Human capital in science and technology: policy typology and recommendations

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Executive Summary: Science and technology workforce development are one of the major concerns in science and technology policy. Science and technology activities are transformative rather than static, and involve a diverse human capital and workforce such as the corporate engineers with practical experiences, university researchers with Ph.D., and laboratory technicians. Policies, directly or indirectly, keep shaping the science and technology workforce in the country, including the state appropriations for higher education and the No Child Left Behind act of 2001 as in the US. There are some dominant approaches in human capital policy, such as the economic approach of human capital and pipeline metaphor. In science and technology workforce and policies, a pipeline metaphor has been dominant for decades, which assumes that the pipeline of training and education systems delivers students from early education to higher education and specialized training, and then into science and technology careers. The pipeline model implies a simplified and linear career trajectory with attention to discrete inputs and outputs for the pipe such as the headcounts of the workforce, and its policy prescriptions are mostly to expand, enhance and repair the pipe.

This article applies the scientific and technical human capital (STHC) model to supplement the economic and pipeline approaches in the analysis of the science and technology workforce policy. The STHC approach sheds light on the capacities and resources of human capital including their know-how and networks, where their diversity potentially benefits the science and technology activities as individual human capital brings unique resources. The STHC approach further regards human capital development as a long-term, accumulative and inherently social process. This article presents a theoretical framework and typology of economic, pipeline and STHC approaches based on the policy examples from a Japanese context. Then five policy recommendations with STHC perspectives are presented with some Japanese policy examples, namely on the (i) variation of opportunities, (ii) mobility and resource exchange, (iii) gifted education, (iv) teachers, and (v) language and cultural capacity. The STHC issues such as the diversity themselves may not be brand-new in human capital policy practice, but this article suggests why they matter and what can be done as the policy prescriptions. Although the examples are drawn from Japanese context, these recommendations are applicable to other contexts

I. Introduction

National governments implement policies to promote science and technology with the public, private and economic values as in the case of the United States (Bozeman and Sarewitz 2005), and human capital is often recognized as an important component of science and technology activities (Stine and Matthews 2009). In this study, human capital and workforce refer to the students and workers who are directly or indirectly involved in the science and technology activities. In a broad sense, they include workers with a range of professions and positions such as the university scientists and engineers, corporate scientists and engineers, laboratory technicians, students in science and technology, and supporting human capital such as research administrators. Despite the circulation of human capital across national borders, national governments seek to manage the development and flow of the science and technology workforce in the country (Davenport 2004; Heitor, Horta and Mendonca 2014; Mahroum 2007). Human capital policy embodies on-going trends such as science, technology, engineering, and mathematics (STEM) education (Kuenzi 2008), gifted education (Ibata-Arens 2012), or a specific legislation such as the No Child Left Behind (NCLB) Act of 2001 in the US. Further, both policy and non-policy mechanisms influence human capital and workforce in science and technology in general (Hira 2010; Mahroum 2007).

On one hand, studies and policies about human capital and workforce contain a set of approaches such as economic analysis (Schultz 1961, Becker 1962), social capital and human capital (Coleman 1988) and the pipeline model (Cannady, Greenwald and Harris 2014). The pipeline model has been dominant in science and technology workforce studies and policies (Cannady, Greenwald and Harris 2014), which assumes more linear and less varied career and training trajectories of human capital. On the other hand, scientific and technical human capital (STHC) model by Bozeman, Dietz and Gaughan (2001) presents an evaluative framework for research activities with a focus on capacities and abilities of science and technology human capital together with social capital. The STHC model can benefit the studies and policies of science and technology human capital by incorporating the perspectives such as resources and social capital and by conceptualizing human capital development as a non-linear, accumulative and socially embedded process.

This article illustrates how the STHC perspectives can be applied to the human capital policies in promoting science and technology at a national level by supplementing the economic and pipeline approaches. This article firstly presents an overview and typology of the three approaches with policy and program examples from the Japanese context, and then five policy recommendations are presented. These recommendations are largely based on the STHC perspectives about diversity, and ties and networks. In so doing, this article suggests the potential benefits and uniqueness of the STHC perspectives in supplementing the economic and pipeline approaches in science and technology workforce policy. Japanese examples are used here because the Japanese national government has made intensive efforts for science and technology development and relatively stronger control over the science and technology human capital development including the university policies, compared to other countries such as the US with federalism.

II. Human capital policy in science and technology- theoretical framework

Human capital here generally refers to the workforce and students in science and technology. As Bush (1945) mentions the importance of preparing appropriate human talent in fostering science and technology at the national level in the postwar US, governments, directly and indirectly, maintain systems to provide certain quantity and quality of human capital. The public education and training schemes for human capital and workforce range from basic schooling systems to higher education, and recurrent education of the existing workforce. For example, some federal departments such as the National Institutes of Health (NIH) fund Ph.D. students in specific ways which shape the human capital in the field with different qualitative experiences (Blume-Kohout and Adhikali 2016). Different countries may have different systems for developing their science and technology workforce, as in the graduate training and funding systems in the US and France (Gaugan and Robin 2004). The mobility of human capital across the national borders also shape the dynamics and national policies on human capital (Heitor, Horta and Mendonca 2014; Davenport 2004).

The quality of human capital can be partly assessed with quantitative measures, often as the standardized tests. The Organization for Economic Co-operation and Development (OECD) conducts the Programme for International Student Assessment (PISA) to assess the knowledge and performance of fifteen-year-old students on the subjects such as reading, mathematics, science, and problem-solving (OECD 2014). The OECD is developing the Assessment of Higher Education Learning Outcomes

(AHELO) as a global measure of the students' higher education learning, which tests both generic skills such as critical thinking, and discipline-specific skills such as those for economics and engineering (OECD 2012a). The NCLB Act of 2001 is another policy example to require and measure certain levels of knowledge and skills among students through standardized testing. However, the workforce in science and technology is diverse in the qualitative aspects such as their educational backgrounds, disciplinary fields, professions and relevant capacities including working habits, personal characteristics, and networks. Furthermore, science and technology and related industry and economy are transformative rather than static. Different forms of science and technology, industry and economy may require human capital and workforce with appropriate capacities (Teixeria and Queirós 2016).

In the analysis of human capital, economic approaches mostly focus on the investment in human capital and corresponding economic returns such as wage, and factors such as healthcare, on-the-job training, formal schooling and education and study programs for adults, which are supposed to improve human capabilities (Becker 1962, Shultz 1961). However, Becker (1962) already points out the limitation of the conventional measurements of human capital in economic approach, as 'Economists have long been aware that conventional measures of ability- intelligence tests or aptitude scores, school grades, and personality tests- while undoubtedly relevant at times, do not reliably measure the talents required to succeed in the economic sphere. (Becker 1962: 45)' In the context of science and technology workforce and research activities, the economic approach may focus on the factors such as the headcounts of scientists and engineers, students' scores on the standardized tests, the amount of research expenditure, and publication of research articles, patents, and other products.

Further, in science and technology workforce policies, a pipeline metaphor has been dominant for decades, which assumes that the pipeline of training and education systems deliver students from early education to higher education and specialized training, and then into science and technology careers (Cannady, Greenwald and Harris 2014; Clark Blickenstaff 2005; Metcalf 2010). The pipeline model is relatively close to the economic approach, as its metaphor implies the simplified and linear career trajectory, and emphasizes inputs and outputs of the pipe rather than the process of human capital development. Policy prescriptions from the pipeline metaphor are largely based on the guiding principles of 'increase the flow and patch the leaks (Cannady, Greenwald and Harris 2014: 448)'. Cannady, Greenwald and Harris (2014) argue that the pipeline metaphor negatively impacts the related policy decisions by suggesting the policy remedy to repair the pipe leakage which can be an inadequate policy measure, and by simplifying the complex career trajectories as a more linear model with 'one inlet, one outlet, and one direction of flow (Cannady, Greenwald and Harris 2014: 445)'. The reliance only on the fixed and unquestioned benchmarks for human capital such as the number of students and standardized testing scores potentially lead to the narrower outcomes by focusing on the completion of certain levels and types of learning, with the expectation of uniform experiences (Cannady, Greenwald and Harris 2014).

Economic and pipeline approaches justify a set of policies especially with the planning of headcounts of students and human capital and standardized measurements of their knowledge and skills. While these planning and measurements may provide a basic strategy to manage science and technology workforce at a national level, they pay less attention to the process, diversity and ties of human capital development and science and technology activities. The level of significance of the issues of diversity and ties may vary among the different types of science and technology activities. For example, on one hand, in a manufacturing factory where its aim is simply to produce a certain quantity of product with a certain quality, in the same way, every day by manual labor, the diversity of human capital may not have a great implication. On the other hand, the diverse human capital potentially with greater creativity and stimulating ideas may benefit the research teams at universities or a company which aims to develop a new product. This is not to argue that economic and pipeline perspectives are inappropriate in science and technology workforce policy, but to suggest that the related policies need to consider other types of factors too.

According to Bozeman, Dietz and Gaughan (2001), microeconomic models such as the benefit-cost analysis are dominant in the professional evaluation of science and technology policy in the US. Bozeman, Dietz and Gaughan (2001) present an original model of STHC as an evaluative framework of science and technology projects and programs that is different from a heavily economic analysis. The original model of STHC is the 'expanded notion of human capital when paired with a productive social capital network that enables researchers to create and transform knowledge and ideas in ways that would not be possible without these resources. (Bozeman, Dietz and Gaughan 2001:718)' Integration of social capital perspectives in the analysis of human capital and research activities makes the STHC model distinct from preceding economic and pipeline approaches. As one of the classical works on human capital and social capital, Coleman (1988) defines social capital by its function, and asserts that social capital is 'not a single entity but a variety of different entities, with two elements in common: they all consist of some aspect of social structures, and they facilitate certain actions of actors- whether persons or corporate actors- within the structure. (Coleman 1988: S98)' For Coleman, social capital is different from other types of capital, as social capital 'inheres in the structure of relations between actors and among actors. (Coleman 1988: S98)' The STHC model basically follows Coleman's interpretation of the intimate interplay of social capital and human capital.

In the STHC model, internal and external resources of human capital have significant roles in shaping the activities, outputs, and outcomes of science and technology (Bozeman, Dietz and Gaughan 2001). The internal resources involve cognitive skills, substantive scientific and technical knowledge and contextual skills of human capital, while external resources refer to social capital and embedded network ties of scientists, and each scientist builds nodes and networks differently (Bozeman, Dietz and Gaughan 2001:726- 728). According to Bozeman, Dietz and Gaughan (2001), the diversity of the network-mediated resources facilitate the works of scientists, and different individuals bring unique STHC to the projects and tasks. Variation of human capital is appreciated because of their variation in STHC resources, as 'even no two physics degrees are the same (Bozeman, Dietz and Gaughan 2001: 721)'. In the STHC model, scientific activities and related human capital development are accumulative and inherently social, although the process itself may take place within the 'black box (Bozeman, Dietz and Gaughan 2001: 721)'. Studies such as Borrás and Edquist (2015) and Mahroum (2007) also point out the importance of capacity, capability, competence, and resources in human capital development or science and technology activities, but the STHC model more explicitly values the diversity of human capital and accumulative and social nature of human capital development.

In addition, the absorptive capacity of individuals and organizations may be part of STHC or foster the acquisition and exploitation of STHC resources. Absorptive capacity originally refers to the firm's capacity to identify, access and exploit the external knowledge to achieve a specific aim such as the invention of products, and the prior knowledge and experiences shape their ability and ways of their access and interaction with external knowledge (Cohen and Levinthal 1990; Fabrizio 2009). In absorptive capacity, awareness and knowledge about the location of useful knowledge such as 'knowledge of who knows what, who can help what problem, or who can exploit new information (Cohen and Levinthal 1990:133)' are also beneficial. As 'in modern science being scientifically brilliant is only necessary, not sufficient (Bozeman, Dietz and Gaughan 2001:724)', individual and organizational abilities to seek, identify, build and exploit internal and external STHC resources also shape their human capital development, and activities and outcomes of science and technology. STHC resources might be acquired intentionally for a specific purpose, or an individual may realize its value after acquiring the access to the resource without a specific purpose. The concept of absorptive capacity reminds us that resources are valued when they are identified, accessed and exploited for a specific purpose.

Studies of STHC largely focus on the topics such as research collaborations (Bozeman and Corley 2004), scientific and technical training systems and career trajectories (Gaughan and Robin 2004) and scientists and engineers' career trajectories and productivity in publication and patent counts (Dietz and Bozeman 2005). This is because the STHC model was originally proposed as an evaluative framework of research activities, which bridges the studies on individual careers in science and technology, and the studies about the role of individual human capital in the circulation of scientific and technical knowledge (Bozeman and Mangematin 2004). These studies tend to focus on specific types of human capital such as scientists, engineers, doctorate degree holders and graduate students (Bozeman, Dietz and Gaughan 2001; Dietz and Bozeman 2005; Bozeman and

Table 1. Policy focus examples

Approach	Policy focus examples
Economic	Increase and manage the headcounts of human capital • Expand educational systems • Attract foreign human capital • Enhance the supporting systems
Pipeline	Expand, enforce and repair the pipeline • Manage inputs and outputs of human capital • Enhance supporting systems and supporting human capital
STHC	Enhance resources, diversity, ties, networks • Increase specific type of human capital for overall diversity • Diversify opportunities and career tracks • Promote interactions and mobility of human capital

Corley 2004; Gaughan and Robin 2004). However, the STHC approach can be applied to analyze or plan the collective science and technology workforce such as the national workforce, which includes not only scientists and engineers but also other types of human capital such as laboratory technicians and research administrators. Studies of the collective STHC at a national level mostly focus on the international mobility of human capital (Davenport 2004; Woolley et al. 2008; Woolley and Turpin 2009).

In sum, the STHC approach brings useful perspectives in the evaluation and analysis of science and technology workforce policy, by supplementing dominant economic and pipeline approaches. While the original STHC model (Bozeman, Dietz and Gaughan 2001) was presented as an evaluative framework of research activities, its focus and premises are mostly transferrable to human capital and workforce policy. For example, human capital and STHC development is inherently social and is neither a solitary nor the singular event. The STHC approach requires the long-term and accumulative understanding of human capital development. The STHC approach emphasizes the individuals' capacity and social capital in addition to the basic knowledge and skills that are measured in general economic and pipeline approaches. This point implies that the increase of the sum of these capacities and resources may matter more than the mere increase of headcounts of the workforce. According to the STHC approach, an even smaller workforce may do better than larger one by enhancing their capacities and STHC resources. Furthermore, the variation of STHC is valued as the diversity may bring unique STHC resources to science and technology activities which facilitate the actions that are not possible without these resources.

III. Methods

In order to explore the application of the STHC perspectives in science and technology workforce policies at a national level, this article presents the policy typology of economic, pipeline and STHC approaches with policy and program examples. Policy and program examples were drawn from existing policies in the Japanese context, mainly by the Ministry of Education, Culture, Sports, Science and Technology (MEXT), the Cabinet Office and the Japan Society for Promotion of Science (JSPS). After presenting the typology and policy examples, policy recommendations are suggested based on the STHC perspectives.

IV. Typology and policy examples

Governments implement policies for the development of their science and technology workforce that are actually a combination of policies with economic, pipeline and STHC approaches. The three approaches are not mutually exclusive, and the boundaries between each approach are not necessarily clear. Table 1 presents a typology of the three approaches with simplified examples of policy orientations.

Science and technology workforce policy here includes the human capital development in both formal and informal education systems and the development in lifelong career tracks. Following part illustrates more detailed characteristics and policy examples in each approach, and the distinction of policy motivation and policy measures in applying the approaches.

IV-a. Economic approach

Policies in economic approaches generally seek to increase or manage the headcounts of human capital. As a typical approach, governments increase the number of students in its education systems. For example, the '8,000-Student Plan' was the first large-scale expansion of higher education after World War II in Japan (Itoh 2014). The Plan aimed to increase 8,000 seating capacity at universities in four years from 1957, which served to supply the science and technology workforce, especially the engineers to achieve the New Long-Range Economic Plan of 1957 as a country (Itoh 2014). The quantitative increase may focus on a specific type of human capital. In Japan, the national government launched a set of policies to reform and expand graduate schools since the late 1980s. The number of the total Ph.D. students increased from 25,880 in 1988 to 73,877 in 2015, and Masters' students increased from 56,596 in 1988 to 158,974 in 2015 according to the Basic Investigation of Schools. Further, the government may establish a new type of institute. The Japanese government officially opened a new type of higher education institutes, the colleges of technology (Koto Senmon Gakko, generally called as Kosen) in 1962 (Itoh 2014), in order to meet the demands for industrial engineers by providing five-year engineering education typically starting at fifteen years old. In total, 57,611 students learn at fifty-one national, three public and three private Kosen in 2015 according to the Basic Investigation of Schools. Encouragements and supports for the recurrent education of existing workforce are also economic policy measures, with the aim to expand the workforce with a specific set of knowledge and skills. Policies to increase foreign students and researchers is another measure to quantitatively expand the national science and technology workforce. As a classical example from Japan, in 1983, then Prime Minister Nakasone launched the 'Plan for 100,000 international students'. These policies intend to increase the supply of human capital for science and technology.

Economic type policies include the financial supporting systems for human capital. JSPS provides the Research Fellowship for Young Scientists, which includes the fellowships for Ph.D. students and post-doctoral researchers, and female post-doctors who temporarily stopped their research career due to the maternity leave and child care. The Fellowship had 5,852 participating fellows in the fiscal year 2015 (JSPS 2015:35). More generally, the Japan Student Services Organization (JASSO) provides scholarships for students in higher education. There are more indirect policies to increase the science and technology workforce, such as those to inspire school children to get involved in science and technology careers in the future. The national government established the National Museum of Emerging Science and Innovation (MIRAIKAN) in Tokyo in 2001 partly to stimulate the people's interests and understanding of science and technology. In 2002, the MEXT started Super Science High School (SSH) programs, in which the selected high schools develop and practice specialized educational curricula for science and technology in cooperation with other organizations such as universities, research institutes, private companies, local educational committees and relevant national government organizations (Japan Science and Technology Agency 2016). 200 high schools all across the country are enrolled in the SSH as of 2016 and engage in the development and practice of specialized curricula such as those on experience-based learning, problem-solving research, English and presentation, and the research presentation meetings for the SSH students (Japan Science and Technology Agency 2016). The economic approaches include not only the direct expansion of educational institutes but also the systems and programs to support and encourage human capital to pursue science and technology careers.

IV-b. Pipeline approach

The pipeline approach involves roughly two types of policies, one on the expansion of the pipeline itself, and another on the leakage prevention and remedies. Policies to expand the pipeline are the same as the economic type of policies, such as the policies to increase the inputs of the pipe by increasing the seating capacities and funding at educational institutes. The policies for the expansion may focus on broad human capital such as school children or on a specific human capital such as female or foreign researchers. Pipeline leakage remedies are more specific to the pipeline approach. The policy examples include the Restart Postdoctoral

Fellowship (RPD) by JSPS, to help re-starting of research career of the researchers who already have PhDs but stopped research career due to their maternity leave or infant care (JSPS 2015: 35). The RPD Fellowship select roughly seventy-five researchers per year, with no gender and age restrictions (JSPS 2015:36). In addition to the policies which directly support core human capital such as scientists and engineers, enrichment of supporting human capital systems such as the training of research administrators also helps the flow in the pipe.

IV-c. STHC approach

The STHC approach supports policies which increase the diversity of human capital, ties, and networks at both individual and collective levels. The diversity of human capital is basically the diversity of internal and external resources including their ties and networks. Individual human capital may vary in their educational and social backgrounds with varying amount and content of knowledge, skills and experiences. Even the college graduates from same academic disciplines or same institutes may have different amount and content of knowledge, skills and experiences. While it might be important that human capital with specific college degrees or qualification obtain a certain set of knowledge and skills, their diversity also matters. The diversity can be especially important in the activities which require the creativity and interaction among the human capital, as diverse human capital implies diverse resources in a certain activity, team or organization. At the collective level, policies for the quantitative increase of the specific types of human capital may serve to increase the overall diversity of types and levels of human capital, such as the policies to increase foreign researchers or female engineers, or policies to support talented elderly researchers to continue their career in a good research environment.

The mobility of human capital potentially increases their diversity, ties, and networks by diversifying their opportunities and career tracks and helping human capital build ties and networks differently. The Japanese government implements policies to promote international mobility of human capital. As mentioned before the national government initiated the 'Plan for 100,000 international students' in 1983, and the 'Plan for 300,000 international students' in 2008 in order to attract foreign human capital and internationalize the domestic institutes. More recently, the Cabinet Office declared their intent to double the number of Japanese students who study abroad by 2020, which led to the launch of Tobitate! (Leap for Tomorrow) Study Abroad Initiative by MEXT in 2013 as a public-private collaborative effort. This Tobitate! Initiative aims to increase the study abroad Japanese university students from 60,000 to 120,000, and high school students 30,000 to 60,000 by 2020 (MEXT 2016). In addition, the JSPS offers the funding for young Japanese researchers to visit foreign institutes for research activities and invite foreign researchers for research visits in Japan (JSPS 2015). The mobility of human capital within domestic institutes may similarly increase the interaction, ties, and networks of human capital, and diversify the career track, opportunities, and resulting experiences.

In addition, the STHC approach enables us to analyze the national human capital system as a more overall system which involves not only the core human capital such as scientists and engineers but also other human capital such as research administrators, science communicators, and school teachers as an important component of the system. In other words, the STHC approach suggests the need to consider the optimization of the science and technology human capital system as a more holistic entity. The potential significance of the supporting human capital such as the research administrators needs to be carefully considered partly because of the increasing complexity of the research management systems. As a policy example, the MEXT launched the 'System to Develop and Secure University Research Administrators (URA)' in 2011 in order to enforce the research administration systems and human capital development to support research activities which led to a rapid growth of the number of URAs (Sugihara, Sonobe and Mutoh 2014). The URAs may not very directly commit to the research activities but comprise a part of the human capital system for science and technology activities.

IV-d. Policy motivation and content

The motivation and content for one policy can involve multiple approaches. For example, a policy to increase the number of qualified female scientists may involve all the economic, pipeline and STHC approaches. A quantitative increase of female researchers can be understood as an economic measure to increase the entire headcounts of science and technology workforce. The actual policy examples may include the programs and funding to encourage female students to join in science and technology, or supporting hiring systems that are specific for female human capital. These policies serve as the pipeline expansion, leakage prevention and remedy. The policy motivation for the increase of female human capital may derive from the STHC reasons such as the need for the diversity of human capital in science and technology activities, as male researchers are dominant in some academic fields and professions.

V. Policy recommendations

As an STHC premise, human capital development and science and technology activities are basically accumulative and social processes that should be analyzed and planned with a long-term perspective. As shown in the policy examples, the STHC perspectives are not necessarily new in practical policy fields. However, the typology in this article and more explicit attention and careful examination of the STHC perspectives and the typology may benefit the explanation and future policy planning of the national science and technology workforce. Mere quantitative increase and supply of human capital with a certain level of knowledge and skills do not automatically serve to stimulate cutting-edge activities.

V-a. Diversity, ties, and networks

Two inter-related STHC perspectives are considered here, namely the diversity of STHC, and ties and networks. The diversity of human capital implies the diversity of internal resources such as cognitive skills, substantive scientific and technical knowledge and contextual skills, and diversity of external resources such as social capital and networks. In science and technology activities, different human capital may build and use the ties and networks differently as Feeney and Bernal (2010) investigate the gender difference of researchers in the formation and use of their ties and networks. The STHC approach encourages policies to foster the formation of ties and networks among human capital, as these ties and networks are expected to facilitate the exchange of their resources which enable certain actions that are otherwise not possible. The diversity of these ties and networks potentially lead to the accumulation of more diverse resources with unique and valuable knowledge, know-how and opportunities.

Individual ties and networks are qualitatively different, as the distinction of strong ties and weak ties by Granovetter (1973). According to Granovetter, the combination of four factors is used to identify the strength of a tie, namely 'the amount of time, the emotional intensity, the intimacy (mutual confiding), and the reciprocal services which characterize the tie (Granovetter 1973:1361)'. Burt (2000) presents the concept of structural holes as social capital, where he conceptualizes society as a place in which people exchange goods and ideas for their individual purposes. Within the network structure with multiple individuals, the weaker connections between the separate groups are understood as the holes in the social structure. These holes give the advantage to the individuals who are located in the linkage of the two groups, which is called 'a function of brokerage opportunities (Burt 2000:353)'. Burt argues that the 'individuals with contact networks rich in structural holes are the individuals who know about, have a hand in, and exercise control over, more rewarding opportunities. (Burt 2000: 355)' More diverse and greater sum of individual's ties and networks potentially increase the chance to reach more and unique and advantageous structural holes in science and technology activities, which may benefit the science and technology outcomes at a collective level. Lazega and Pattison (1999) argue that the structures and patterns of exchanges formulate and involve certain regularities. Policy interventions may facilitate the formation of such structures and patterns.

Thus the diversity of human capital, including the diversity and uniqueness of their ties, networks may enhance the access to broader and more unique sets of STHC resources. While individuals acquire and utilize the resources to achieve their purposes, organizations may provide resources that can be accessed and utilized by individuals at the organization (Lazega et al. 2006). In science and technology context, organizations at various levels such as a research institute, laboratory, research team, educational unit or local government may provide organizational social capital to facilitate the individual or collective tasks. Furthermore, an exchange may take place either in a restricted dyadic, triadic or larger network with multiple members (Lazega and Pattison 1999). A long-term friendship of researchers, the three-year mentoring relationship between an adviser and a Ph.D. student, and three-week research activities as a collaborative team at a private company laboratory facilitate the formation of STHC all differently.

V-b. STHC recommendations

From the STHC perspectives, following five points can be the policy focus in the science and technology workforce policy. The insights are generally based on the Japanese context, but mostly applicable to other contexts.

(i) Variation of opportunities

For the entire national system for the science and technology workforce, the variation of the opportunities for human capital can be an important policy issue. As an example, the diversification of funding styles for graduate students may help to yield greater and diverse sum of STHC resources at the collective national level. Because the diversity of the experiences of researchers result in the diversity of their internal and external STHC resources and capacities. In Japan, as already noted, the JSPS offers the Fellowship for Young Researchers to fund selected Ph.D. students and post-doctors. These fellowships help young researchers to pursue their education and research careers, but may partly homogenize their training styles, career tracks and resulting and available STHC resources. The STHC perspectives may demand policies to diversify the funding and training for graduate students, such as the development of a system to encourage the private companies and research institutes to fund and collaborate with graduate students, or fund students to pursue undergraduate or graduate degrees at foreign institutes. For the variation of opportunities, non-linear and flexible educational and career trajectories of human capital may bring more diversified experiences and resources too. While the linear and fixed educational and career tracks may bear more stability for individuals, the diverse trajectory choices and diversify individuals' experiences may enhance the collective STHC. In addition to the opportunities themselves, surrounding supports and encouragements such as the assurance of job security and financial assistance would matter.

(ii) Mobility and resource exchange

From the STHC perspectives, mobility and circulation of human capital potentially diversify the educational and career tracks of human capital and foster resource exchange. The mobility may result in the better sum of STHC at both individual and collective level in the long run. Human capital in science and technology, either as a student, corporate engineer or university biochemist, interact with others and exchange resources partly by being mobile. Policies may stimulate this mobility and exchange by facilitating international and domestic human capital circulation, those across institutes, disciplines, and sectors. In addition to the mobility with the change of official affiliation, short-term mobility such as sabbatical research visits, short-term research visits for young faculty, conference participation, and temporary research collaborations may also foster the resource exchange. For the institutes with fewer resources, human capital mobility may enable the access a to a greater amount of resources and unique and important resources that are available through the human capital at other teams and institutions. However, a mere increase of flow of human capital does not automatically enhance resource exchange and exploitation. In meeting people and visiting somewhere, people actually need further efforts to make connections and exchange resources. For international mobility, factors such as the process and content of experiences of individual human capital (Velema 2012), science policy and conditions in the country of origin (Velema 2012; Heitor, Horta and Mendonca 2014; Davenport 2004), and non-policy mechanisms such as employment trends (Hira 2010) also shape the human capital development and resulting science and technology outcomes. The mobility policy needs a careful consideration because some of them such as the increase of short-term untenured jobs may lead to a greater job insecurity.

(iii) Gifted education

The STHC perspectives support a supply of different types and levels of education and training for people with different abilities and curiosities, rather than offering a uniform set of education for all students without any questions. Gifted education is one of the ways to enrich individual and collective human capital development. Gifted learners can develop to be the leading human capital in science and technology such as the scientists, entrepreneurs, and innovators, when they receive the appropriate set of education with intellectual stimulation and enrichment (Ibata-Arens 2012). For gifted education, the standardized testing in economic approach may be used as the measurement of ability and performance but it may not suffice to understand other dimensions of human capital such as the STHC resources and creativity. Ibata-Arens (2012) points out that the Japanese education system has less attention on the gifted education, while other Asian countries are more eager on this issue such as the gifted schools and special programs at public educational institutes. From economic measurements on the achievement of students' learning, the Japanese education system may appear as successful as Japanese students scored second in mathematics performance and first in both reading and science performance among the OECD countries in the PISA 2012 (OECD 2012b). However, these measurements do not address the diversity and uniqueness of human capital that can be important in knowledge-intensive science and technology activities. The STHC perspectives may encourage the gifted education and the diversity within education in order to increase the sum and diversity of internal and external STHC resources and capacities of human capital more effectively.

(iv) Teachers

School teachers can be an important supporting human capital in science and technology human capital system. Teachers themselves may not engage in the research activities or product development at companies, but teachers are important because they shape the development of human capital who may join in the science and technology careers in the future. Teachers may directly or indirectly offer STHC resources including the ties and networks which potentially bring beneficial opportunities for the students. Or teachers may inspire the students for their future science and technology careers. While teachers may teach classes in a standardized way, individual teachers have different STHC resources and experiences, and these elements potentially shape the students' learning and experience through formal and informal interactions. In addition to stimulating the teachers' roles in everyday learning, policies may offer other opportunities and teaching human capital such as the summer camps and visiting lecturers in order enhance the students' access, acquisition, and utilization of STHC resources. Teachers' STHC resources are not homogeneous, as one's decades-long experience as a school science teacher, one's research career at a university, and one's experience as a computer scientist at a private company. These teachers' STHC resources may be utilized in providing resources to the students and shaping stimulating the students' learning.

(v) Language and cultural capacity

For those whose primary language is not English, English language competency can be an important ability, as English is often required as a common language in academic journal publications and in interaction with human capital from different language traditions. The language and cultural capacity of the human capital enhance both individual and collective STHC capacities and resources. For example, again, a mere mobility of human capital does not enhance individuals' and collective STHC. They have to meet people, talk to people, get connected, and then they may have opportunities to use these ties for certain purposes thereafter. The language and cultural capacity are important for the non-mobile and English-native human capital too, in interacting with mobile human capital. Both of them need to be capable of building and utilizing the resources and ties for their purposes if they aim to maximize the outcomes of the opportunities just like an absorptive capacity of the firms. Science and technology activities and human capital development almost inevitably involve human and social interactions. Although the individuals may need these language and cultural capacities, the governmental policies and organizations can help human capital's acquisition of these capacities.

VI. Conclusions

This article presented the typology of the economic, pipeline and STHC approaches in the science and technology workforce policy basically at the national level, and five policy recommendations from the STHC perspectives. The STHC approaches in policies such as the diversity of human capital may not be brand-new in human capital policy practice. However, this article suggests why they matter and what can be done in the field of science and technology human capital and workforce policy. The policy typology with STHC approach helps a more systematic analysis and planning of the science and technology workforce policies both for researchers and policy makers. The development of the science and technology workforce takes a long time and takes further time to observe the ultimate outcomes in science and technology activities. The measurement of the STHC and long-term policy outcomes can be more challenging compared to the measurements of discrete products and benchmarks, but this does not reduce the value of the STHC perspectives in human capital policy. Moreover, the Japanese cases indicate the importance to consider the surrounding social, economic, political and cultural contexts such as English education. The perspectives and recommendations in this study are applicable to national, regional and local levels and individual program levels.

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