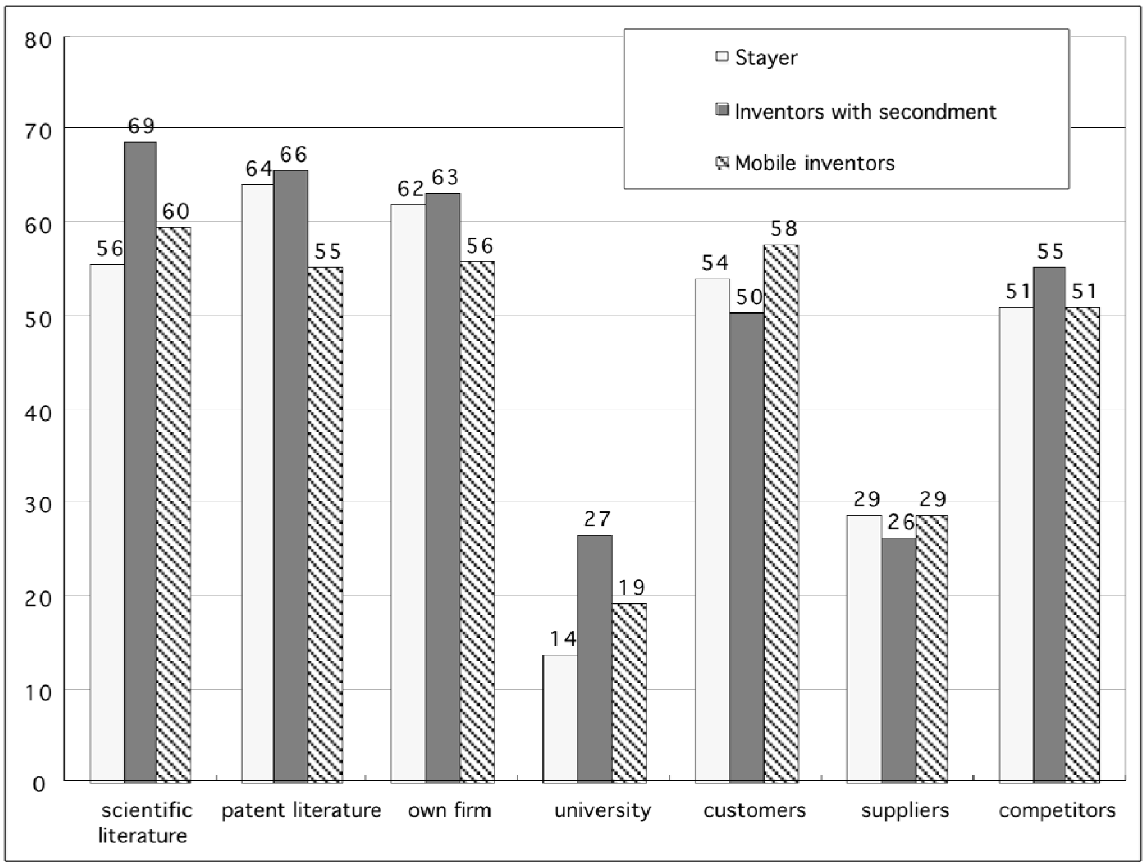


Figure 18B. Mobility and Information Flows, US Respondents.

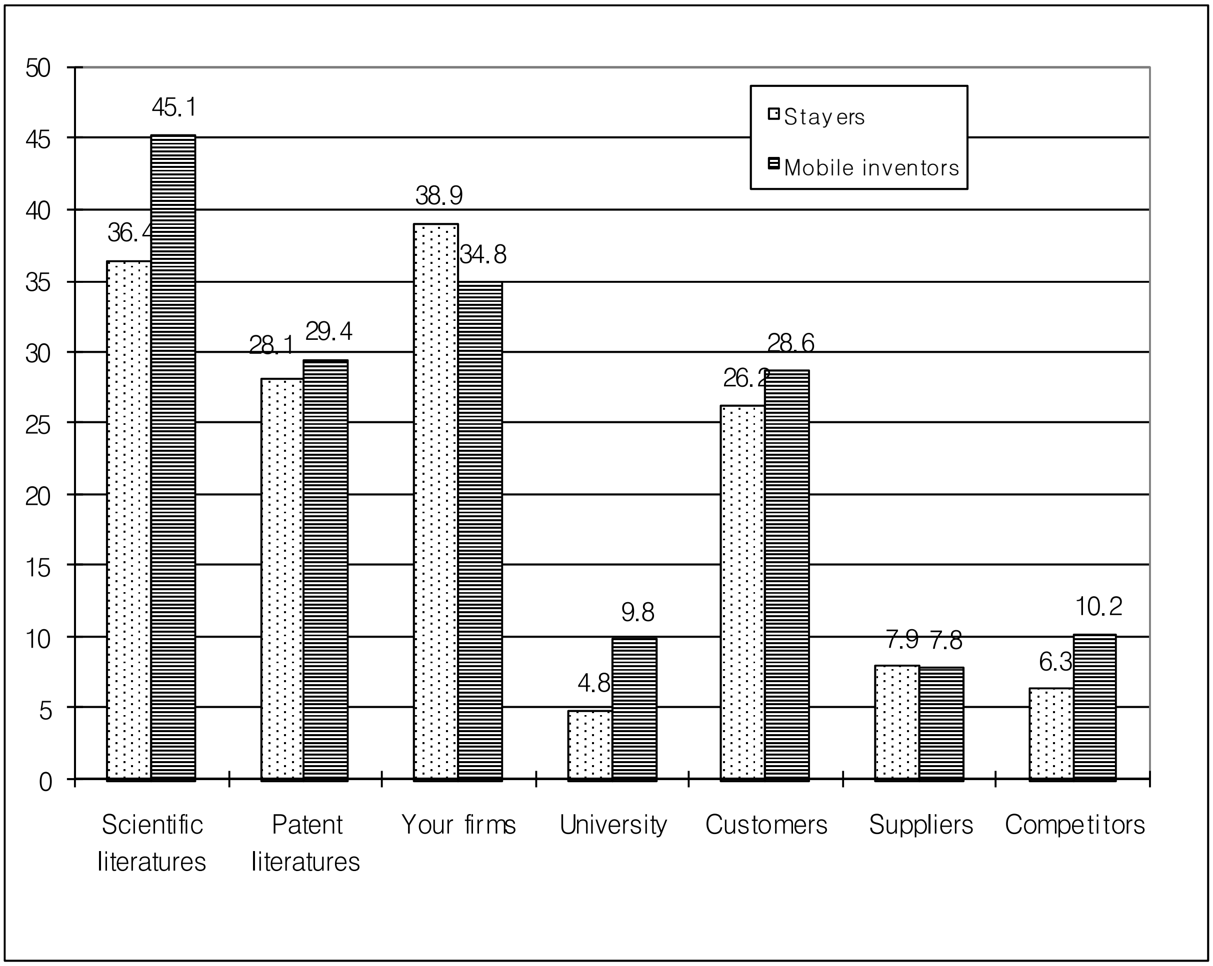


Figure 19. Inventor Functional Affiliation, common technology weights.

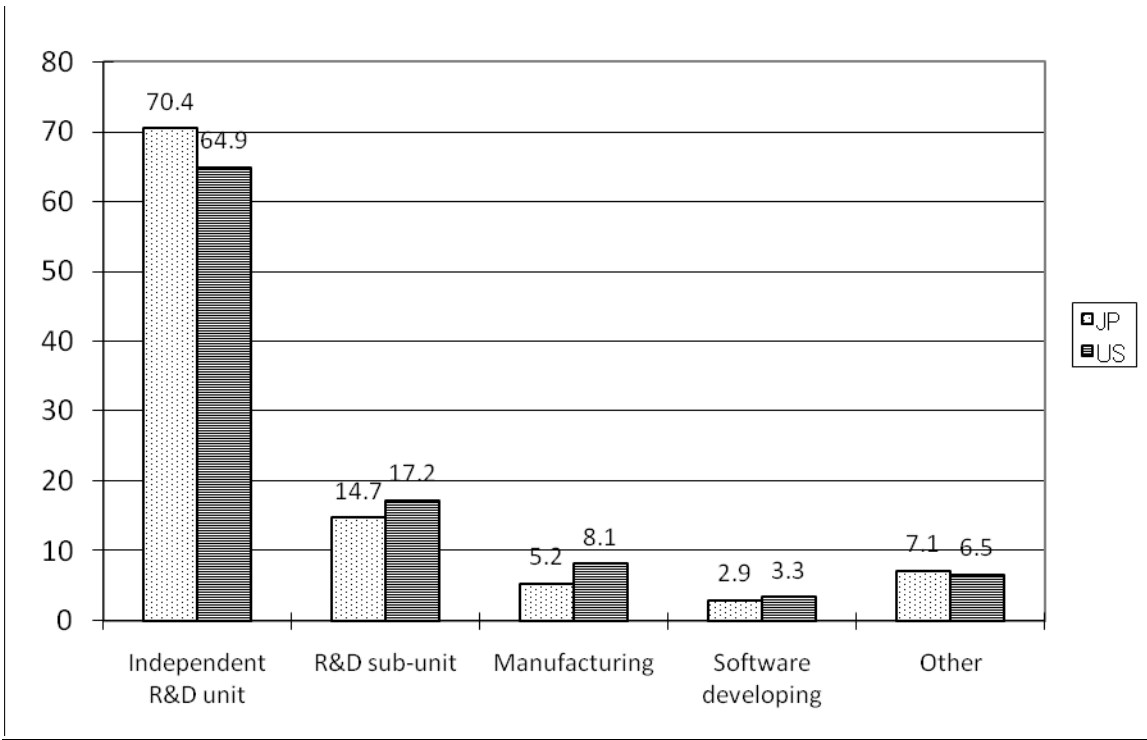


Figure 20. Inventor Functional Affiliation, by Firm Size, US and Japan.

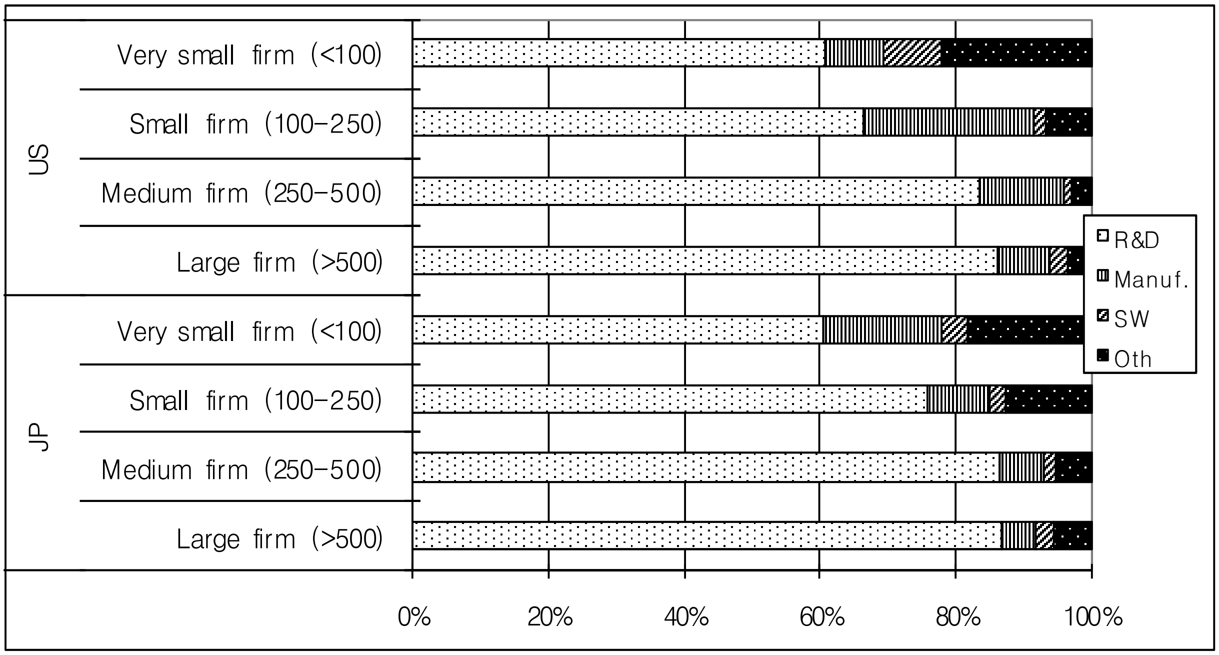


Figure 21. Inventor Motivations, US and Japan, common technology weights.

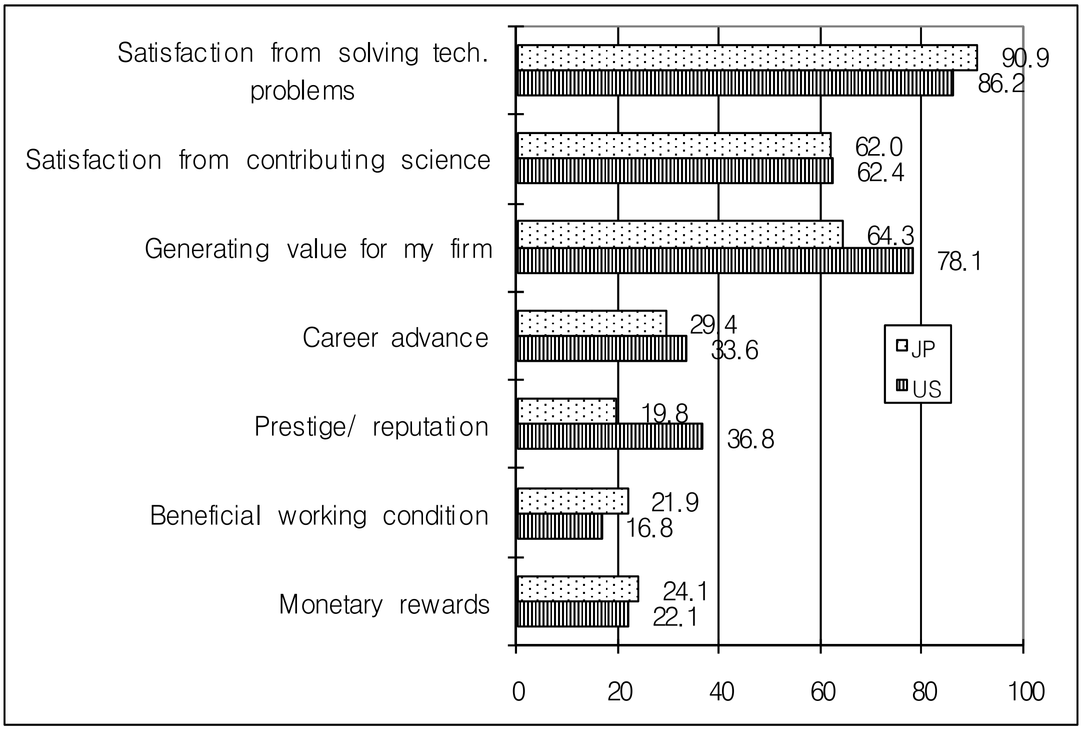
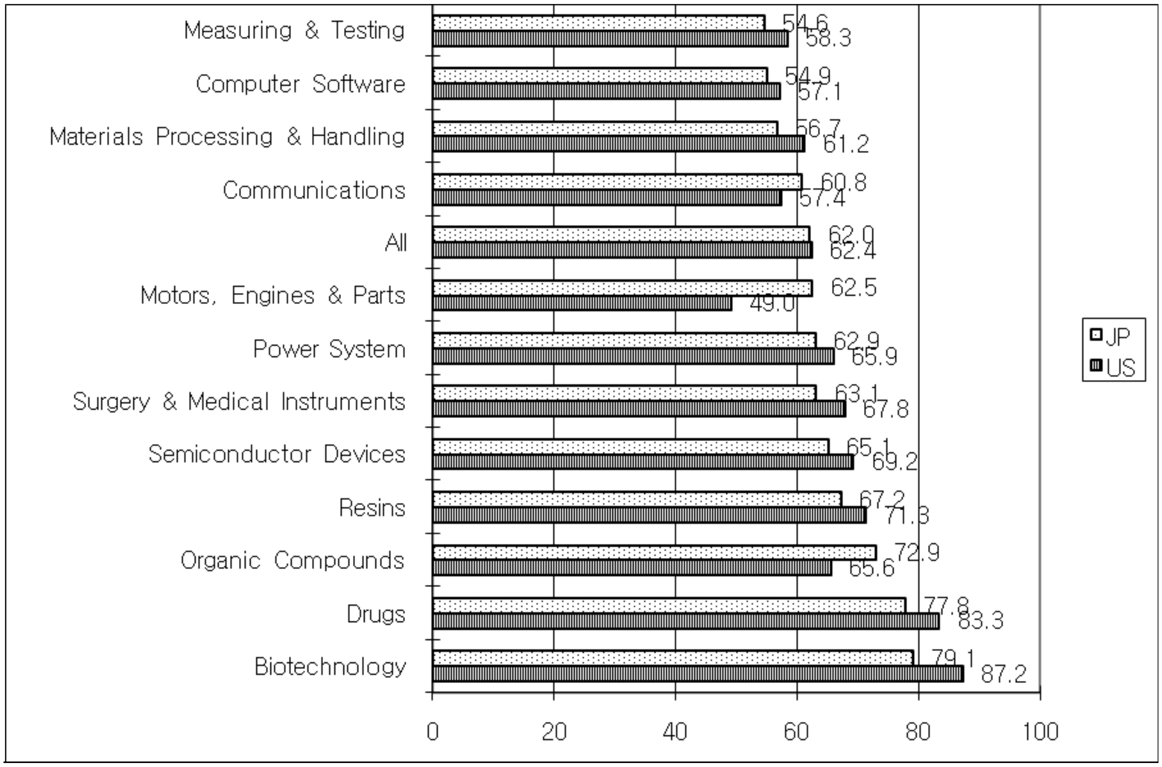


Figure 22. Inventor Motivation, Contributing to Science, US and Japan, by sector.



Note: “All” includes common technology weights.

Figure 23. Inventor Motivation, Contributing to Science, US and Japan, by firm size.

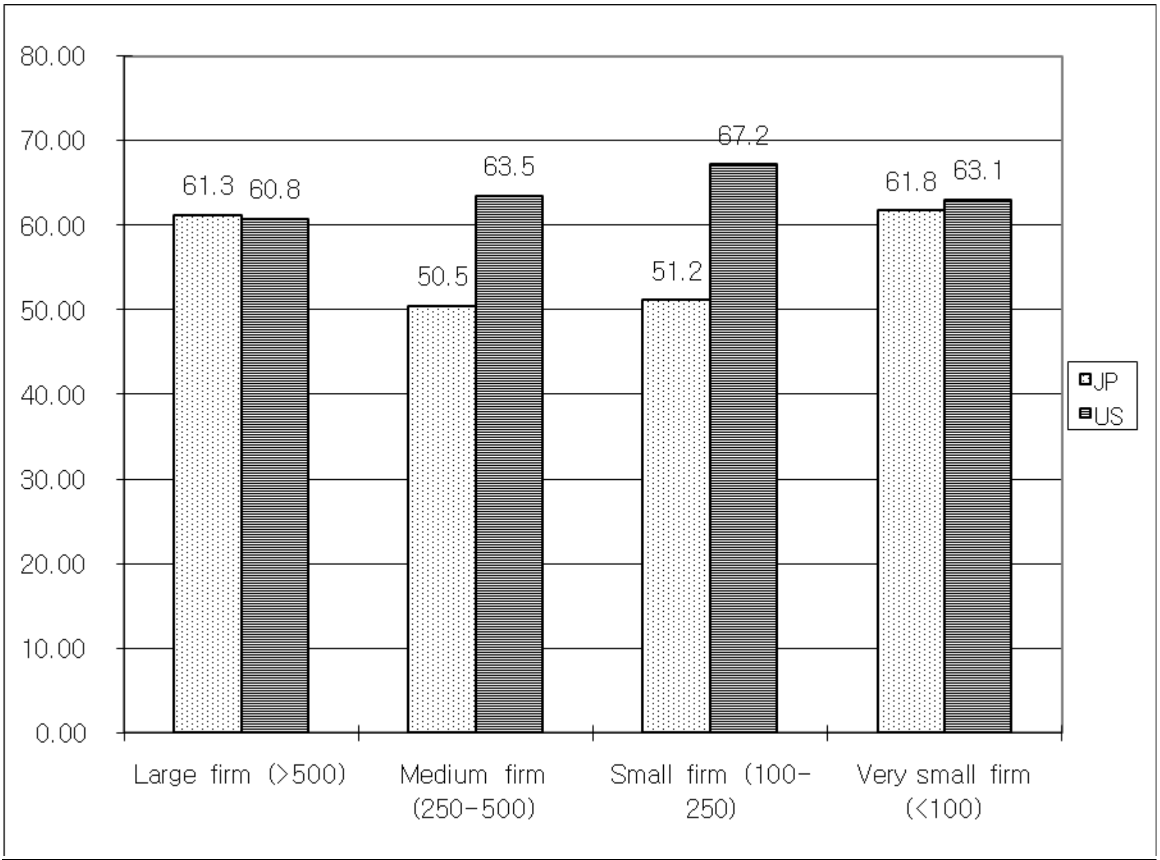


Figure 24. Inventor Motivation, Improving Firm Performance, by Firm Size, US and Japan

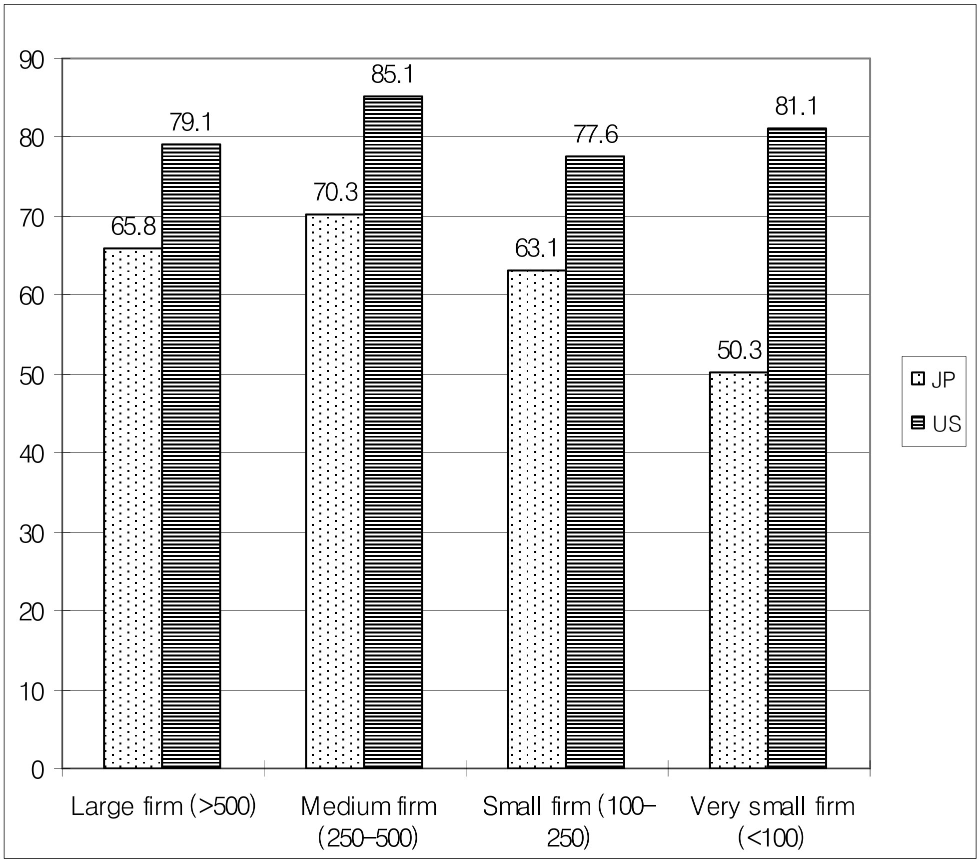


Figure 25A. Inventor motivations by mobility, Japan, common technology weights.

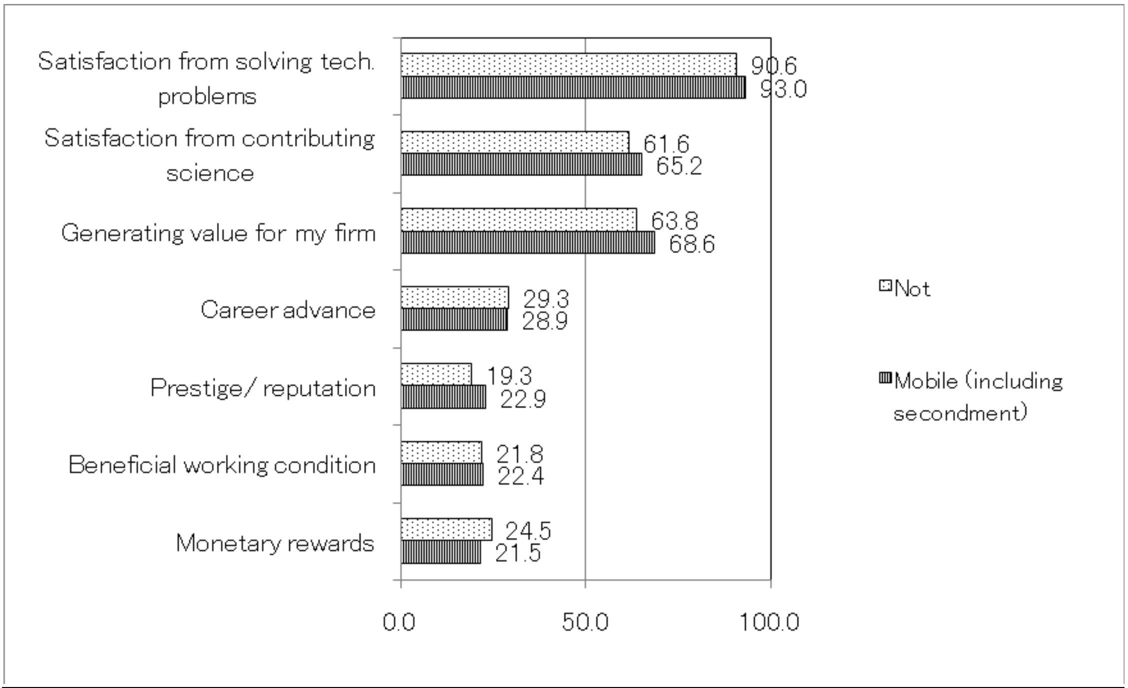


Figure 25B. Inventor motivations by mobility, US, common technology weights.

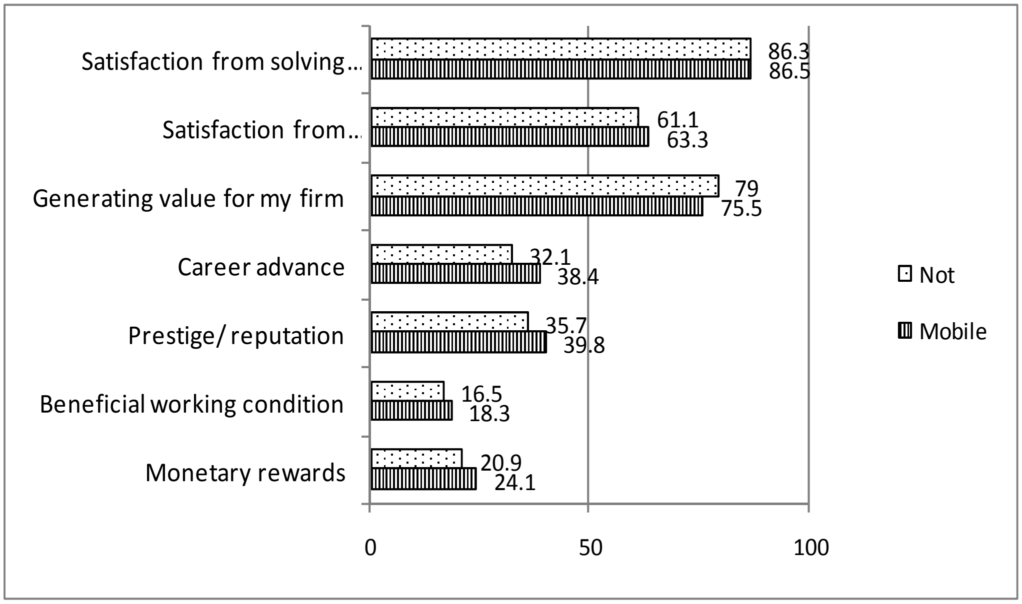


Figure 26A. Inventor motivations by work unit, Japan, common technology weights.

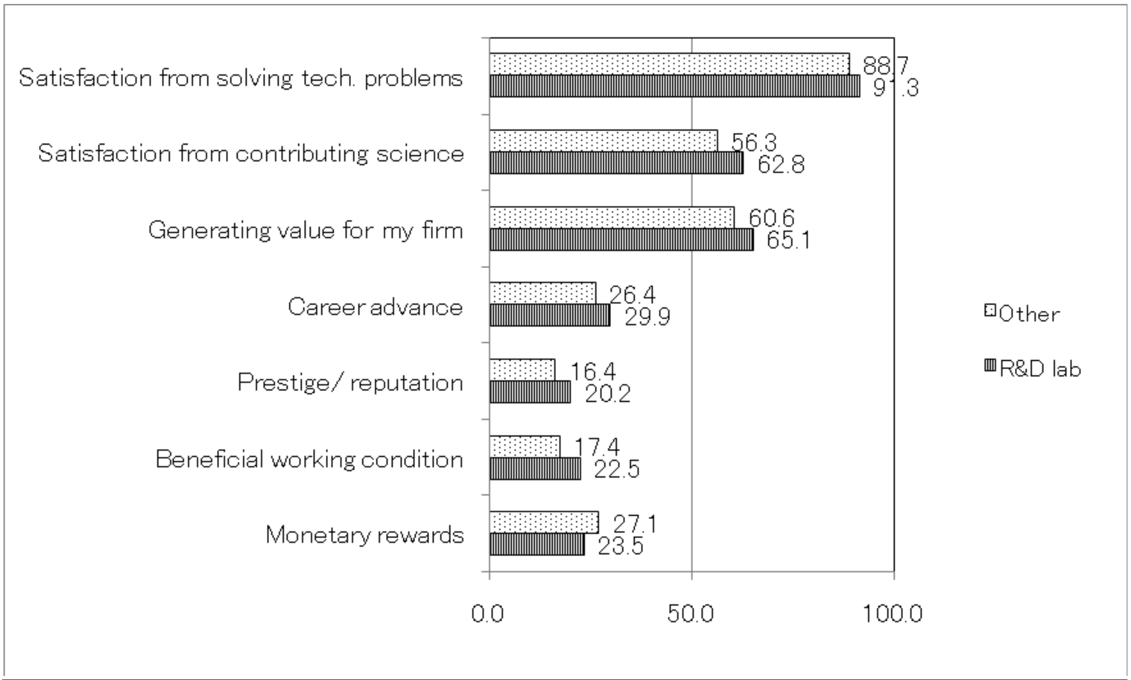


Figure 26A. Inventor motivations by work unit, US, common technology weights.

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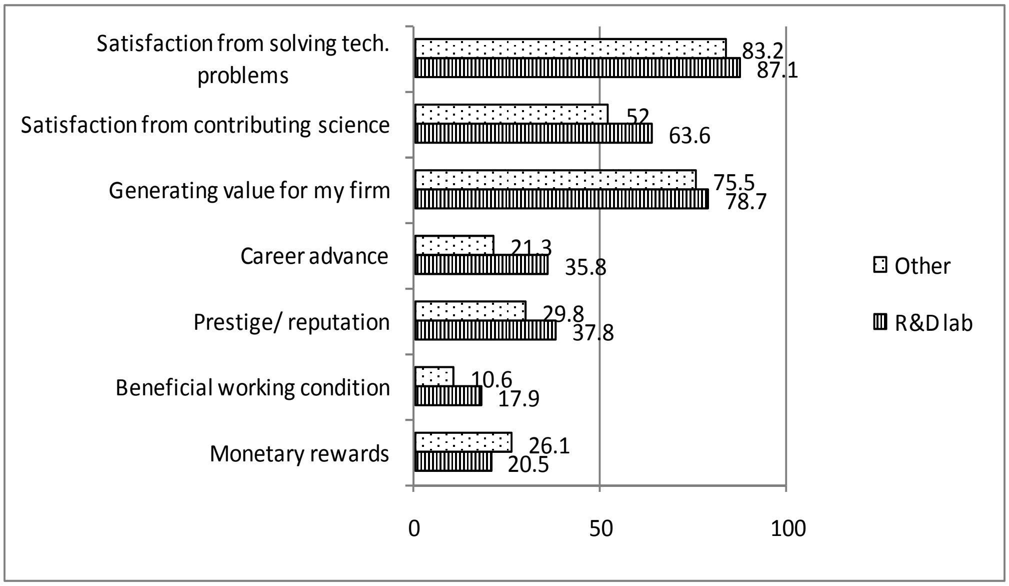

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