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The R&D process in the US and Japan: Major findings from the RIETI-Georgia Tech inventor survey

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The R&D process in the US and Japan: Major findings from the RIETI-Georgia Tech inventor survey[1]

Summary

This paper analyzes and compares the objective, the nature and the performance of R&D projects in the US and Japan, based on the first large scale systematic survey of inventors, focusing on the R&D projects yielding triadic patents. Major findings are the following. First, the projects for enhancing the existing business line of a firm account for a large share of R&D projects in both countries, confirming the view that the R&D investment is significantly conditioned by the existing complementary asset of a firm. In both countries, the inventions from R&D for existing business have the highest in-house utilization rate but use least the scientific and technical literature for their conceptions, while the reverse is the case for the inventions from R&D for new technology base (or for cultivating seeds). R&D projects for enhancing the technology base are much more common in the US. This difference can be partly accounted for by US inventors being more likely to have a PhD, but not by the differences in the structure of finance. US government financial support is relatively more targeted to projects for existing business and US venture capital provides support mainly projects for creating new business (6% of them), but not for more upstream projects.

Only about 20-30% of the projects are for process innovation in both countries, providing direct evidence for the earlier findings that were based on US patent information. Product innovation generates process patents more often in Japan than in the US (25% vs. 10%), while product innovation projects are relatively more numerous in Japan. In both countries a significant share of inventions (more than 20%) were not the result of an R&D project, and a substantial proportion of such inventions are valued among the top 10% of patents, suggesting that R&D expenditure significantly underestimates inventive activities. A US invention is more often an unexpected by-product of an R&D project (11%) than in Japan (3.4%). The two countries have surprisingly similar distributions of R&D projects in man month and the average team size. In both countries, smaller firms tend to have relatively more high-value patents. In the US, inventors from very small firms (with less than 100 employees) and universities jointly account for more than one quarter of the top 10% inventions, even though they account for only 14% of all inventions.

Man-months expended for an invention has a significant correlation with the performance of the R&D projects for existing business, less so for new business and not at all for those enhancing the technology base,

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suggesting substantial heterogeneity by project types in the determinants of the performance and in the uncertainty. A PhD has a significant correlation with R&D project performance especially for new business.

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1. **Introduction**

R&D projects are heterogeneous in many respects. A project may aim at enhancing the existing business line or for creating a new business. It may be for product innovation or for process innovation, and the invention may be an expected outcome or an unexpected outcome. Thus, understanding the sources of such heterogeneity as well as the consequences would be very important to understand the R&D process and the determinants of R&D performance. This paper gives an account of such heterogeneity of the R&D projects in Japan and the USA as well as the commonalities and differences between the two countries, based on the project level information made available from the RIETI-Georgia Tech inventor surveys, focusing on the OECD patent families (triadic patents, hereafter, see Appendix for the key aspects of the survey method). This is the first systematic patent-based survey of R&D projects in both countries.

Our sampling is based on the triadic patents and the questions were asked about the R&D project which yielded the (basic) patent with the earliest priority year in the randomly selected patent family (see Appendix 1 for details on the survey methodology)[2]. Thus, an R&D project that yielded a greater number of patent families is more likely to be surveyed. However, at the same time, such R&D would be economically more important. In particular, if the importance of an R&D project, such as its size, can be measured by the number of patent families generated from it, then the simple average of R&D project characteristics based on the randomly selected OECD patent families, as in this paper, would give us the average of these characteristics with the weights based on the importance of the R&D projects.

In the following section 2, we discuss the distribution of R&D projects by business objective. We then discuss the nature of projects, focusing on product vs. process innovation as well as the invention process in section 3.We analyze the distribution of the time and inventors

[2] While our sample can have a bias for more productive R&D projects, the supplementary survey results for non-triadic patents in Japan produces substantially similar results as those for triadic patents in Japan.

input for projects in section 4 and the project performance in section 5. Section 6 concludes, with a discussion of the implications.

2. **Business objectives of R&D**

The research objective is a key variable for us to understand the R&D process and its performance. We asked inventors to identify the business objective of the research, from which the patent family (*patent*, hereafter) was generated, which is one of the novel aspects in our inventor survey, relative to the PatVal-EU survey (Giuri, Mariani et at (2007))). There are three basic business objectives defined in our survey: *the enhancement of existing business line*, *creating a new business line* and *the enhancement of the technology base of the firm* or *the long-term cultivation of technology seeds, not directly associated with a business line*("enhancement of the technology base" for brevity hereafter).

As shown in Figure 1, the projects for enhancing the existing business line of a firm account for a very large share of R&D projects in both countries (roughly 70% in Japan and 50% in the USA)[3]. Although this figure covers all inventions, including those by inventors not affiliated with firms, inventions by those affiliated with firms accounted for more than 95% in both countries (we will see the results by organization type later in Figure 3). The result is consistent with the view that R&D investment is significantly conditioned by the existing business line of a firm, that is, its manufacturing, sales and technology assets complementary to the R&D (see Cohen (1995) and Cohen and Klepper (1996)). R&D for enhancing the existing business of a firm is significantly more common in Japan (66% in Japan vs. 48% in the US). On the other hand, R&D projects for enhancing the technology base (or for cultivating seeds) is much more common in US (24% in the US vs. 8% in Japan). In both countries R&D for

[3] The figures for overall means for cross-country comparison, including this figure, adjust fully the technology composition difference between the US and Japan, based on the common technology class weights (see Appendix 1).

creating a new business line accounts for roughly 20% of the R&D projects. The higher share of R&D projects for enhancing technology base in US is across all technology areas, but especially in semiconductors, information storage, computer software, and optics. As seen in Figure 2, in both countries, the larger is the scientific and technological opportunities of the sector, as measured by the importance of scientific and technical literature in conception of the invention, the more R&D in that sector is oriented to enhancing the technology base, although the response is significantly stronger in the US than in Japan. In both countries, the biotechnology area has the highest incidence of having the enhancement of the technology base as the objective of research.

(Figure 1 and 2)

There is an inverted U-shape relationship between firm size and the share of R&D projects for the enhancement of the exiting business in both countries, as shown in Figure 3. Such share is the smallest for very small firms[4] and increases with firm size but then declines. Less than 30% of the R&D projects of the very small firms in the US are for the existing business, while 45% are for creating new business. The very small firms might not have an established existing business, so that the R&D opportunities enhancing the existing business would be limited and they would spend more for the R&D projects oriented to creating new business. The focus on creating new business is especially strong (45% of the projects) for the very small US firms presumably because many of them (25%) are startups (less than 5 years old). Among US startups, 62% of the projects are for creating new business. On the other hand, the profitability of the R&D for existing business would decline as those businesses mature.

[4] The border lines between large, medium, small and very small firms are 500, 250 and 100.More specifically, very small firm: employment with 100 or less (less than 100 in the US), small firm: employment with 101-250 (100-250 in the US), medium firm: employment with 251-500 (250-500 in the US), and a large firm: employment with 500 or more (with 501 or more in the US).

This might explain why a large firm spends a higher share of R&D resources for creating new business, relative to small and medium size firms.

(Figure 3)

In the rest of this section, we will examine the sources of the difference of the composition of R&D projects between the US and Japan, in particular, the finding of a larger share of R&D projects for enhancing the technology base in the US. Human capital and the structure of R&D finance are two of the potential sources of the differences, since a firm with stronger human capital base as measured by PhD training may be able to absorb more scientific opportunities for an invention, and the government and venture finance may play substantially different roles in the US, compared to Japan. The share of inventors with PhDs is significantly smaller in Japan (12% in Japan and 45% in USA). As shown in Figure 4, compared to projects for enhancing the existing business, R&D projects for enhancing the technology base (or for cultivating seeds) are significantly more likely to have PhDs as inventors and to use the knowledge embodied in the scientific and technical literature in both countries, especially in Japan. Since the capability to absorb scientific knowledge is especially important in R&D for strengthening the technology base, a smaller share of the inventors with PhDs in Japan is likely to constrain Japanese firms to pursue more R&D projects for enhancing the technology base. The results show that scientific and technical literature is also important for projects targeted to creating new businesses, suggesting that access to such information may also be important for R&D targeted to new business. In fact, in Japan, these projects rank scientific publications higher than do those involved in enhancing the technology base (while the reverse in true in the US), suggesting that the scientific and technical literature may play a different role in the two countries.

(Figure 4)

Differences in the financing of R&D does not seem to contribute to explaining a larger share of R&D projects for enhancing the technology base in the US. As shown in Figure 5, a significant share of the R&D projects for new business and for the technology base of the firm receives at least some government support in both countries, but the US assistance is relatively more oriented to the R&D for the existing business lines, compared with the support of the Japanese government. That is, the incidence of the government support is 11% of the projects for enhancing the technology base in Japan and 8% in the US, while it is 1.7% for the existing business line in Japan and 3.9% in the US[5]. Thus, the government assistance pattern does not seem to contribute to explaining the above difference. Venture capital and angels support a large share for R&Ds creating a new business line in the US (6.1% of the R&D projects), although only 1.9% of those for enhancing the technology base. In Japan, very few projects of any type received venture capital funding. Thus, while venture capital funding is more common in the US, it is largely targeted to projects for creating new lines of business. Therefore, more availability of venture capital (and angel) money does not explain the large US share of R&D projects for enhancing the technology base.

(Figure 5)

3. Nature of projects

3.1 Product vs. process innovation

Another key variable characterizing the nature of R&D projects is the distinction of product vs. process innovation. We asked two questions: first, the technological goal of the R&D project itself (product development vs. process development) and secondly the type of invention (product patent vs. process patent). Note that product patent (process patent) may be generated from a R&D project for process development (product development). Note, also, that the same

[5] The average finance share of the government (or venture capital) gives the essentially the same results.

invention of machinery or materials can be characterized as the output of product innovation when it is done by a capital goods producer or a material supplier and as the output of process innovation if it is done by a firm using these products in its production process.[6] A systematic survey on the incidence of product and process innovation at the project level does not exist to the best of our knowledge (there is, however, a closely related study by Scherer (1982), based on patent information to identify the use of the patent). We classify the technological goal of a R&D project into the following five categories: *new product development, its improvement, new process development, its improvement* and *others*. "*Others*" include the development of new use of the existing products and the development of new measurement technology.

As shown in Figure 6, product innovation is substantially more important than process innovation in both countries. Only about 20% of the R&D projects are for process innovation (25% in the US and 17% in Japan).[7] This is consistent with the share of process innovations (29.7%) estimated by Link (1982) based on the survey of the R&D expenditure structure and the share of process patents[8] (26.2%) estimated by Scherer (1984) based on patent counts and the share of process R&D (27.9 %) estimated by Cohen and Klepper (1996), using the Scherer's patent data. In both countries, product innovation is important for R&D projects in such technology areas as drugs and computer peripherals, and least important in biotechnology and metal working. In addition, a higher percentage of Japanese projects are focused on creating new products than in the US (62% v. 46%). In both countries an improvement is relatively more important for process innovations than for product innovation. An improvement is as frequent

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[6] We would like to thank Richard Nelson for this point.

[7] Note, however, that the process innovation may be under-reported in our survey, since the inventions from such innovations may be less likely to be patented than those from product innovation, given that secrecy is likely to be often more effective for protecting process innovations.

[8] Scherer distinguished process patents from product patents by assuming that the former are those that are employed in their industry of origin.

as a new development for process innovation, which may indicate a more cumulative nature for process innovation, which is significantly conditioned by the equipments and materials used for the production process (see Cohen and Klepper (1996)).

(Figure 6)

Figure 7 shows the product and process composition of the R&D projects by firm size. Cohen and Klepper (1996) hypothesize that the fraction of R&D a firm devotes to process R&D will rise with the ex ante output of the firm, based on the premise that process innovations are less saleable in disembodied form and spawn less growth, and they present evidence consistent with this view. The combined share of R&D projects for new process development and for process improvement increases with firm size (22% for very small firm to 30% for medium size firm) except for the comparison between large and medium size firms in the US, partially consistent with their finding. Such a relationship does not hold for Japan. The combined share of the R&D projects for process innovation declines monotonically with firm size (23 % for very small firm and 17% for large firm). Thus, in both countries, both large firms and very small firms devote most of their R&D resources to creating new products, casting some doubt on the underlying assumptions of Cohen and Klepper (1996).[9]

(Figure 7)

One of the novel aspects of our survey was to ask an inventor to identify whether the patent is a product patent, process patent or both (that is, the patent has both product and process claims). To the best of our knowledge there is no systematic empirical study on this issue. It is important to note that process innovation can generate a product patent: for example, a chemical firm might invent a catalyst (product) for improving the yield of a chemical process. Similarly,

[9] A new product development may be often just an incremental quality improvement from the perspective of consumers. In this case, product development is similarly conditioned by the complementary assets of the firm.

product innovation can generate a process patent: for an example, a capital goods producer inventing a new process that was embodied in a new machinery for sale. In both countries pure product patents are most numerous (44% in Japan and 50% in the US), as shown in Figure 8. In addition, 25% of the patents have both product and process claims in Japan (29% in the US). There is, however, a major difference in the incidence of process patents from product innovation. While one quarter of product innovation results in pure process patents in Japan, only 10% of product innovations results in pure process patents in the US (see 9A, 9B). The gap is especially large for computer software inventions, where 70% of the R&D projects aim at product innovation and 70% of the patents from the R&D projects have product claims in the US, while more than 80% of the R&D projects aim at product innovation, but only 40% of the patents from these R&D projects have product claims in Japan. This gap in the software industry could be partly due to the fact that a pure software invention could become patentable as a product patent only recently (2002) in Japan. On the other hand process innovations yield product patents at about the same rate in each country (around 20%).

(Figures 8, 9A, 9B)

3.2 Invention process

The invention process, in particular, how an invention is generated in light of the objective of the R&D project, is also critical for us to understand the knowledge production process. Our survey asked an inventor to characterize the process by which the invention was generated, in particular whether R&D was involved or not and whether the invention was the outcome expected ex ante, following the PAT-VAL survey.[10] As shown in Figure 10, in both countries, more than 20% of the inventions were not the result of an R&D project. 11% of the inventions

[10] One important aspect which this paper does not address is collaboration. Please refer to Walsh and Nagaoka (2008).

in Japan and 14% of the inventions in the US involved no R&D.[11] These inventions would not have needed the patent protection for its generation, even though patents may have played a role for their disclosure and commercialization. In addition, 11% of the inventions in both countries did not depend on R&D for its source of idea. These results clearly suggest that the R&D expenditure of a firm underestimates the inventive activities of a firm. In Japan, the share of inventions with no R&D tends to be larger for small and very small firms (15% and 18% respectively), suggesting a significant underestimation of inventive activities of small firms based on their R&D expenditures, consistent with the finding by Kleinknecht (1987). The firm size difference, however, is not so significant in the US, suggesting that the invention process is formalized as R&D in small and very small firms as much as in large firms in the US. Half of the patented inventions are the targeted outcome of R&D in both countries. In addition, 23% of the patents are the expected by-product of R&D in Japan, while the corresponding rate is 12% in the US. On the other hand, in the US, 12% of the patents are an unexpected outcome of a research project, while the corresponding share is 3.5% in Japan. If we measure the degree of uncertainty of an R&D project by the following index:

Uncertainty index= unexpected by-product/(targeted achievement + expected product) (1),

the corresponding ratios are 0.048 for Japan and 0.19 for the US. A US firm seems to face much larger uncertainty in R&D.

(Figure 10)

The business objective of the R&D significantly affects the invention process, as shown in Figure 11A in the case of Japan. In Japan, exploratory R&D for enhancing the technology base of a firm involves more uncertainty, so that the above measure of uncertainty is much larger for such R&D (0.15 for the R&D oriented to the technology base vs. 0.04 for the

[11] Note that our sample consists of the basic patents of the OECD patent families, so that continuations are unlikely to be the reason for inventions without R&D in our sample.

R&D oriented to the existing business). Thus, one contributing factor to the relatively low unexpected byproduct inventions in Japan is the lower share of the R&D projects for new technology base in Japan. On the other hand, in the US, the difference in uncertainty is much lower across project types, with an uncertainty index of 0.20 for enhancing the technology base and 0.18 for projects linked to existing business. Another important observation is that, in both countries, inventions which were not generated by an R&D project account for a larger share of inventions targeted toward existing business than from those for new business. This would not be surprising, given that more non-R&D personnel are involved in the existing business in terms of production and sales and they could be a major source of ideas and even inventions useful for improving the technology used in the exiting business. Surprisingly, 20% of the inventions for enhancing technology base in Japan and 16% in the US do not involve R&D at all.

(Figure 11A, 11B)

The technical objective of R&D in terms of product vs. process innovation as well as new development vs. improvement also would affect the invention process. In both countries, the incidence of inventions that did not start with an R&D project is substantially higher for improvement-oriented R&D in both process and product innovation, while the incidence of targeted achievement is the lowest for such invention. Thus, inventions associated with non-R&D tasks play an important role for in improvements to existing products or processes. In Japan, an unexpected invention is most frequently observed for the R&D project for process innovation as shown in Figure 12A (although we do not see this difference in the US, see Figure 12B).

(Figures 12A, 12B)

4. Time and inventors required

The time and effort by inventors are the most important inputs to the invention process. Our survey asked how many man-months were required by the research until the application for the focal patent, including those of co-inventors and the other researchers. The two countries have surprisingly similar distributions of the projects in terms of man-month, although slightly more months are required for the Japanese R&D projects. In both countries, around 20 % of the R&D projects leading to the triadic patent inventions require less than 3 man-months, which is not surprising, given that a substantial share of inventions involve no or only a small amount of R&D (see section 3). A relatively small share of the projects accounts for a large share of the total man-months: Projects that require more than 49 man-months (around 10 % of all projects) account for at least 50% of the total R&D man-months.

(Figure 13)

Two countries also have similar average number of co-inventors as shown in Figure 14, with just under 3 inventors on average. In both countries, the average number of co-inventors increases with firm size, indicating that a larger firm has an advantage in pursuing R&D projects that require a larger research team. Figure 15 also shows the distribution of calendar years for the R&D projects. Here the calendar time required is significantly shorter in the US: more than a half of the inventions in the US require less than one calendar year from the initiation of the research to its application for the patent but only 20% of the inventions fall into this category in Japan[12]. Longer calendar time for the identical total man months and the identical number of inventors for a project would imply that Japanese inventors work more for

[12] The results are not consistent with Clark, Chew, and Fujimoto (1987) who found that the Japanese auto industry was more capable of rapid product development, due to supplier involvement, multifunctional teams, and overlapping product development stages. However, invention is only one component of product development.

multiple projects simultaneously. In both countries, the share of projects requiring 5 years or more is small (11% in Japan and 6% in the US). Compared to the estimated share of R&D projects lasting five or more years by Mansfield (1981) (32%), our results involve significantly smaller share for long-term projects. This would be surprising for the following two reasons. Our survey measures the length of the R&D project until the application of the patent under the survey and it covers more comprehensively the projects, including non-R&D projects, since the sampling is based on patents.

(Figure 14,15)

5. Project performance

The basic performance measures of an R&D project we can use are the number of patents and their values. Our surveys asked the inventors to evaluate the relative economic value of his invention in the respective technology field by four ranks (top 10%, top 25%, top half and the bottom half).[13] We asked respondents to rank their invention compared to others in their domestic market, and world-wide. Because the answers tended to be very similar, and because we have somewhat more confidence in the inventor's ability to evaluate his invention compared to others in his own country, we will use the economic value in the domestic market. Being a subjective measure, it is likely to have an upward bias. However, in both countries, the proportion of the inventions that the inventors ranked in the top 10% is close to 10% (11% in Japan and 12% in the US), as shown in Figure 16A and 16B. In addition, there is a positive correlation between the economic value (rank variable) and bibliographic indicators, especially with the frequency of forward citations by others' patents,[14] as seen in Tables 1A and 1B. In Japan, a patent belonging to the top 10% is, on average, cited twice as often as a patent

[13] In the US, we also asked for the relative technological significance of the invention, using the same scale.
[14] This variable for Japan is the number of citations to the invention made by other inventors in their description of their inventions.

belonging to the bottom 50%. In the US, the top 10% of patents are cited about 30% more often than those in the bottom half. In addition, the higher valued patent application is more likely to be granted a patent from the Japan patent office (43% for top 10% inventions vs. 35% for the bottom half inventions).

(Figure 16A and 16B, Table 1)

If we look at the value distribution of the patents by organization type, the distribution shifts downward with firm size, as shown in Figure 16A and 16B. While large firms report that 10% of their inventions belong to the top 10% in both countries, very small firms report that more than 20% of their inventions belong to the top 10% in each country. As pointed out by Cohen and Klepper (1994), the apparent negative effect of firm size on the value of the invention can simply represent a higher patenting propensity in larger firms, which is based on the advantage of a large firm in appropriating a return from a given invention or in patent applications and patent enforcement. Significant difference exists between Japan and the US in the inventions by inventors affiliated with universities.[15] In the US, 30% of university-affiliated inventions belong to the top 10%, but in Japan, less than 10% do, similar to the level of the inventors from large firms. Since the top 10% of patents can account for as much as 80% of the total value of the patents, due to the skewed nature of the value of patents (Scherer and Harhoff (2000)), the share of inventions with top 10% value by organizations may give a more accurate assessment of the contribution of each class of organization. Figure 17 shows the distribution of patents with top 10% values, by organization. In the US, the inventors from very small firms and universities jointly account for more than one quarter of high value inventions, even though

[15] Inventors affiliated with university can include those by students in both countries as well as the visiting researchers seconded by the firms in Japan (The seconded inventors account for 11% of them in Japan) .

they account for only 14% of all inventions. In Japan, these two sectors account for only 12% of the high value inventions, and 7% of all inventions.

(Figure 17)

The Japanese survey also asked the number of domestic patents granted from the R&D project. As shown in Figure 18, only 17% of the projects have only one patent from the project and 4% of the projects have more than 51 patents from the project. This figure suggests two important observations. First, there is a U-shape relationship between the number of patents from a project and firm size. Both large firms and very small firms tend to have projects yielding a large number of granted patents. Our preferred interpretation, which is consistent with both the value distribution (Figure 16A) and the size distribution (Figure 18), is the following: A large firm tends to have high patenting propensity, due to its high level of complementary assets. As a result, it obtains more patents per project, but the average value of the patent is low, as pointed out above. On the other hand, a very small firm implements relatively more productive R&D projects, due to the screening coming from the financial constraints. As a result, smaller firms tend to generate both higher value patents as well as a larger number of patents from a given project. Secondly, the projects in which an inventor from a university participates tend to produce a larger number of granted inventions from a research.

(Figure 18)

Figures 19A and 19B provide the distribution of values by invention process for both Japan and the US. On average, in both countries, an expected byproduct inventions is less valuable than a targeted achievement, as we would expect. In both countries, an invention which involves no R&D or which was generated out of a non-R&D job is often valuable in the sense that a substantial proportion of such patents have top 10% values. In Japan, an invention for which the idea is not from R&D or which required no R&D at all is almost as likely to be a high value patent (top 10%) as is the patent that was the targeted achievement of an R&D project. In the case of the US, an invention involving no R&D is more likely to be a high value patent than is the targeted achievement patent. One major difference between the US and Japan is that in Japan unexpected by-product patents are as likely to be high value as are targeted achievements, but in the US, such unexpected by product inventions are the least likely to be high value. This may reflect the fact that US firms engage in more R&D projects targeted to technology capabilities or seeds development (three times more than Japanese firms), projects with high uncertainty, so that the marginal value of the unexpected by-product is lower.

(Figure 19)

6. Determinants of R&D performance

The business objectives of the research is a key determinant what type of R&D project a firm pursues, what type of R&D strategy a firm adopts, as well as the commercialization possibilities. For example, research for enhancing the existing business of a firm can exploit existing complementary assets of a firm for turning inventions into commercialization, giving a lower risk in commercializing that R&D. On the other hand, such a project may be more constrained in utilizing the recent scientific or technological advances or in creating a chance for serendipity, due to the constraint that such R&D has to be complementary with the existing assets. Thus, there would be a tradeoff between the in-house utilization possibilities of the inventions on the one hand and the use of new scientific and technological knowledge and the chance for serendipity on the other. As shown in Figure 20A for Japan, the in-house utilization rate is 61% for inventions from R&D for existing business, down to 51% for the inventions from R&D for new business and further down to 27% for the inventions for strengthening technology base. On the other hand, 15% of the inventors said that science and technology literature was very important for R&D oriented to existing business, while the corresponding rate was 22% for

R&D targeting the generation of new business and 26% for R&D enhancing the technology base of the firm. Furthermore, unexpected inventions or serendipities account for only 4% of the inventions from R&D for existing business, but they account for 9% of the inventions from R&D for enhancing the technology base of the firm. Finally, the probability that an invention belongs to the top 25% of the inventions is the highest when it is from the R&D for new business. Similar observations hold for US inventions, as shown in Figure 20B. The in-house utilization rate is the highest for inventions from R&D for existing business, while the importance of the scientific and technical literature is the lowest. In addition, the share of unexpected by-product is also the lowest (although the difference is very small) for the inventions from such R&D and the probability that an invention belongs to the top 25% of the inventions is the highest when it is from the R&D for new business.

(Figure 20A and 20B)

The following statistical analysis of the determinants of R&D performance by business objectives, focusing on the effects of research effort for an invention, provides the results complementary with the above finding. We use a very parsimonious specification for R&D productivity, which is given by the following ordered logit equation for each business objective:

$$Pr(y_i = \gamma) = f(manmonth_i, human\_capital_i, external\_knowledge_i, type\_organzation_i, controls, \varepsilon_i ; \gamma) \quad (2)$$

, in which the value of the invention *(y=valued2*) or the number of domestic patents from the project (*y=size_pat*) is supposed to depend on project size in man-months (*manmonths*, the index number), the educational level of the inventor (PhD or not, *PhD*)[16], the level of knowledge input from science and technical literature (*cncpt_sci,* index) and that from patent literature *(cncpt_pat*, index). We use firm size dummies (large firms as the excluded category or

[16] We assume that the educational levels of co-inventors are the same for each invention.

the base), and 6 technology area dummies as controls. The value of an invention is a relative valuation placed by the inventor in all technical achievements during the corresponding period. Since there can be important missing variables in our estimation such as the firm specific or the project specific demand side factor which we cannot control for (ε_i), we need to be aware of the potential effects of endogeneity on the coefficient estimates[17], the extent of which can be related to the degree of uncertainty as discussed below. Table 2A provides the estimation results, using the Japanese sample, with two dependent variables. The upper panel is for the value of a patent and the lower panel is for the number of patents produced by the project. Table 2B (the upper panel) shows the economic value regression for the US, using the same specification. The lower panel shows the same model, with technological significance as the measure of R&D productivity.

The four equations have very similar results with respect to the coefficients of research labor input. *Man-months* is highly linear for R&D for existing businesses. That is, the more man months are spent for the project, the higher the value of the patent and the more patents the project tends to yield. It has a weaker relationship for R&D targeted to new business and no clear relationship for projects for enhancing the technology base.[18] These results indicate that simply spending more research time or hiring more inventors would unlikely to be effective for increasing the output of an R&D project for enhancing the technology base. As the project becomes more exploratory, the success of the project would depend more on uncertain conditions external to the firm, such as the availability of complementary technologies and the emergence of demand for new technologies. The projects with an inventor with a PhD degree

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17 For an example, higher demand for the output of the R&D project would not only increase the value of the patent and the patenting propensity of a given project, but also would increase the R&D efforts themselves to the extent that such demand increase can be recognized by the inventors ex ante.

18 This is true for marginal effects as well.

tends to yield a significantly higher value patent for existing business and new business in both countries, while the coefficient being larger for new business. Such project also tends to yield significantly more patents in new business (see the lower panel for Japan). On the other hand, an inventor with a PhD degree is not associated with significantly higher value for projects targeted to enhancing the technology base, somewhat surprisingly given that PhDs are more involved in such projects (see Figure 4). One potential explanation is higher uncertainty for such exploratory research, which would also imply less endogeneity of the R&D efforts, given that an inventor knows less about the potential outcome of such research and therefore is less able to modify his behavior in anticipation of this (higher or lower) payoff.

In Japan, scientific and technical literature has a significant and positive coefficient in both the value and quantity equations only for the existing business projects (and only the value equation for technology base projects). In the US, the coefficient is only significant for the technological significance of projects focusing on existing business. Thus, while scientific and technical literature is on the average less important in the R&D targeted to existing business (as seen in Figure 4), it is estimated to have a larger economic effect in such R&D. This might, however, again reflect the difference in the extent of the endogeneity of research efforts in the sense that scientific and technical literature can be more exploited in R&D as demand or technological opportunities arise in the case of existing business, since such opportunities can be more easily foreseen.. In Japan, the patent literature has a positive and significant coefficient only in the quantity equation for enhancing the technology base. Once we control for PhDs and the science and technical literature, use of patent literature is not significant at all in the US. Overall, these results suggest that there exist substantial heterogeneity across types of R&D projects.

(Table 2A and 2B)

6. Conclusions

This paper has analyzed and compared the objective, the process and the performance of R&D projects in the US and Japan, based on the first large scale systematic survey of inventors, focusing on R&D projects yielding triadic patents. The survey has allowed us to analyze the invention process from a new, micro perspective. Major findings are the following. First, projects with the objective of enhancing the existing business line of a firm accounts for a very large share of R&D projects in both countries (close to 70% in Japan and 50% in the US), consistent with the view that R&D investment is significantly conditioned by the existing complementary asset of a firm. R&D projects for enhancing the technology base (or for cultivating seeds) are much more common in the US. This difference may be partly accounted for by more PhDs among inventors in the US, since PhDs are more engaged in such R&D projects. In both countries R&D projects for enhancing the technology base receives the highest incidence of the government support (11% in Japan and 8% in the US), followed by those creating new business, with those for enhancing existing business being the least likely to receive government support (2% in Japan and 4% in the US). The differentiation of government funding by R&D objectives is thus lower in the US than in Japan. Venture capital in the US provides significant support for R&D projects for creating new businesses (6% of them), but not more upstream exploratory projects.

In both countries, only about 20% of the projects are for process innovation, providing direct evidence for the earlier findings based only on US patent information. One of the novel aspects of our survey was to identify the product and process patents, and it is found that while the rate of process innovation is somewhat higher in the US, the reverse is the case for the rate of process patents. This is due to the fact that product innovation results in process patents significantly more often in Japan than in the US. In both countries a significant share of inventions (more than 20%) did not originate in an R&D project, and a substantial proportion of such patents have top 10% values, suggesting that R&D expenditure significantly underestimates inventive activities. An invention is significantly more often an unexpected by-product (11%) in the US than in Japan (3.4%). This may reflect differences in R&D management practices in the design of the scope of the R&D project and in the project portfolio[19] .

The two countries have surprisingly similar distributions of R&D projects in terms of man-months and the average team size, although Japanese inventions take more calendar time. In both countries, smaller firms tend to have relatively more high value patents. In the US, the inventors affiliated with very small firm (with less than 100 employees) and universities jointly account for more than one quarter of top 10% inventions, even though they account for only 14% of all inventions. In Japan, small firms are also over-represented among the high value patents, although to a lesser extent. In both countries, the inventions from R&D for existing business have the highest in-house utilization rate, but use least the scientific and technical literature for their conceptions, while the reverse is the case for the inventions from R&D for new technology base. In addition, man-months has a significant correlation with the performance of the R&D projects (the value of a patent and the number of domestic patents) for existing business, less so for those creating new business and not at all for those enhancing the technology base. The PhD degree of an inventor is very significant for the value for R&D for new business, but less significant for that for existing business and not significant at all for that for technology base. These results suggest that there exist substantial heterogeneity by project type in uncertainty and in the determinants of the project performance.

[19] While US firms are more likely to engage in projects focusing on technology enhancement or seeds generation than Japanese firms, such projects are not more likely to generate unexpected results in the US unlike in Japan. Thus, this country difference in the propensity to generated unexpected by products is not entirely due to the higher rate of seeds oriented research in the US.

The above analysis suggests several managerial and policy implications as well as poses a number of future research questions. First, effective management and policy practices would depend significantly on the types of R&D projects. While simply spending more research time or hiring more inventors does not seems to be effective for exploratory research, such resource commitments seem to be very important for R&D for the existing business. Secondly, PhD seems to matter both in the invention performance as well as in the portfolio of research projects. The team with a PhD produces higher value patents, especially in the R&D targeted at new business, controlling man months and other factors. Exploratory research, which is likely to have a higher social return,[20]is more likely to engage a PhD as an inventor. Thirdly, although R&D is the central pillar of inventive activity, an invention often arises from non-R&D activity and such inventions are often valuable. Thus, broadening and enhancing the inventive activity beyond R&D may enhance the overall inventive activity of a nation. Fourthly, although the R&D process of the US and Japan are surprising similar, our survey suggests that one of the key strengths of the US innovation system seems to be the existence of small firms with high inventive capability, as well as university-affiliated inventors with many high value patents. Our results provide significant support to the view that nurturing high-tech small firms in collaboration with university will be an important policy agenda for Japan, although realizing that would require complementary changes in many fronts.

We would like to mention just two important research questions. One is to deepen our understanding of the relationship between the structure of R&D projects and firm characteristics. Our analysis suggests that both large and small firms devote the most resources to product innovation (creating a new product). This U-shape relationship between the share of product innovation and firm size is not very consistent with the existing model based on the

[20] R&D projects targeted at enhancing technology have the highest incidence of basic research, followed by those for new business and then by those for existing business.

appropriation advantage such as Cohen and Klepper (1996). The second question is why is an invention with no R&D often economically valuable? Is such an invention socially valuable too?

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Appendix 1. Japan and US inventor survey

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[21], 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.

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

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

distribution of patents enhances the comparability of patented inventions between patents as well as among nations (Criscuolo, 2006; Dernis 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.[22]

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[23] (Hall, Jaffe, and Trajtenberg, 2001), with oversampling for the technology sectors such as biotechnology with a relatively small number of patent applications[24]. 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

[22] 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.

[23] We separated computer hardware and software.

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

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 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.

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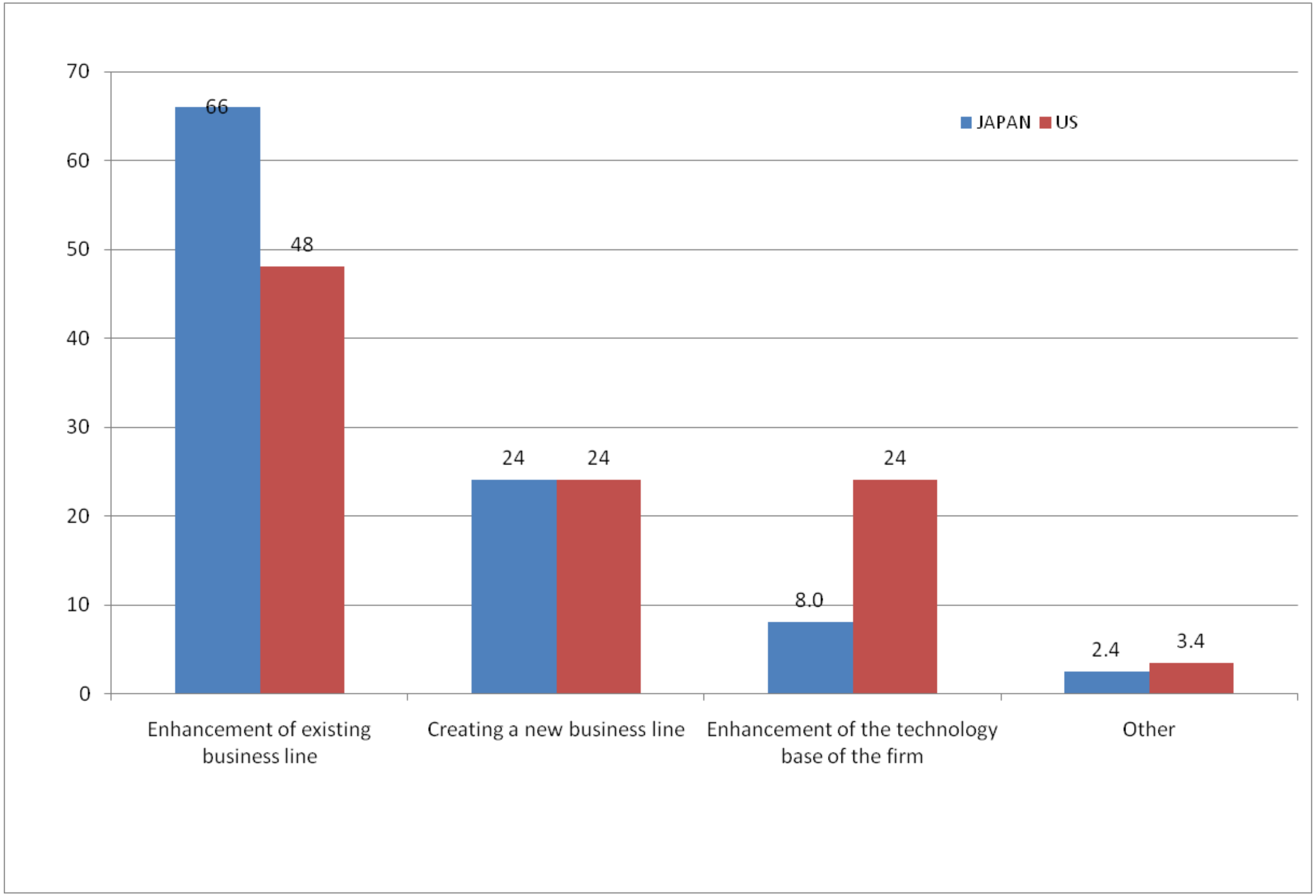
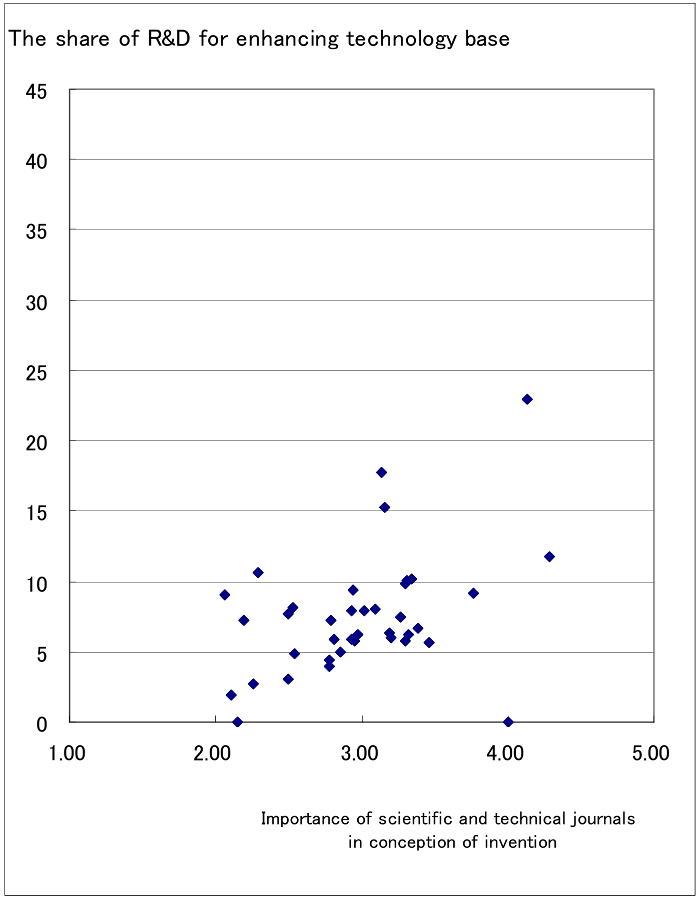
Figure 1 Business objectives of the research (%Yes)

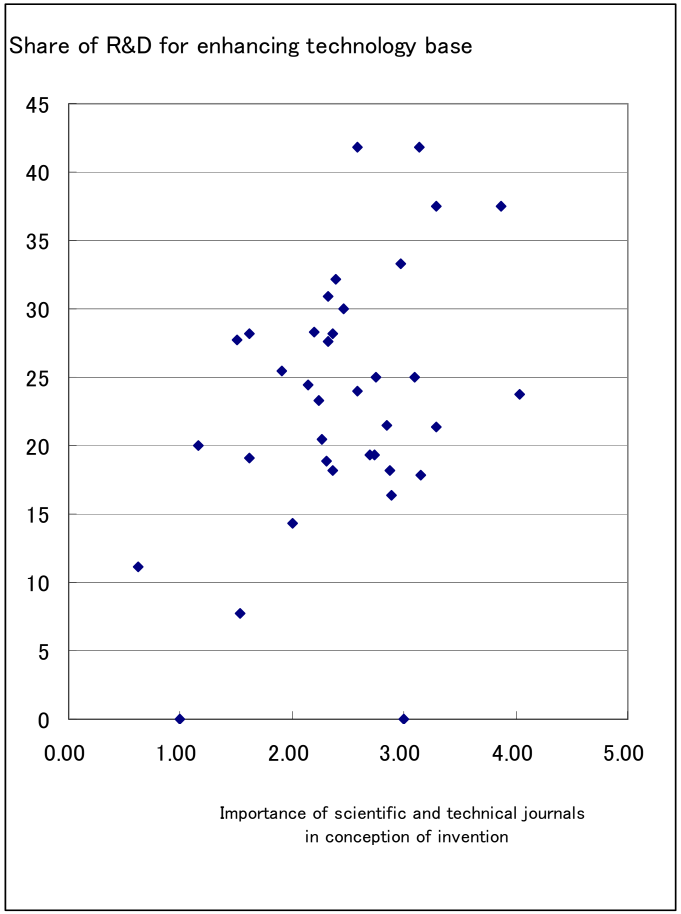


Note. More than 95% of the samples in both countries are from the inventors affiliated with business firm. Based on the common technology class weights.

Figure 2. Share of R&D for enhancing technology base vs. Importance of scientific and technical journals in conception of inventions by technology sectors, Triadic patents

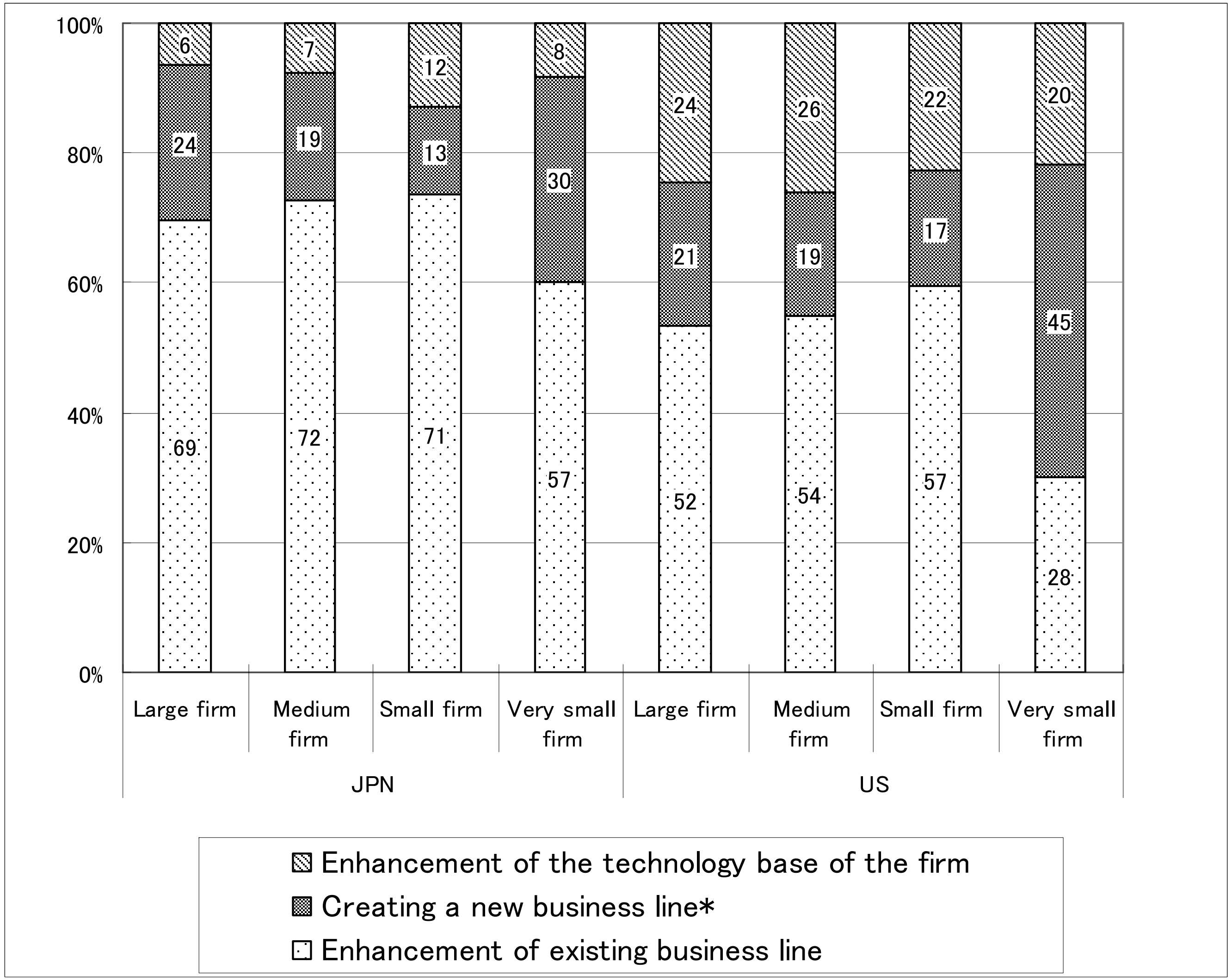


Japan



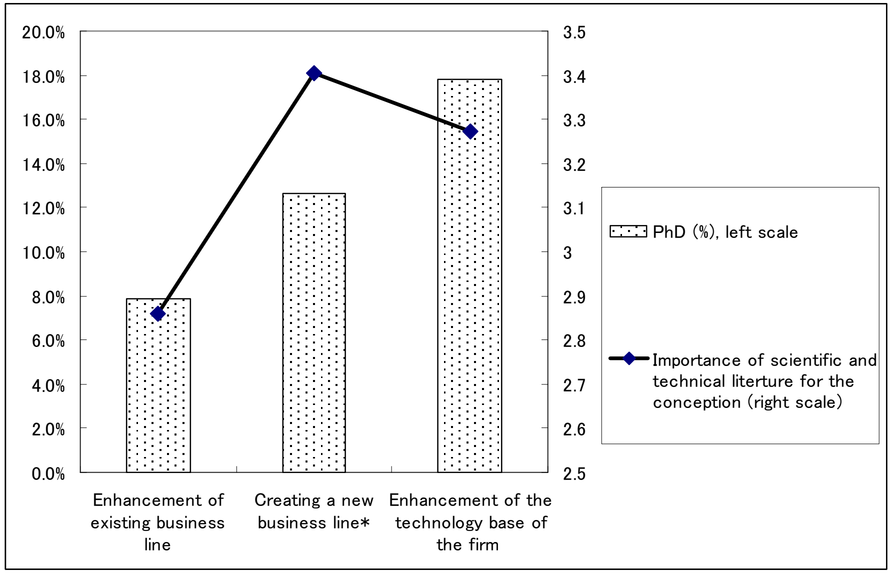
USA

Figure 3 Business objectives of the research (%) by firm size

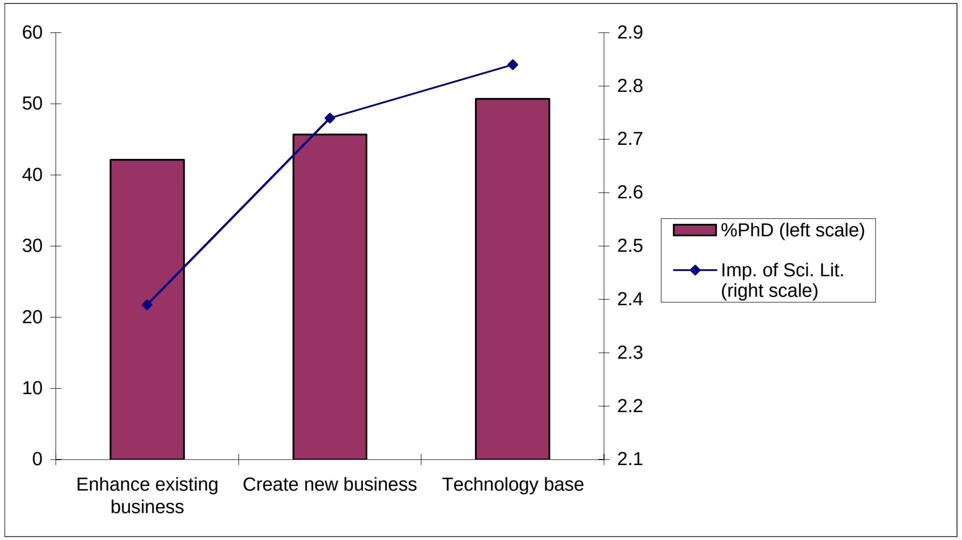


Note: The border lines between large, medium, small and very small firms are 500, 250 and 100.

Figure 4 Capability requirements by business objective of R&D

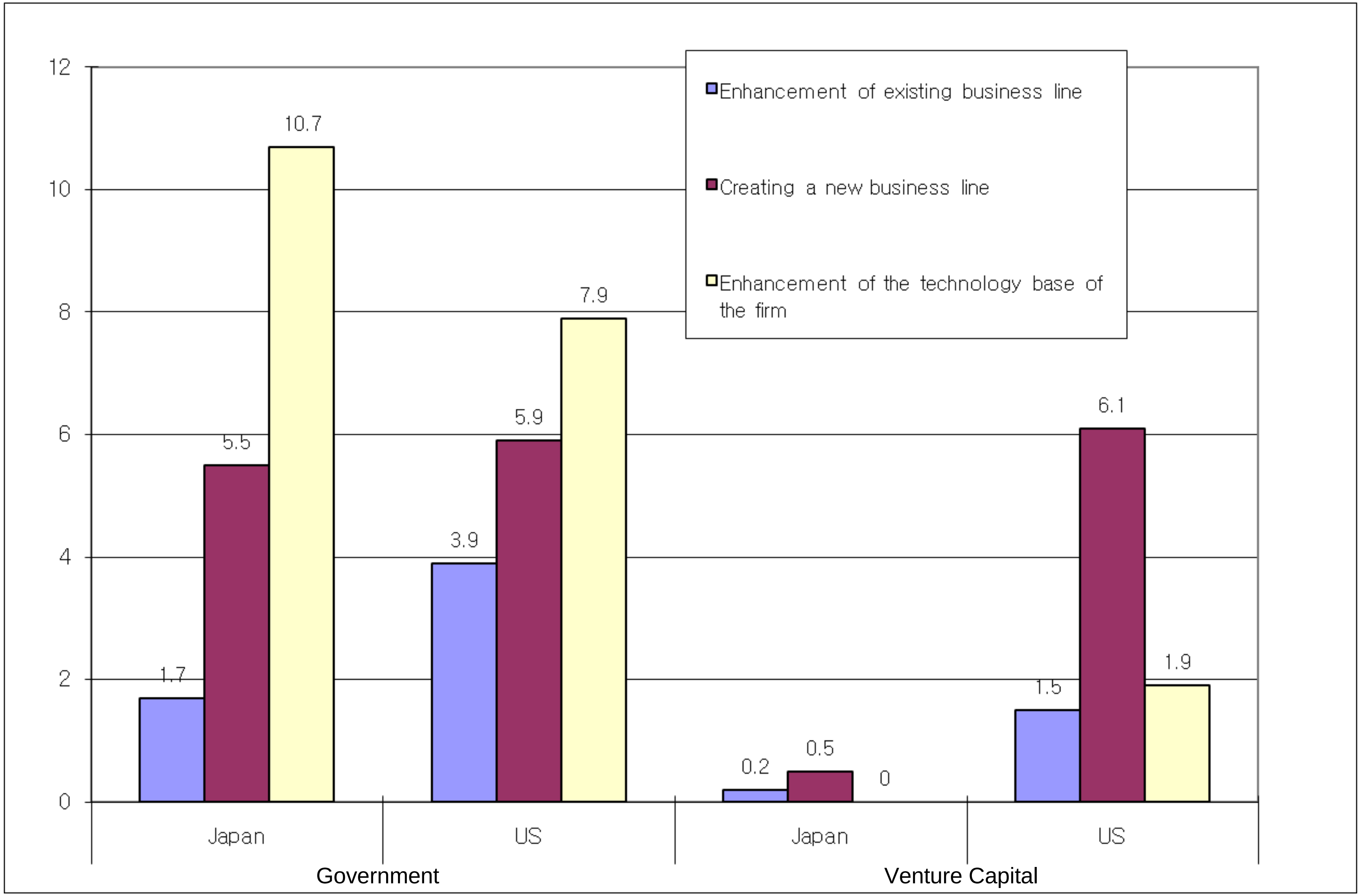


(Japan)



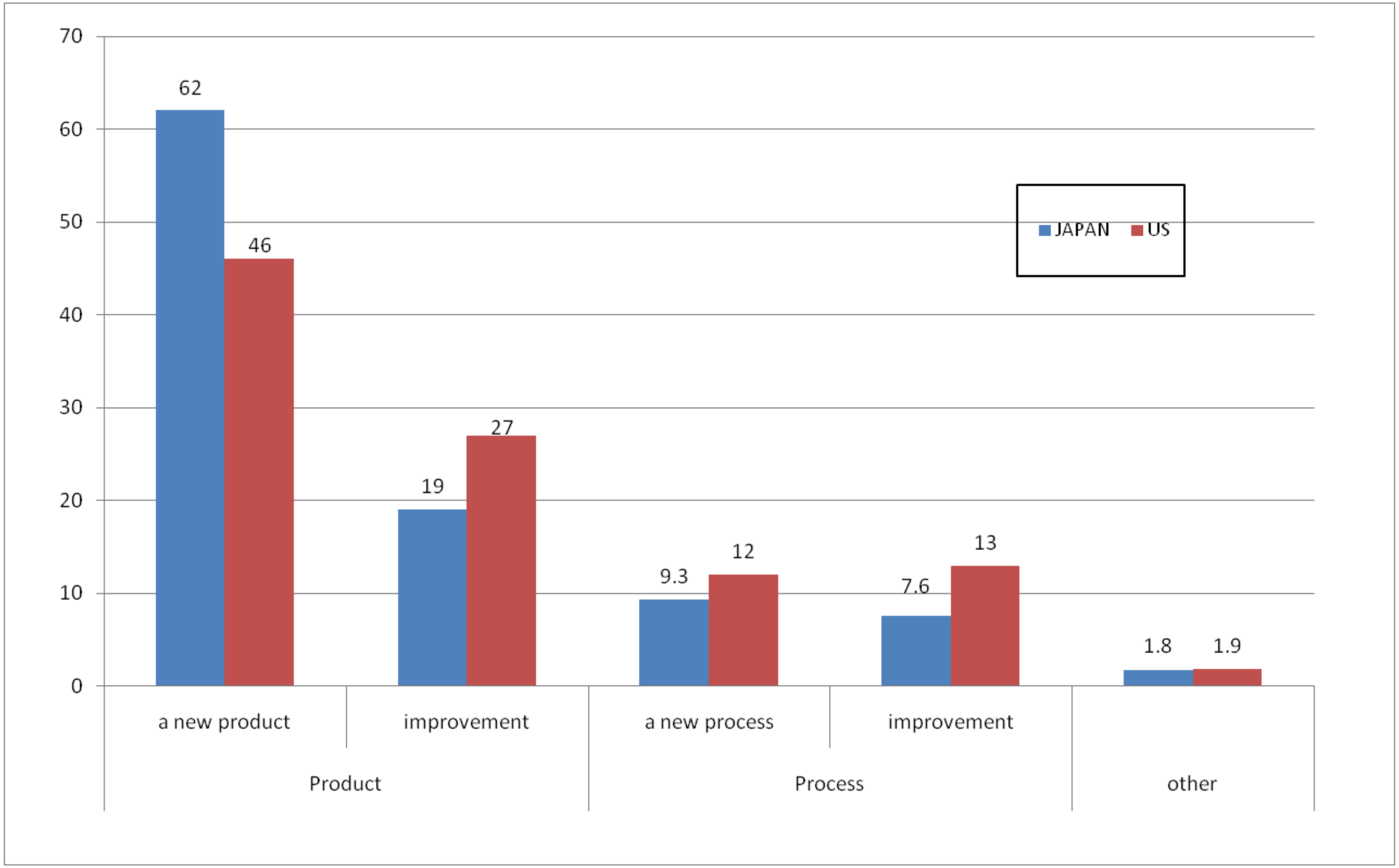
(USA)

Figure 5 The Incidence of the government and venture capital (or angel) finance of R&D by business objective (%)



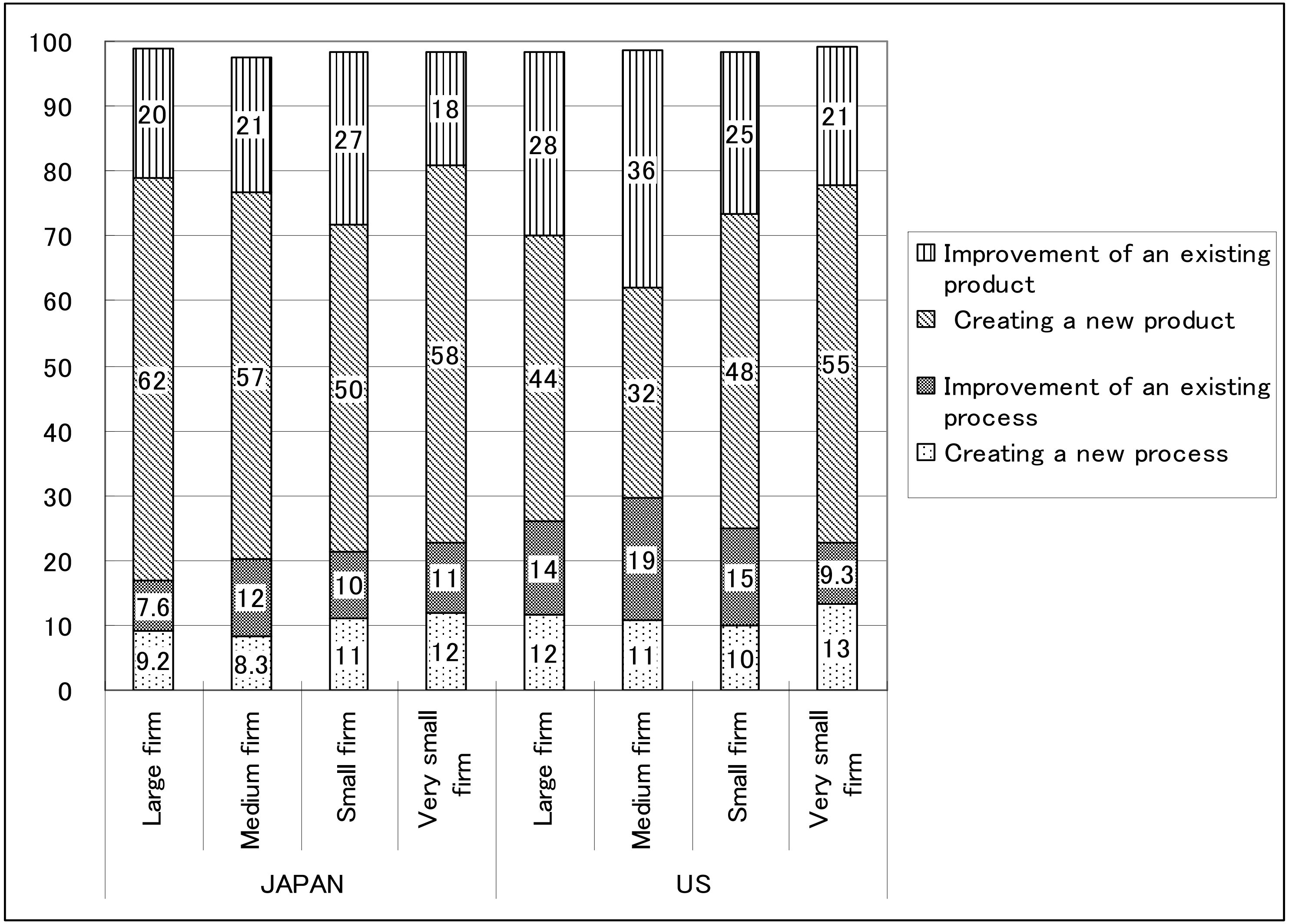
Note. Focusing on business R&D (inventors affiliated with a firm). The incidence covers the cases of partial finance of the business R&D.

Figure 6 Technological Goal of Research Project



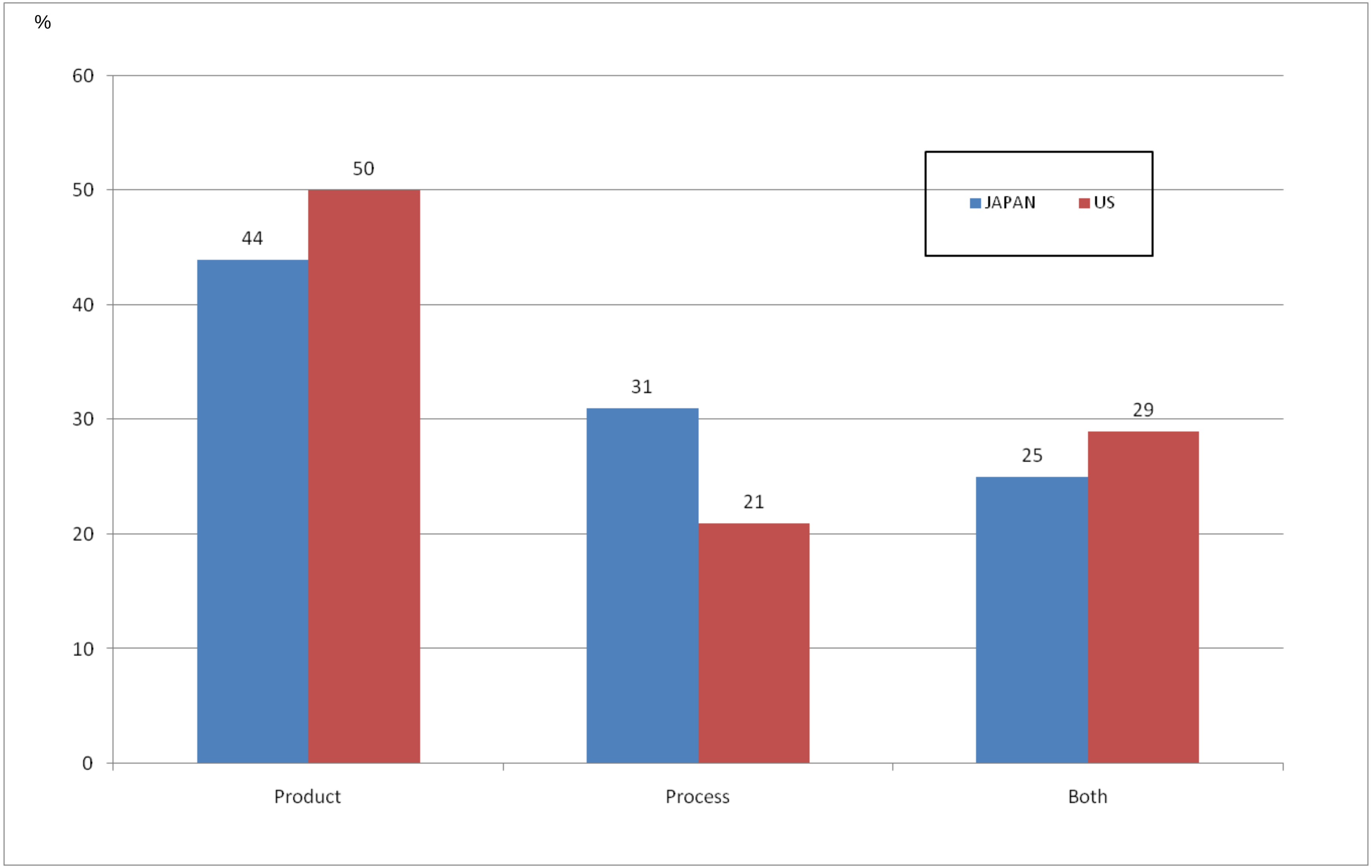
Note. Based on the common technology class weights.

Figure 7 Proportions of product and process innovations by firm size in Japan and USA



Note. The border lines between large, medium, small and very small firms are 500, 250 and 100.

Figure 8. Product vs. process patents



Note. Based on the common technology class weights.

Figure 9A. Types of patents by R&D technical goals (Japan)

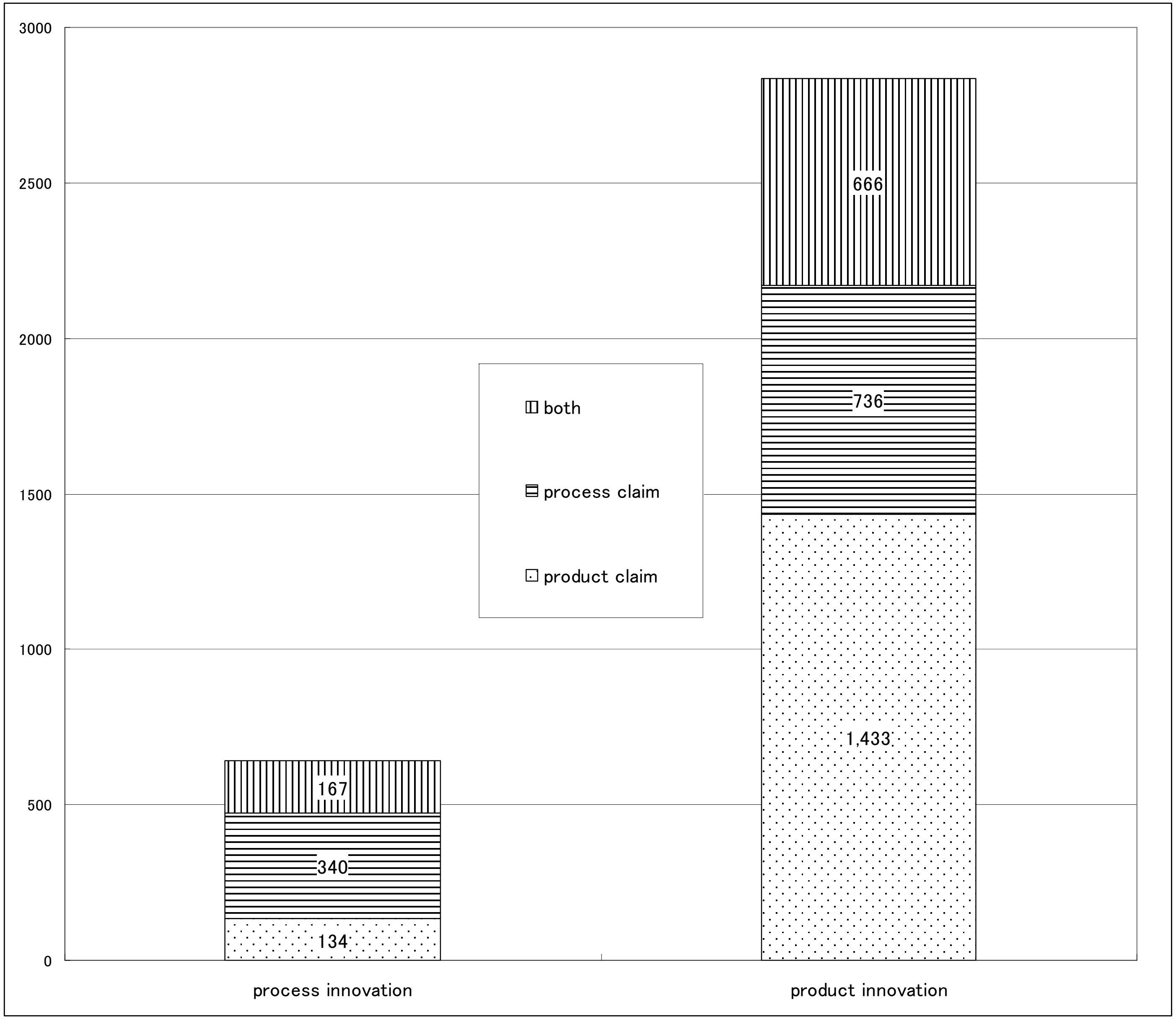


Figure 9B. Types of patents by R&D technical goals (US)

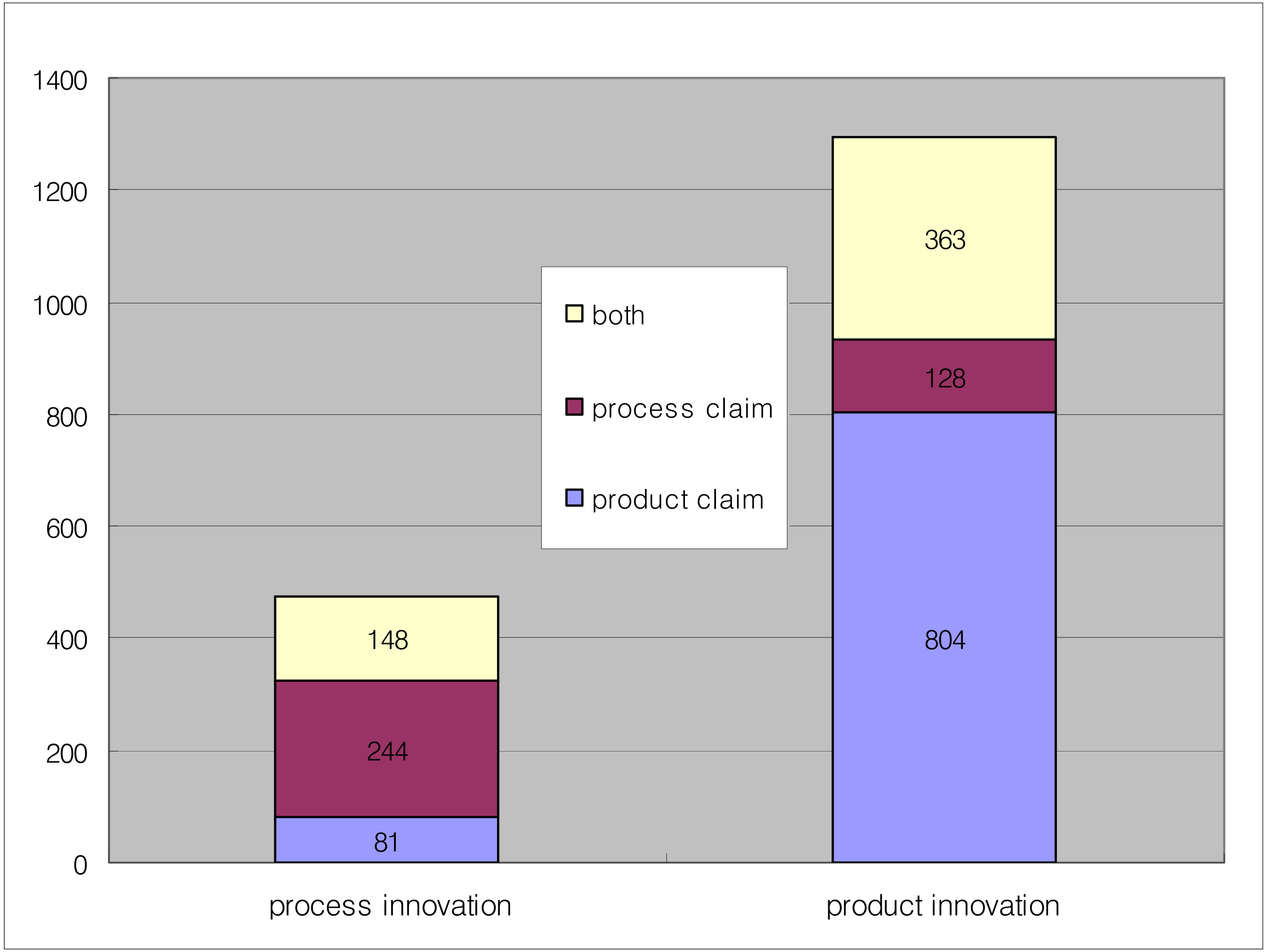
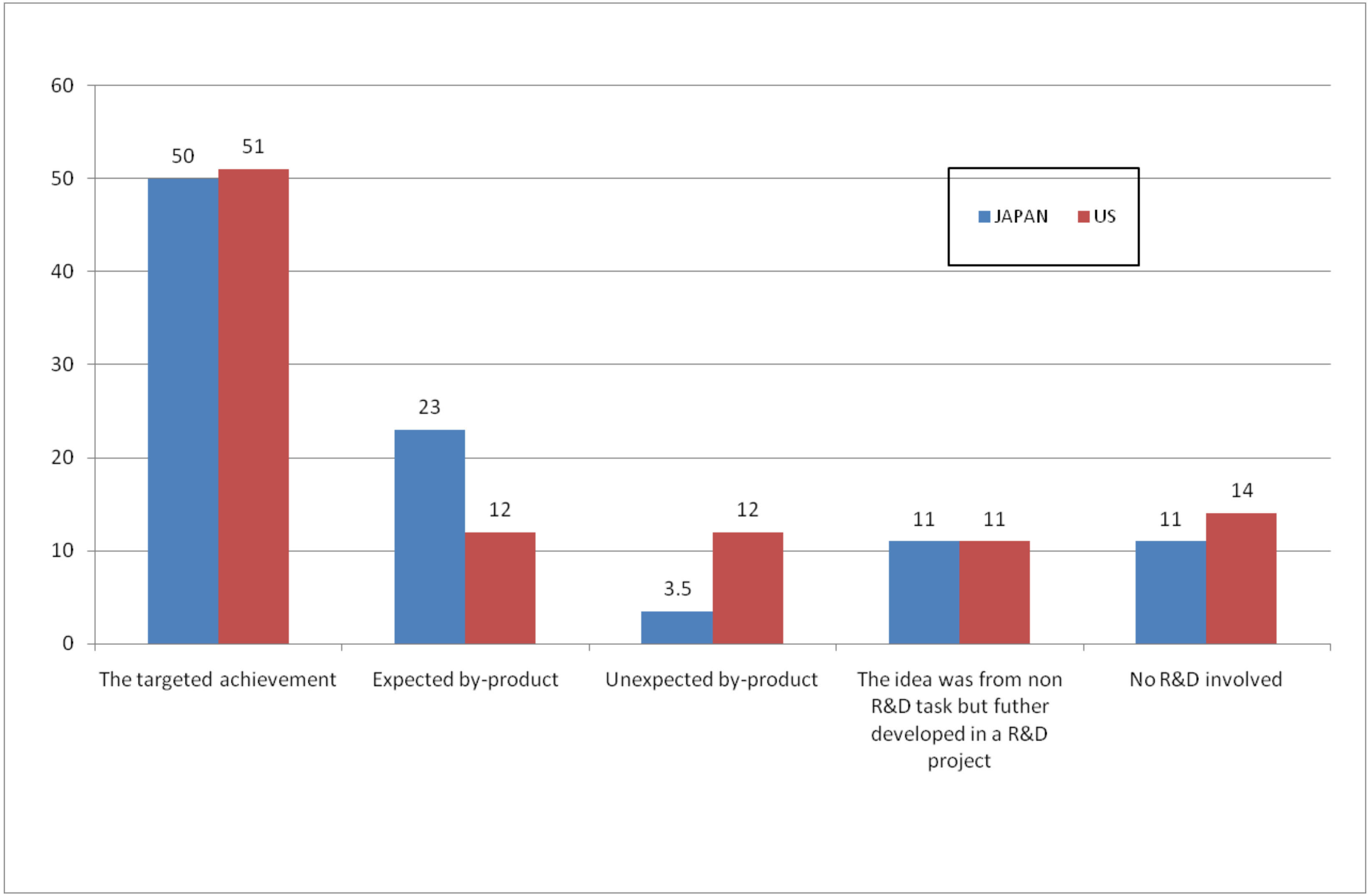


Figure10 Invention Process (Targeted v. others)



Note. Based on the common technology class weights.

Figure 11A. Invention process by business objectives (Japan)

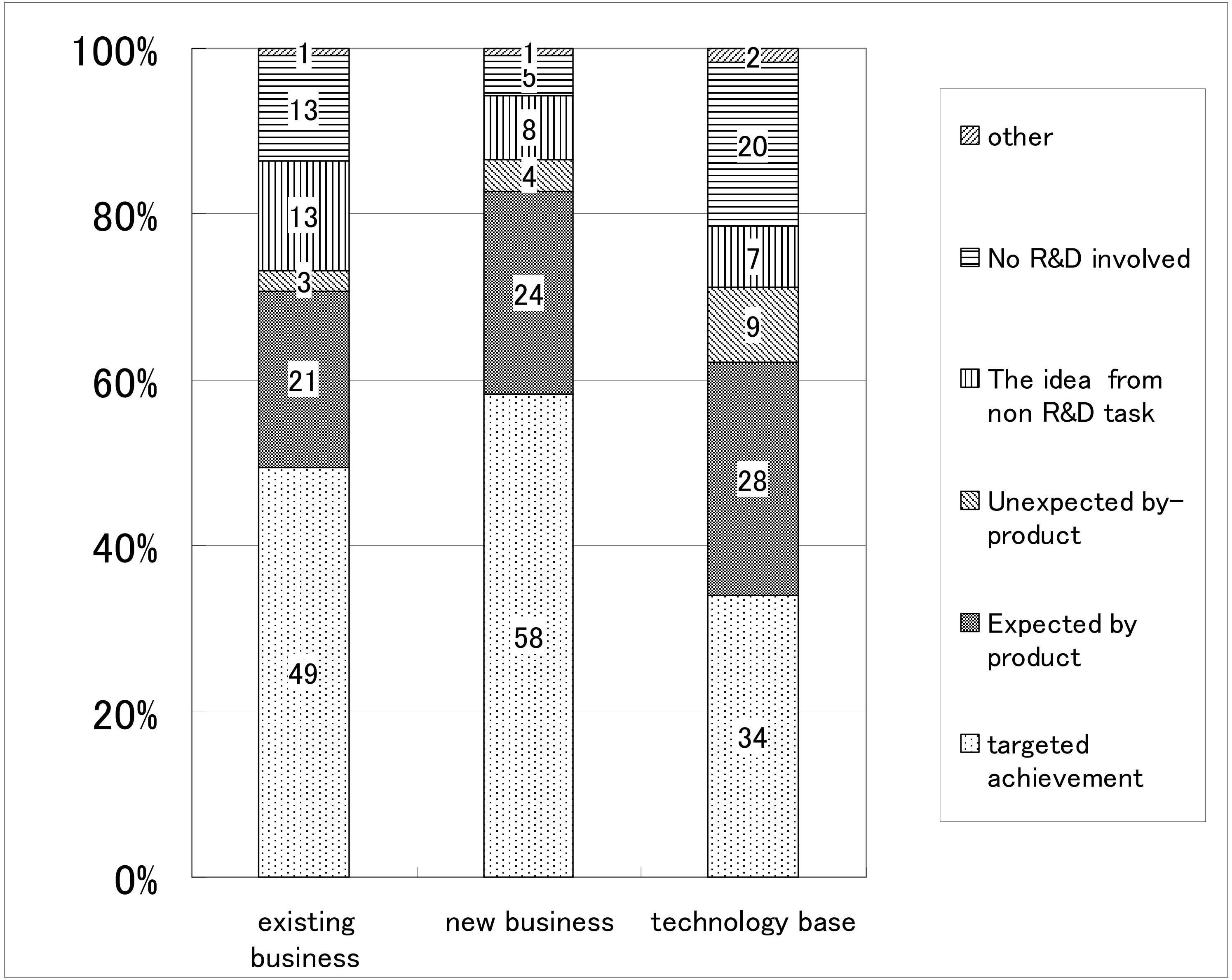


Figure 11B. Invention process by business objectives (US)

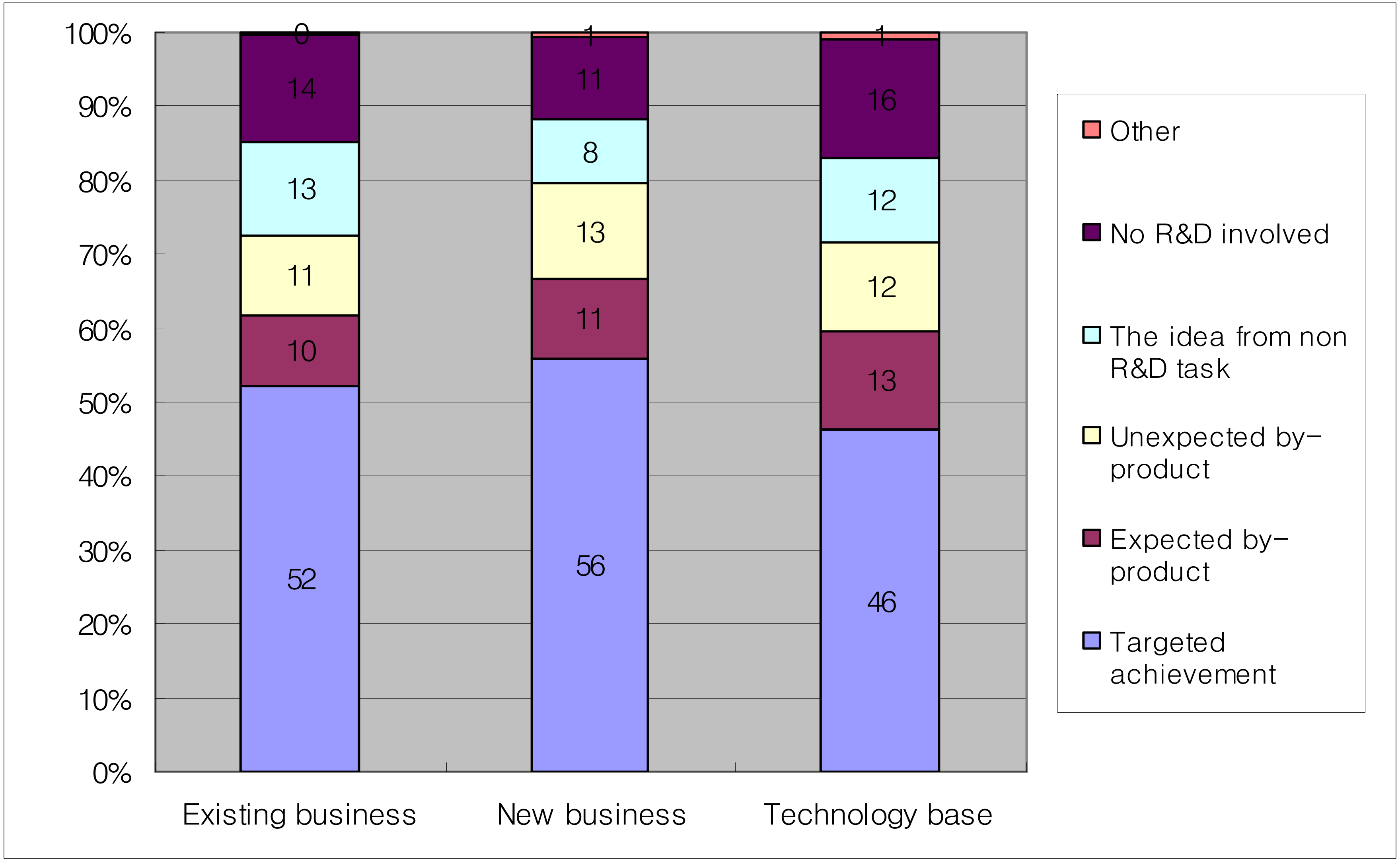


Figure 12A. Invention process by technical objective of R&D (Japan)

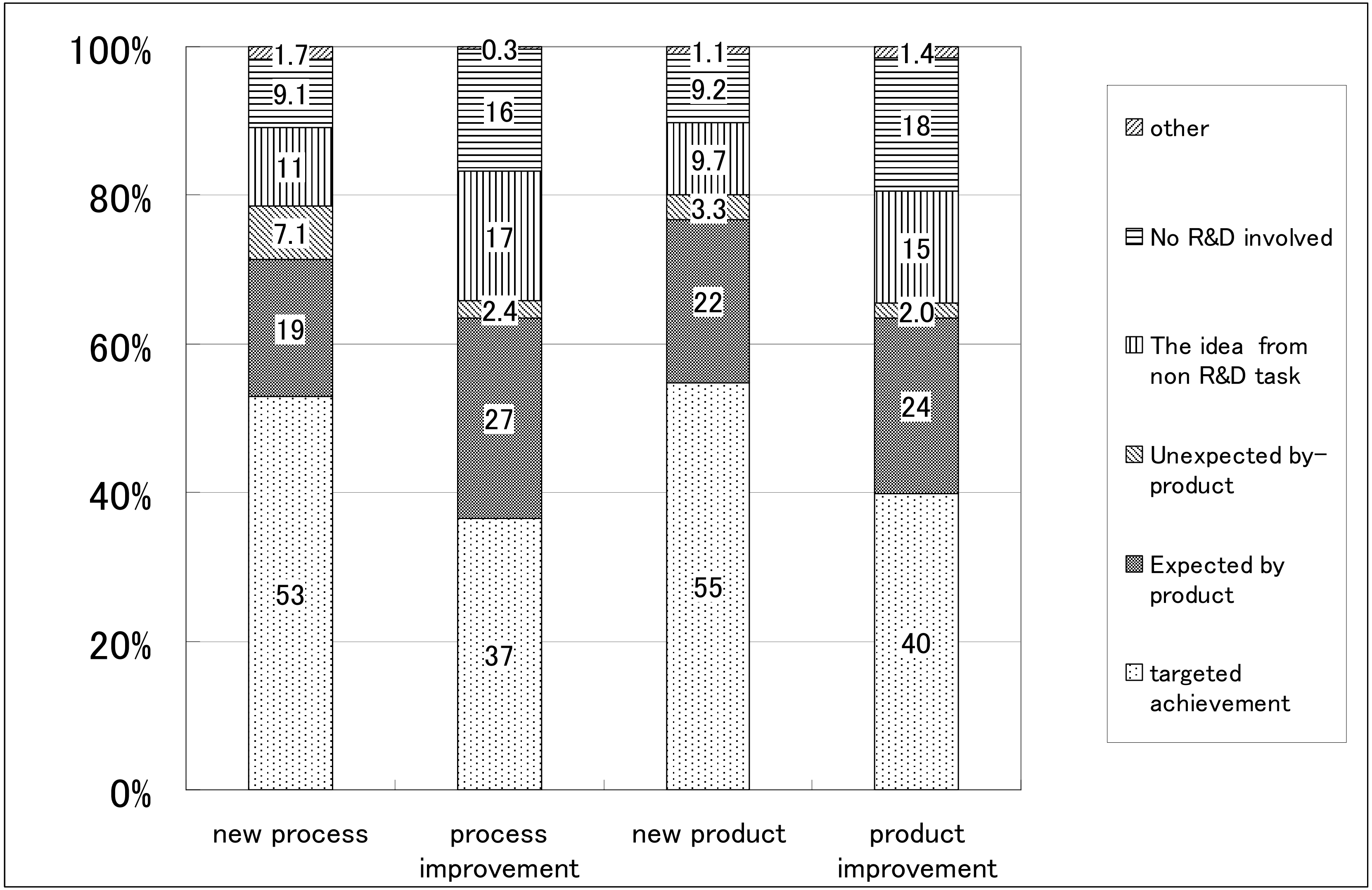


Figure 12B. Invention process by technical objective of R&D (US)

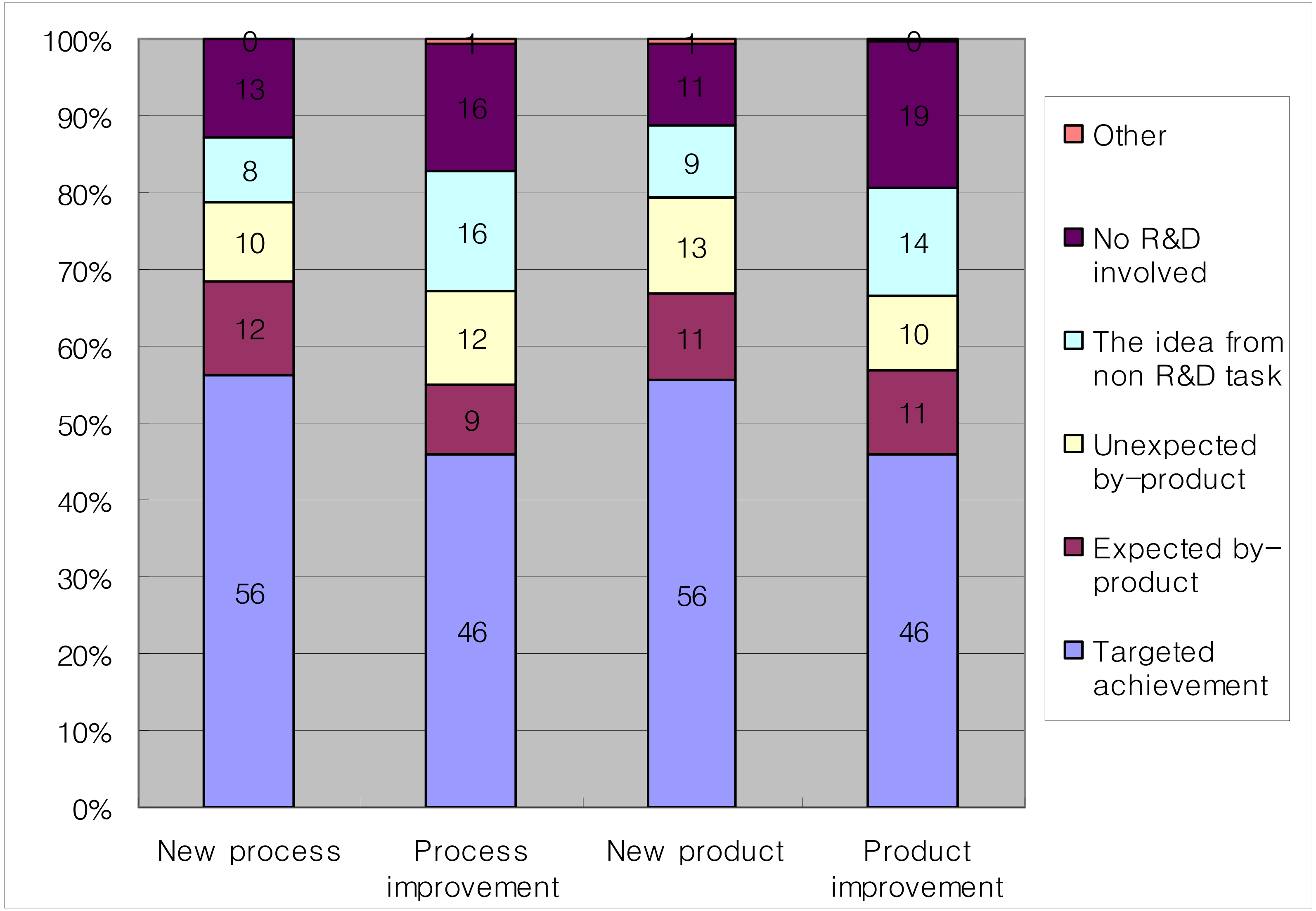
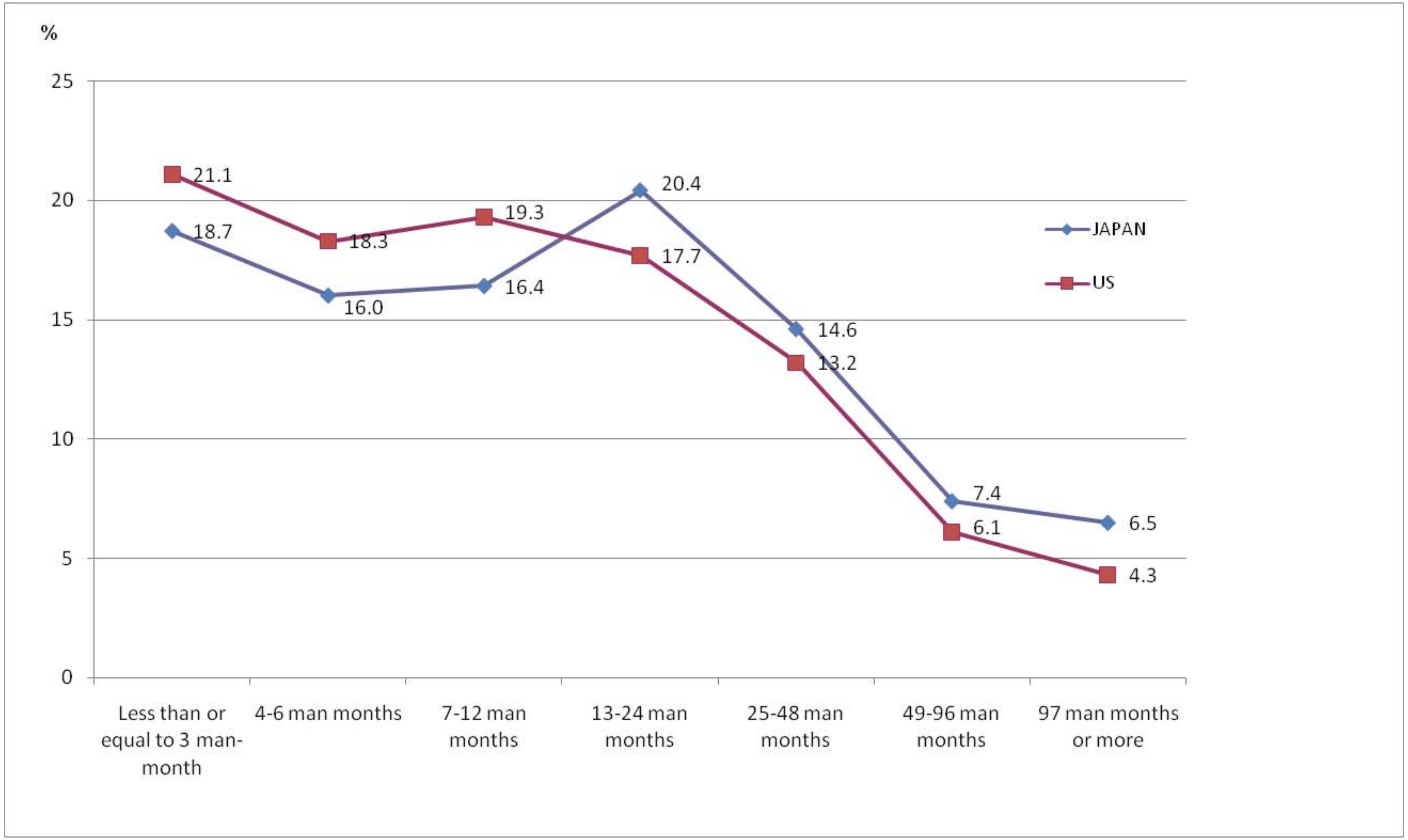


Figure 13. Man months required for the research yielding the patent



Note. based on the common technology class weights.

Figure 14 Average number of inventors

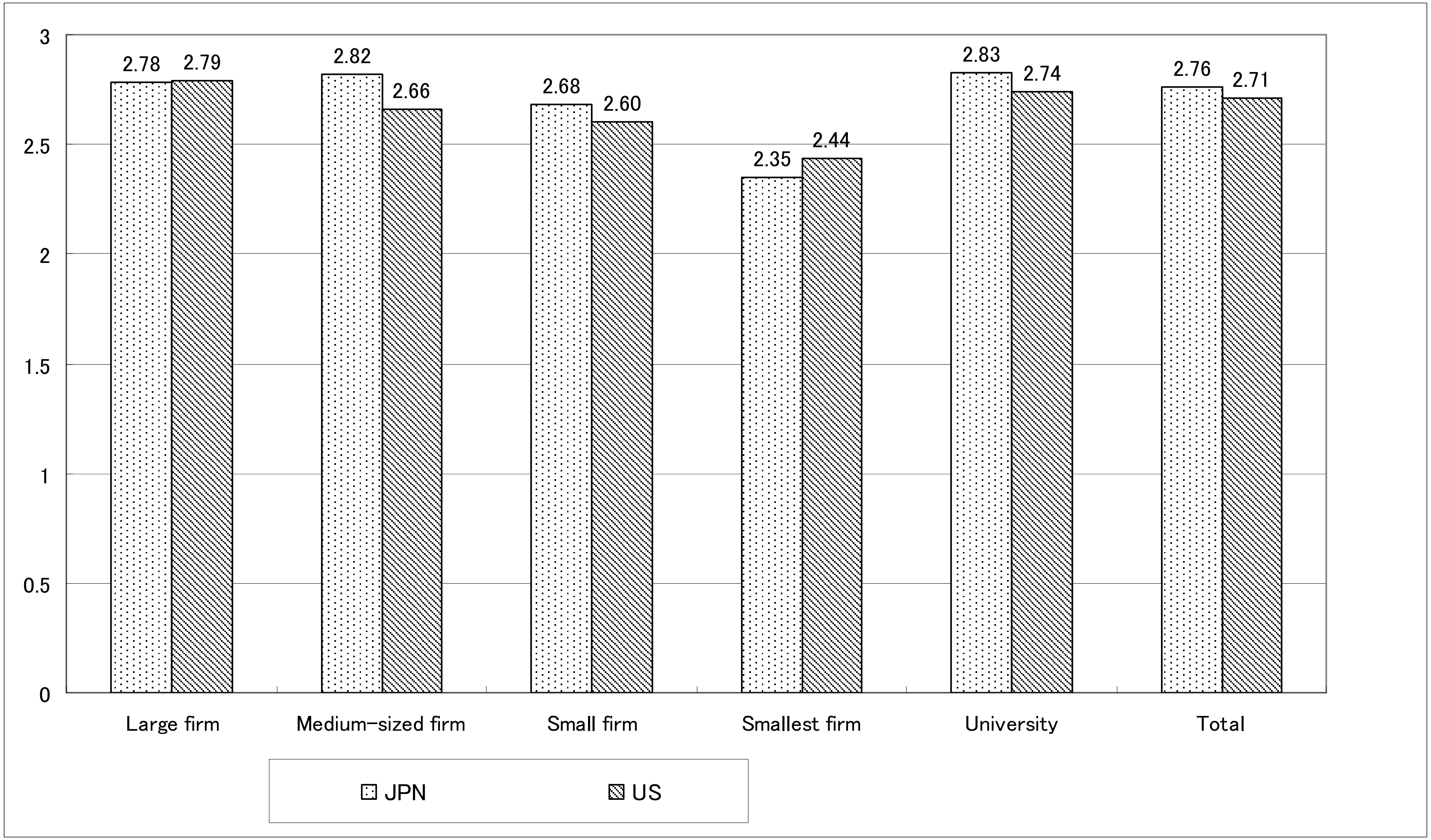
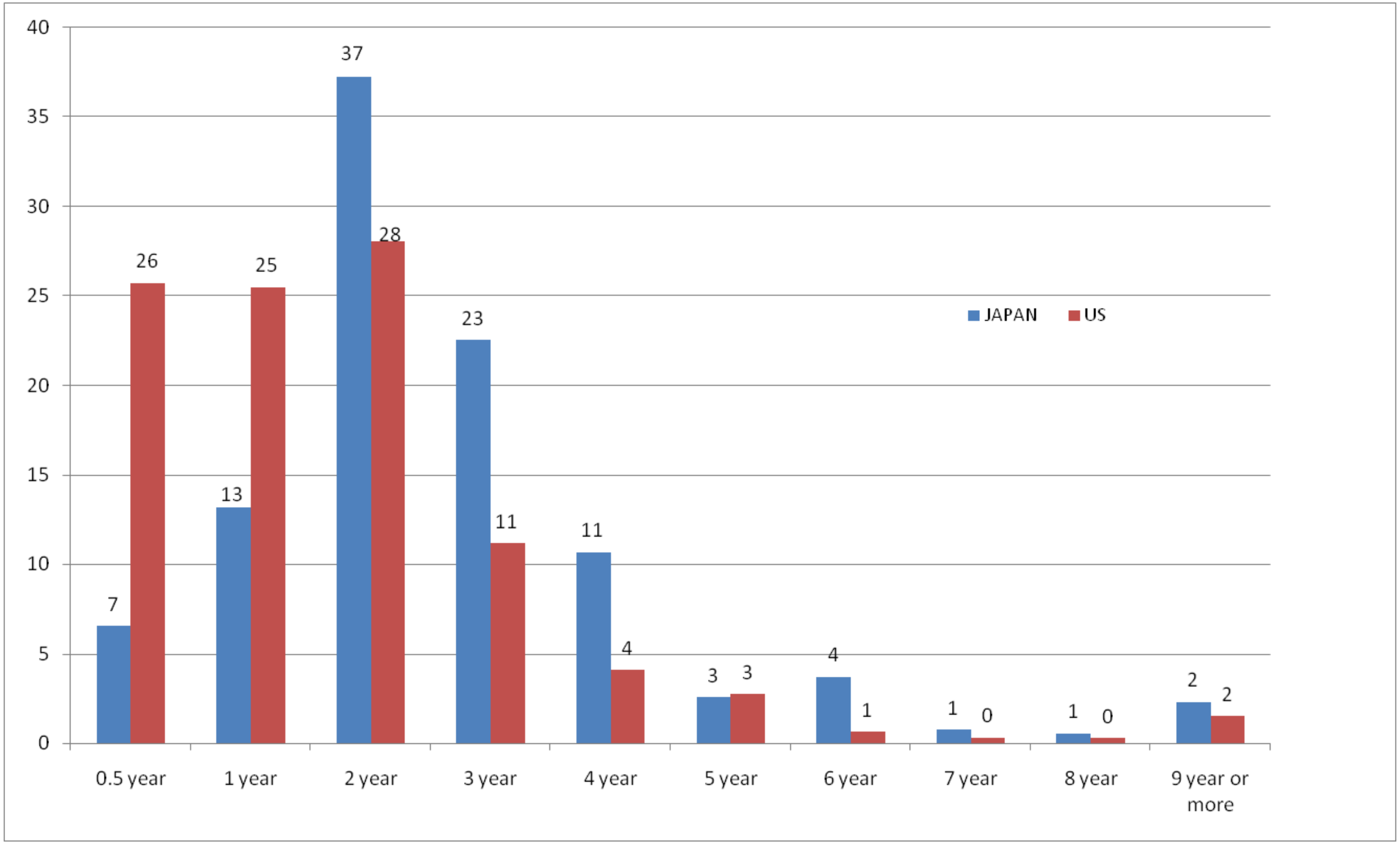


Figure15. Calendar year required for the R&D yielding the patent (distribution, %)



Note. based on the common technology class weights.

Figure 16A. Distribution of values by organization (Japan)

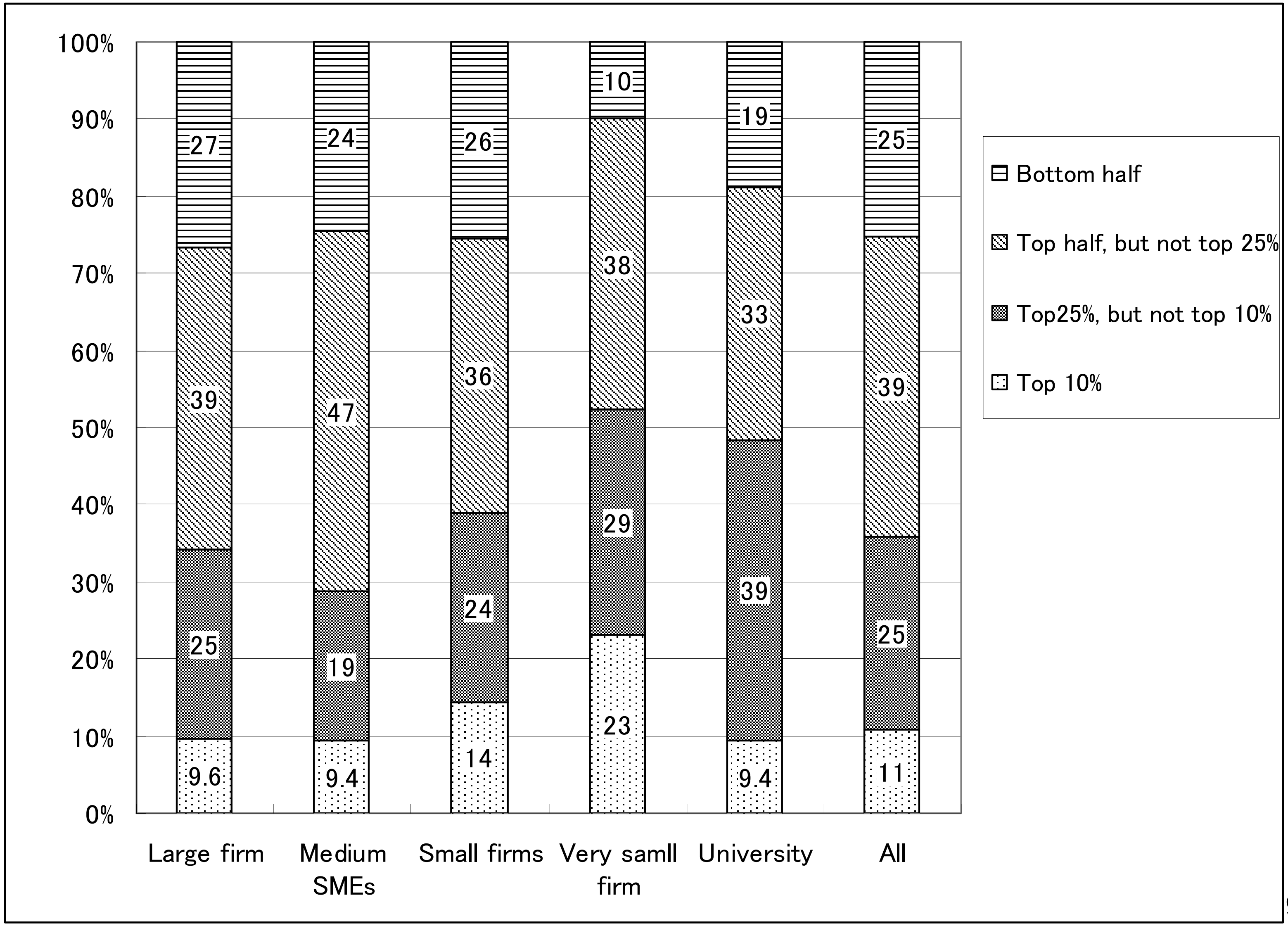


Figure 16B. Distribution of values by organization (US)

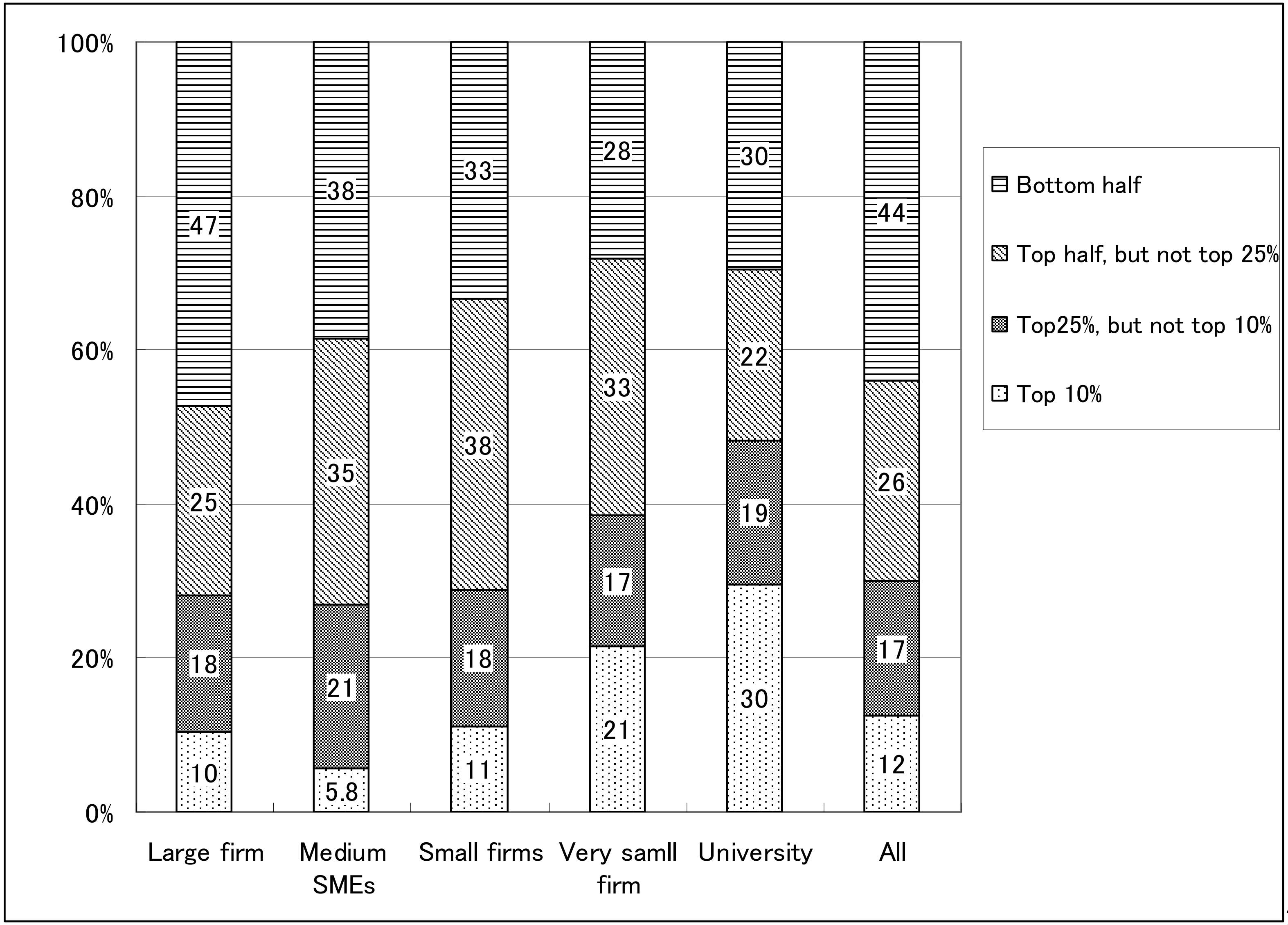


Figure17 Share of patents by organizations (Top 10%)

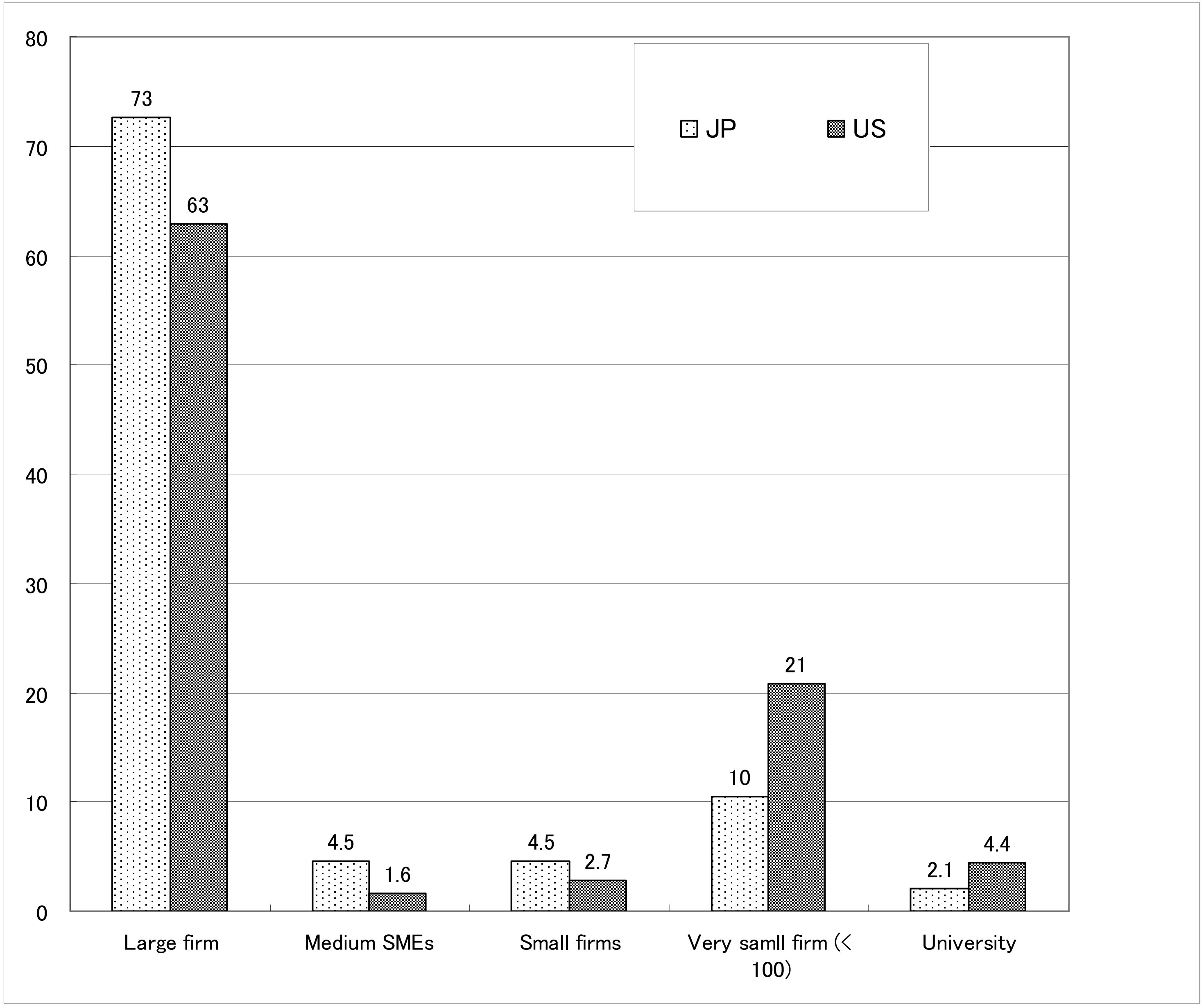


Figure18 Distribution of the number of patents granted from the project (Japan)

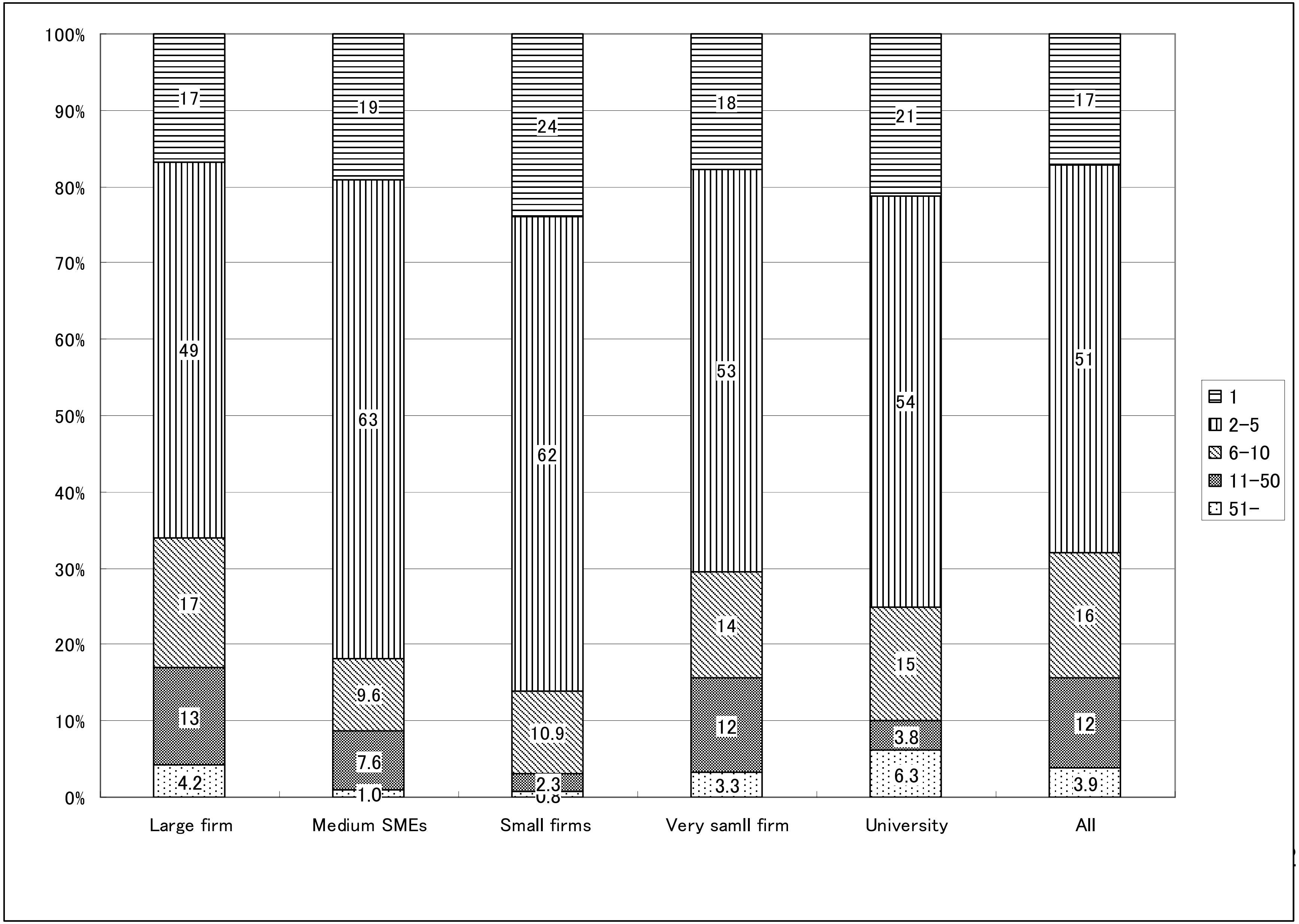


Figure 19A Value distribution by a patent by invention process (Japan)

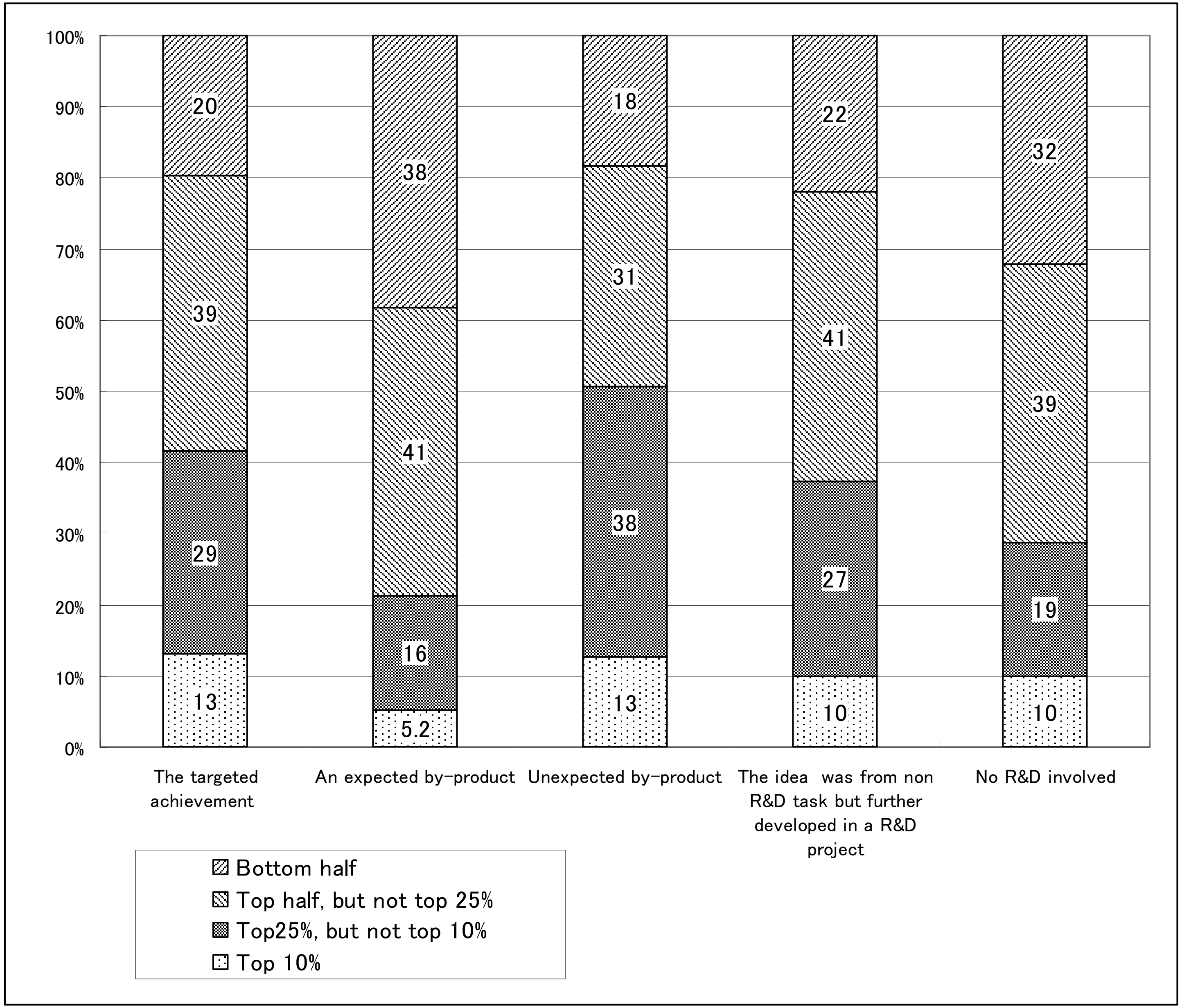


Figure 19B. Value distribution of a patent by invention process (US)

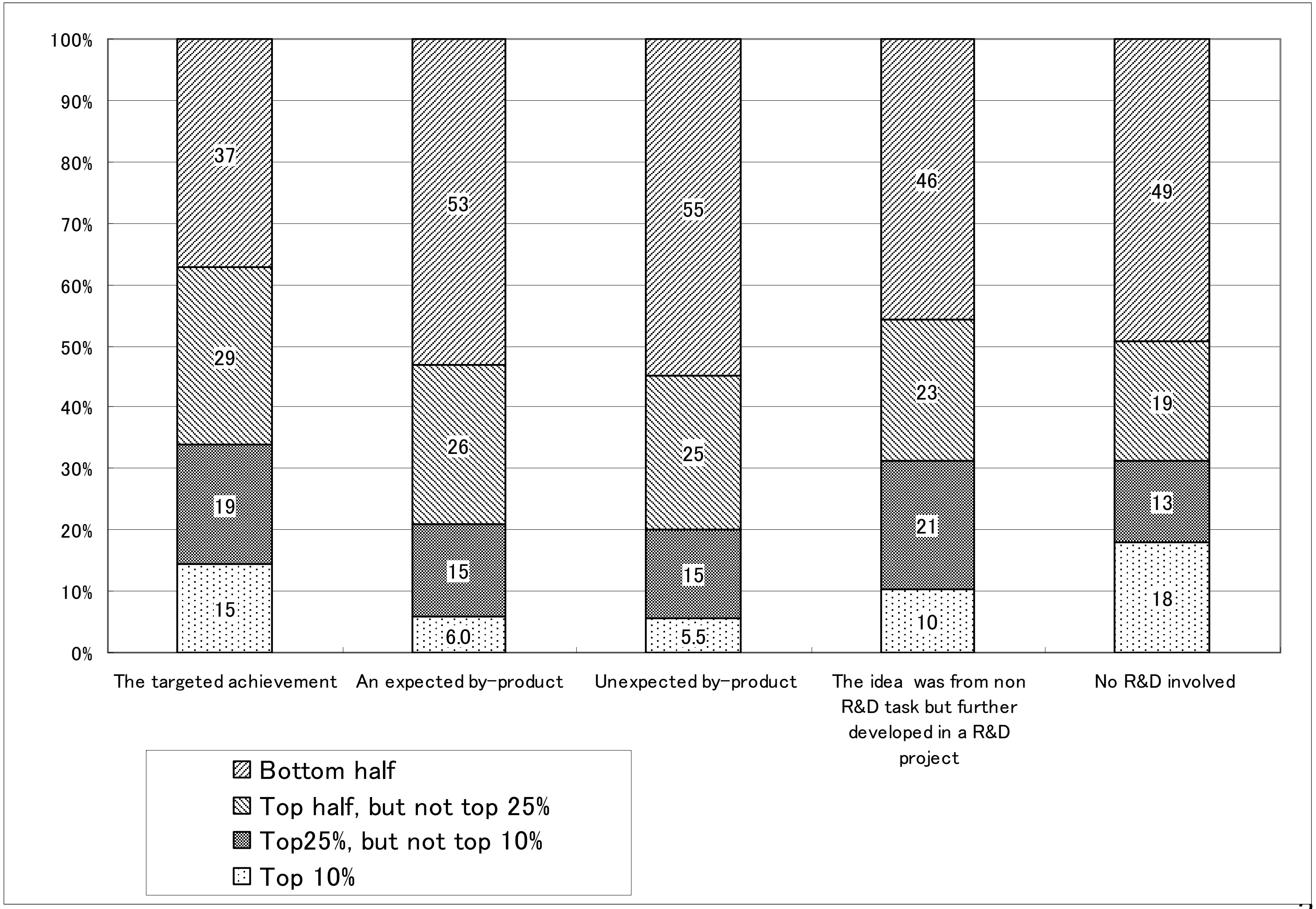
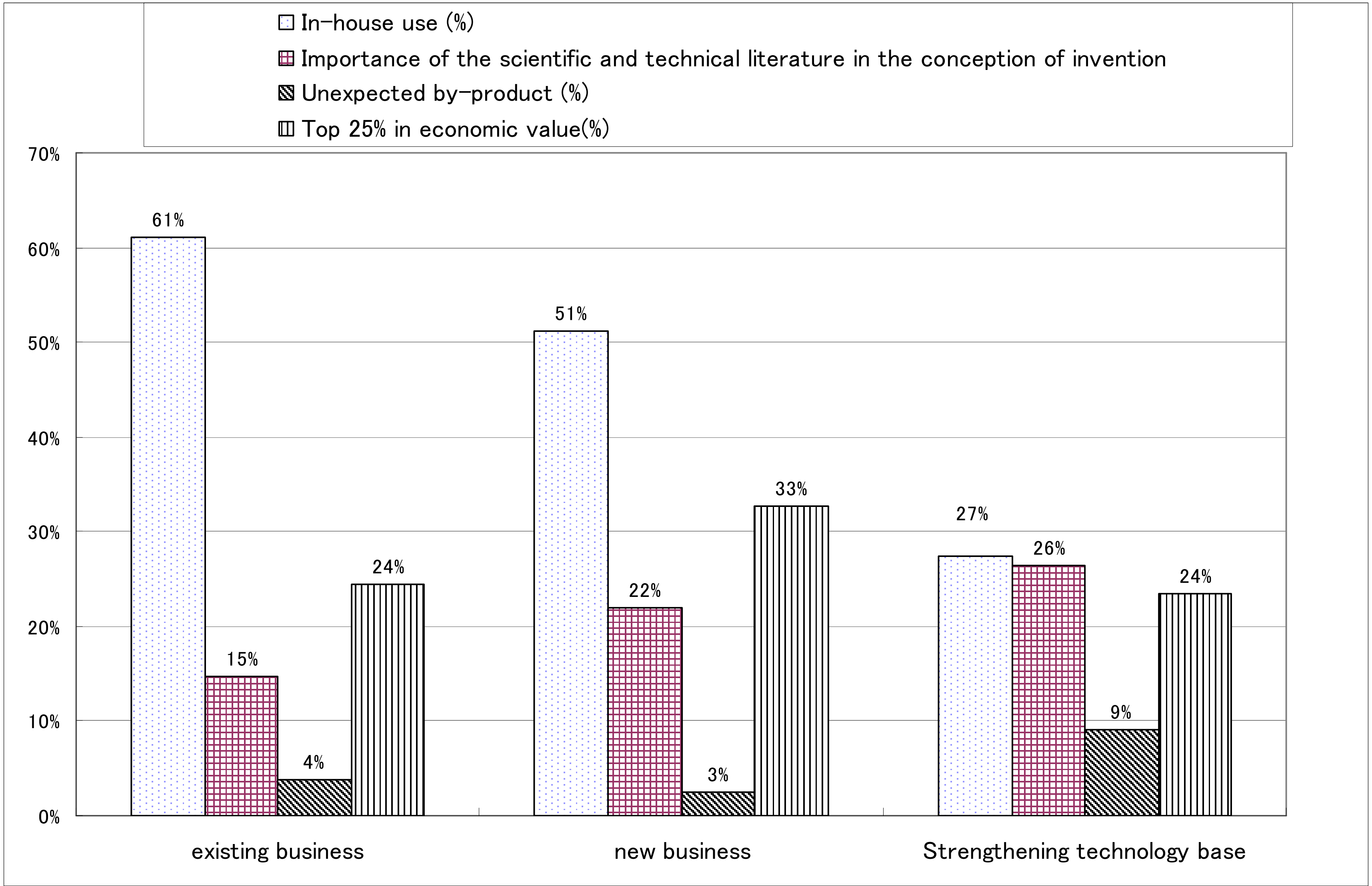


Figure 20A. Characteristics of R&D by business objectives (Japan)



Note: "In-house utilization" indicates the ratio of inventions used in the products or production processes of the firm in question. "Importance of science and technology papers in the conception of invention" refers to the responses stating that such papers are very important in inspiring the invention. Unexpected by-product indicates the share of unexpected inventions. "Top 25% in economic value" refers to the ratio judged by the inventors to fall in the nation's economic top quarter of the technology accomplishments.

Figure 20B. Characteristics of R&D by business objectives (USA)

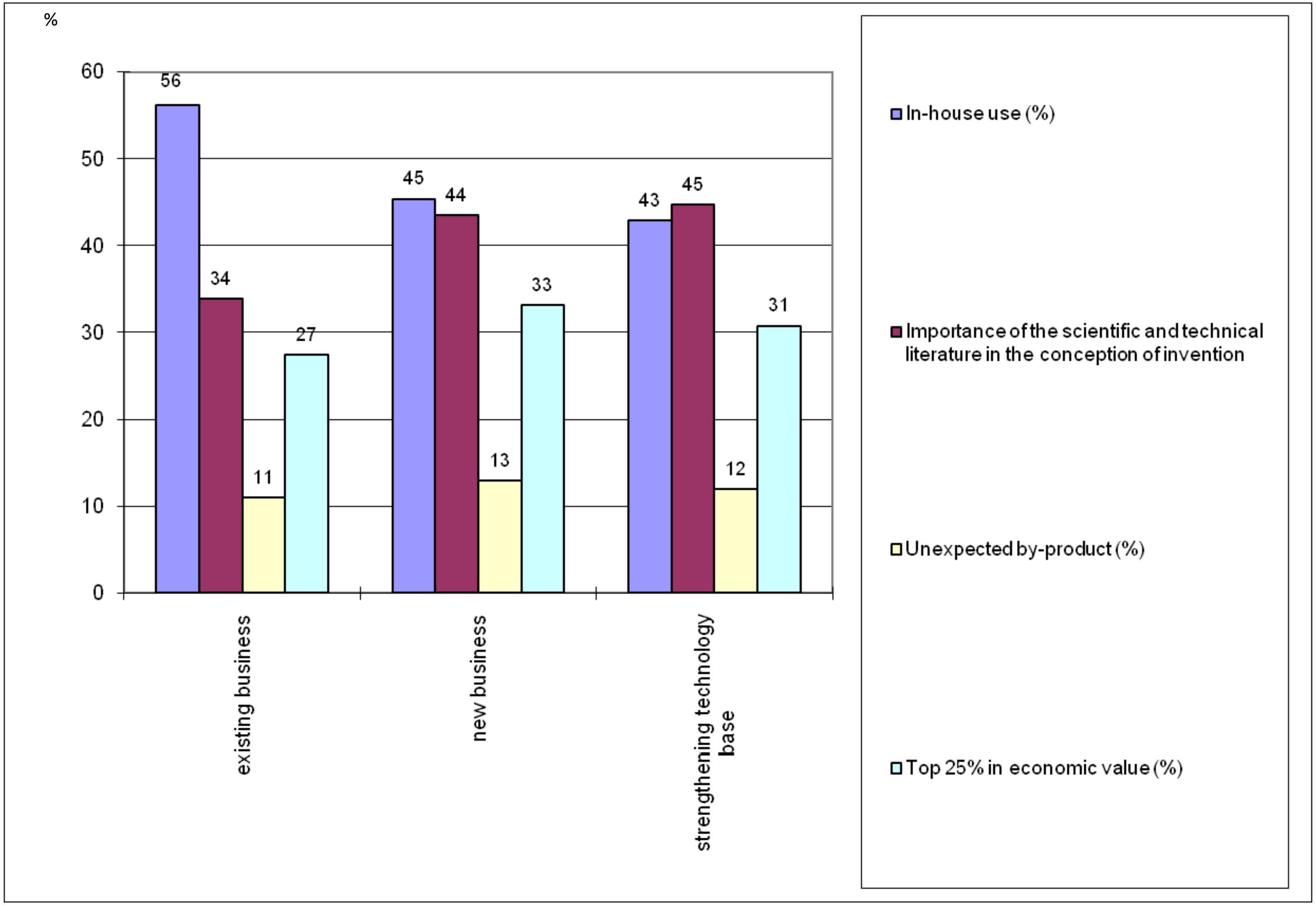


Table 1A. Bibliographic and other indicators by economic value of patent

	Forward citation	claims	scope in IPC	JP grant
Bottom half	1.4	7.9	2.5	0.35
Top half, but not top 25%	1.5	8.1	2.6	0.34
Top25%, but not top 10%	1.9	9.5	2.8	0.36
Top 10%	2.9	9.3	2.7	0.43

Table 1B. Bibliographic indicators by domestic economic value of patent (US)

	Forward Citations	**Number of claims**	**Number of IPC codes (scope)**
Bottom half	2.8	22.6	4.4
Top half, but not top 25%	3.1	23.2	5.0
Top 25%, but not top 10%	3.6	23.3	5.0
Top 10%	3.7	24.3	4.8

Table 2A R&D productivity determinants by business objectives (Ordered-logit Estimations, Japan)

			Existing business line: model 1			New Business: model 2			New Technology Base: Model 3		
	Dependent variable: Value of the patent		Coef.	Robust Std. Err.		Coef.	Robust Std. Err.		Coef.	Robust Std. Err.	
Value of the invention	Man months	4-6MM	0.134	0.157		0.083	0.301		1.285	0.530	**
		7-12MM	0.250	0.160		0.543	0.278	**	-1.139	0.629	*
		13-24 MM	0.624	0.153	***	0.679	0.263	***	-0.897	0.590	
		25-48 MM	0.688	0.166	***	0.635	0.300	**	-0.172	0.473	
		49-72 MM	1.137	0.239	***	0.814	0.358	**	-0.245	1.141	
		73-96 MM	1.672	0.402	***	1.018	0.538	*	2.868	0.736	***
		97MM-	1.088	0.254	***	1.010	0.343	***	0.426	0.924	
	Human capital	phd	0.407	0.157	***	0.635	0.205	***	0.421	0.535	
	Use of external knowledge	cncpt_sci	0.085	0.036	**	0.076	0.073		0.292	0.145	**
		cncpt_pat	-0.032	0.038		-0.083	0.073		-0.113	0.144	
	Size of organization	medium	-0.118	0.183		0.358	0.352		1.207	0.524	**
		small	-0.163	0.265		1.033	0.830		0.376	0.618	
		very small	0.782	0.259	***	0.776	0.357	**	0.819	0.535	
		Number of obs	1637			603			139		
		Log pseudo-likelihood	-2042.285			-769.783			-769.783		
		Pseudo R2	0.028			0.024			0.024		
	Dependent variable: Number of domestic patents to be granted		Existing business line: model 4			New Business: model 5			New Technology Base: Model 6		
			Coef.	Robust Std. Err.		Coef.	Robust Std. Err.		Coef.	Robust Std. Err.	
Number of domestic patents granted	Man months	4-6MM	0.489	0.149	***	0.041	0.267		-0.519	0.447	
		7-12MM	0.621	0.146	***	0.306	0.264		-0.218	0.463	
		13-24 MM	1.001	0.144	***	0.539	0.260	**	0.242	0.388	
		25-48 MM	1.236	0.149	***	1.200	0.272	***	0.524	0.476	
		49-72 MM	1.628	0.221	***	1.590	0.323	***	-0.303	0.579	
		73-96 MM	2.268	0.345	***	1.576	0.379	***	1.650	0.511	***
		97MM-	2.638	0.216	***	2.144	0.347	***	1.256	0.682	*
	Human capital	phd	0.148	0.149		0.585	0.224	***	0.195	0.298	
	Use of external knowledge	cncpt_sci	0.145	0.030	***	0.054	0.060		0.005	0.090	
		cncpt_pat	0.036	0.032		0.080	0.061		0.162	0.081	**
	Size of organization	medium	-0.412	0.163	**	-0.901	0.292	***	-1.199	0.437	***
		small	-0.641	0.213	***	-0.754	0.304	**	-0.219	0.428	
		very small	-0.230	0.194		-0.079	0.310		0.054	0.614	
		Number of obs	2210.000			762.000			216.000		
		Log pseudo-likelihood	-2642.951			-1031.292			-291.438		
		Pseudo R2	0.062			0.061			0.050		

Note: *** 1% significant, ** 5% significant, * 10% significant. 6 NBER technology category dummies not reported.

Table 2B. R&D productivity determinants by business objectives (Ordered-logit Estimations, US)

			Existing line			New line			Tech Base		
US Econ			Coefficient	Std. Error		Coefficient	Std. Error		Coefficient	Std. Error	
Value of Invention		4-6 months	0.365	0.244		0.907	0.390	**	0.969	0.368	***
		7-12 months	0.621	0.239	***	0.594	0.378		0.891	0.373	**
	Manmonth	13-24 months	0.813	0.242	***	0.929	0.374	**	0.915	0.378	**
		25-48 months	0.964	0.290	***	1.131	0.390	***	0.744	0.402	*
		49-72 months	1.122	0.368	***	1.247	0.534	**	0.951	0.608	
		72-96 months	1.490	0.831	*	0.864	0.675		1.248	0.974	
		97 months +	2.011	0.441	***	0.437	0.526		0.714	0.624	
	Human Capital	deg_phd	0.319	0.163	*	0.700	0.230	***	0.171	0.237	
	Use of External	Science	0.044	0.049		-0.043	0.066		0.039	0.069	
	Knowledge	Patent lit	0.040	0.048		0.003	0.062		0.037	0.066	
	Organization	Med	0.075	0.392		-0.363	0.621		0.248	0.568	
		Small	0.516	0.375		0.225	1.075		-0.216	0.692	
		Very Small	0.271	0.286		0.704	0.259	***	0.707	0.343	**
		Observation	925			450			455		
		R-Square	0.086			0.127			0.072		

			Existing line			New line			Tech Base		
US Tech			Coefficient	Std. Error		Coefficient	Std. Error		Coefficient	Std. Error	
Value of Invention		4-6 months	0.627	0.234	***	0.297	0.373		1.046	0.352	***
		7-12 months	0.843	0.232	***	0.509	0.353		0.856	0.354	**
	Manmonth	13-24 months	1.006	0.234	***	0.982	0.360	***	0.779	0.359	**
		25-48 months	1.226	0.281	***	0.977	0.374	***	0.674	0.380	*
		49-72 months	1.483	0.369	***	0.867	0.517	*	1.046	0.572	*
		72-96 months	2.377	0.844	***	1.041	0.661		2.507	1.019	**
		97 months +	2.563	0.433	***	0.964	0.485	**	1.411	0.621	**
	Human Capital	deg_phd	0.142	0.159		0.846	0.223	***	0.124	0.231	
	Use of External	Science	0.138	0.048	***	0.031	0.064		0.103	0.067	
	Knowledge	Patent lit	-0.031	0.047		-0.085	0.060		0.014	0.064	
	Organization	Med	0.396	0.390		-0.806	0.619		0.000	0.558	
		Small	0.462	0.380		-1.255	0.940		-0.566	0.679	
		Very Small	0.635	0.279	**	0.540	0.253	**	1.130	0.339	***
		Observation	925			450			455		
		R-Square	0.136			0.1524			0.13		

Note: *** 1% significant, ** 5% significant, * 10% significant. 6 NBER technology category dummies not reported.