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【要旨】

Japan promotes doctoral education by providing financial support to Ph.D. students and encouraging firms to hire graduates. To evaluate these policies, this paper develops a heterogeneous agent macroeconomic model in which Ph.D. graduates can work in the industrial sector as well as in the academic sector. In general equilibrium, the industrial-sector career option barely works as insurance for students who aim for an academic career. In the economy with this career option, a student subsidy generates a larger increase in overall enrollment than a hiring subsidy of the same fiscal cost. The hiring subsidy instead moves some students who would have entered academia into industry and raises aggregate output. These results suggest that the choice between these fiscal policies should depend on whether the goal is to attract new Ph.D. students or to change the careers of those who would enroll anyway.

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Ph.D. Enrollment and the Option Value of Industrial Careers*

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November 9, 2026

Abstract

Japan promotes doctoral education by providing financial support to Ph.D. students and encouraging firms to hire graduates. To evaluate these policies, this paper develops a heterogeneous agent macroeconomic model in which Ph.D. graduates can work in the industrial sector as well as in the academic sector. In general equilibrium, the industrial-sector career option barely works as insurance for students who aim for an academic career. In the economy with this career option, a student subsidy generates a larger increase in overall enrollment than a hiring subsidy of the same fiscal cost. The hiring subsidy instead moves some students who would have entered academia into industry and raises aggregate output. These results suggest that the choice between these fiscal policies should depend on whether the goal is to attract new Ph.D. students or to change the careers of those who would enroll anyway.

Keywords: Ph.D. Enrollment, Career Options, Subsidy Policy, General Equilibrium

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1 Introduction

The human capital of Ph.D. holders is important for innovation and aggregate output, but Ph.D. enrollment in Japan has been declining. The Japanese government's plan sets a target of raising the number of Ph.D. graduates per million population to about three times the fiscal year 2020 level by 2040. The government cites financial concerns during doctoral study and uncertainty about career opportunities after graduation as reasons for the decline in enrollment. It states that Ph.D. graduates can bring innovation to society, but that they are not yet employed in a wide range of industries in Japan. Among FY2012 graduates in Japan, the share working in private firms is 26.2% 1.5 years after graduation and 26.8% 6.5 years after graduation (NISTEP, 2020). In the United States, the corresponding share among Ph.D. holders in science and engineering is 28.2% at the time of the degree and 45.9% six to ten years after the degree (NCSES, 2026; NCSES, 2025). For this reason, the government also aims to increase the number of Ph.D. graduates working outside universities. The government pursues these goals through policies for doctoral students and policies for firms. Since fiscal year 2021, the government has provided doctoral students with financial aid and support for entering the industrial sector. The government also encourages firms to hire Ph.D. graduates through a research and development tax credit for part of their personnel costs. The government has also asked business associations to expand the hiring of Ph.D. graduates and improve their treatment, and it has published a guidebook for firms on hiring Ph.D. graduates.[1]

These policies assume that career options after graduation affect Ph.D. enroll-

[1]See MEXT (2024), MEXT (2025a) and MEXT and METI (2025).

ment decisions. The option of working in the industrial sector can encourage two types of households to enroll. The first type is households with high human capital that can earn more in the industrial sector after a Ph.D. than with only a Master's degree. The second type is households that want to work in the academic sector. Because Ph.D. enrollment is irreversible, these households may view the industrial sector as insurance in case an academic career does not go well.

To conduct this analysis, I develop a heterogeneous agent macroeconomic model of Ph.D. enrollment with a two-stage decision process. Households differ in assets, human capital, and academic taste. They first choose whether to enroll in a Ph.D. program. Those who enroll can then choose between the academic and industrial sectors after graduation. At the time of enrollment, households face uncertainty about their future human capital and sector-specific productivity. Sector-specific productivity makes some households better suited to the academic sector and others to the industrial sector. After these are realized, they can choose which sector to enter. Thus, the enrollment decision reflects the option value of choosing a career based on the realized human capital and sector-specific productivity. Here, a career means the job that a household takes after graduation in the academic or industrial sector.

I conduct the analysis in two steps. First, I examine how the option of working in the industrial sector affects Ph.D. enrollment, and which type of households it encourages to enroll. Second, given this option, I examine how policies for doctoral students and for firms affect enrollment and career choices. I represent the tax credit for firms as a hiring subsidy. Under this subsidy, the government pays a share of firms' wage costs for Ph.D. graduates in the industrial sector. I evaluate how this

subsidy affects enrollment, career choices, and aggregate output, and I compare it with financial support for doctoral students at the same fiscal cost.

The analysis provides four main findings. First, the option of working in the industrial sector after a Ph.D. encourages doctoral enrollment. However, in general equilibrium, the option as insurance gives academia-bound households almost no incentive to enroll, because they would enroll to work in the academic sector even without the option. Almost all households that enroll because of the option work in the industrial sector after graduation. Second, the availability of this career option increases the enrollment response to financial support during doctoral study. Financial support reduces the cost of doctoral study and relaxes the borrowing constraint, so marginal households that are close to enrolling choose to enroll. The option increases the number of such households. Third, the effect of hiring subsidies for Ph.D. graduates in the industrial sector depends on the scale of the subsidies. Small subsidies increase the number of Ph.D. graduates in the industrial sector without reducing the number in the academic sector, because some new enrollees choose the academic sector after graduation. Large subsidies reduce the number of Ph.D. graduates in the academic sector, because more enrollees choose the industrial sector instead. Fourth, at the same fiscal cost, financial support for doctoral students leads to a larger increase in Ph.D. enrollment, including among households with few assets. It also increases the number of Ph.D. graduates working in the industrial sector more than hiring subsidies. This is because the new enrollees have lower academic taste than baseline enrollees, and more than half of them choose the industrial sector after graduation. However, the increase in enrollment still occurs almost entirely in a relatively high quartile of academic taste. In contrast, hiring subsidies lead some households that enroll with or without the policy to choose

the industrial sector instead of the academic sector. Financial support for doctoral students does not have this effect. Financial support for doctoral students therefore mainly increases enrollment, while hiring subsidies also change the allocation of Ph.D. graduates between the two sectors. This change in allocation increases aggregate output, because Ph.D. graduates are more productive in the industrial sector than in the academic sector.

The remainder of this paper is organized as follows. Section 2 reviews the literature on Ph.D. enrollment and the careers of Ph.D. graduates. Section 3 presents the model. Section 4 calibrates the model to Japanese data and evaluates its fit. Section 5 examines the value of the industrial-sector career option and presents the policy experiments. Section 6 concludes the paper and discusses directions for future research.

2 Literature Review

This paper relates to four strands: sequential education decisions, sector choices of Ph.D. graduates, subsidies for firms, and the allocation of research talent.

First, education can be viewed as a sequence of decisions under uncertainty (Altonji, 1993). The opportunity to make further choices after enrollment gives an option value to entering college (Stange, 2012; Trachter, 2015). Hayama (2026) studies Ph.D. enrollment in Japan using a heterogeneous agent model in which Ph.D. graduates work only in the academic sector. It finds that enrollment responds only modestly to larger subsidies for doctoral students. I examine how the option to choose between the academic and industrial sectors after the Ph.D. affects enrollment and its response to subsidies.

Second, this paper relates to the sector choices of Ph.D. graduates. Sector-specific productivity provides a basis for occupational selection (Roy, 1951; Heckman and Honoré, 1990). Career preferences can also change during doctoral study, including a decline in interest in academic careers (Sauermann and Roach, 2012; Roach and Sauermann, 2017). I model sector choices using sector-specific productivity and taste shocks, and examine how these later choices affect doctoral enrollment.

Third, studies of hiring subsidies and R&D tax incentives examine how firms respond to financial support (Neumark and Grijalva, 2017; Cahuc et al., 2019; Dechezleprêtre et al., 2023). For highly educated labor, Kaiser and Kuhn (2016) find that a wage subsidy increases employment but has no significant effect on labor productivity or profits. I examine how a subsidy for hiring Ph.D. holders also affects the earlier decision to enter doctoral study.

Fourth, the allocation of talent matters for aggregate output and policy effects (Hsieh et al., 2019). Akcigit et al. (2021) show that research subsidies can distort the allocation of resources between basic and applied research. In this paper, effective labor in the academic and industrial sectors is complementary in production. I examine how subsidies affect the supply and allocation of Ph.D. holders in general equilibrium.

The closest paper is Akcigit et al. (2025), which studies education and innovation policies in an endogenous growth model. They show that R&D subsidies are more effective when combined with education subsidies for talented young people from low-income families. I focus on doctoral enrollment and sector choices in Japan, comparing financial support for doctoral students with hiring subsidies at the same

fiscal cost.

3 Model Economy

The economy consists of three types of agents: households, firms, and a government. Time is discrete and given by $t = 0, 1, 2, \ldots$, and persists over an infinite horizon. In what follows, I omit the time subscript t and the household index i for notational simplicity, as the Bellman equation represents the problem for any household given its state. I model a household's decision to enroll in a Ph.D. program and the subsequent choice between the academic and industrial sectors after graduation. I also introduce production complementarity between the effective labor of Ph.D. holders in the two sectors. I begin by describing the demographic structure and career paths. Next, I define the economic environment and the household's problem. Appendix A defines the stationary recursive competitive equilibrium.

3.1 Demography

The economy is populated by a continuum of households (dynasties), indexed by i.

Each household is a unitary family comprising two members called the "Young" and the "Old," who pool income and assets and share a common objective. An individual who is the Young in period t becomes the Old in period $t + 1$, while the dynasty continues indefinitely. I interpret one model period as a 30-year generational interval.

In this model, I define three occupations for households: immediate employment with a Master's degree (M), academic research positions after a Ph.D. (A),

and employment in the industrial sector after a Ph.D. (I). I model the occupational choice as a two-stage process. In the first stage, the Young chooses between immediate employment with a Master's degree (M) and Ph.D. enrollment (D). Once the household chooses D, it cannot return to M. In the second stage, a household that has chosen D compares A with I upon graduation, when it observes its realized general human capital and sector-specific productivity, with taste shocks.

3.2 Environment

All markets, including the final goods market and the factor markets for labor and capital, are assumed to be perfectly competitive.

3.2.1 Households

Households are heterogeneous in assets, human capital, occupation, academic taste, and sector-specific productivity. The state of a household is $(a, h, \kappa, \theta, \psi)$. Because each household acts as a unitary family, these state variables describe the family as a whole or its specific members. Specifically, a denotes the pooled assets of the family. The variables h and θ represent the human capital and academic taste of the dynasty, which are persistent across generations. The occupation κ and the sector-specific productivity ψ apply to the Old member and determine current labor income.

Human capital is specified in logarithms and follows an AR(1) process:

$$\ln h' = \varphi^h \ln h + \varepsilon^h, \quad \varepsilon^h \sim N\Big(0, {\sigma^h}^2\Big). \tag{1}$$

Here, $\varphi^h \in (0, 1)$ is the autoregressive coefficient, and ε^h is an i.i.d. shock.

Academic taste θ is the non-pecuniary value that the household attaches to working in the academic sector after the Ph.D. This value captures the preference for research freedom, including the ability to conduct independent research and publish papers. Previous studies show that researchers place a significant monetary value on the freedom to publish and often accept lower wages to obtain it (Stern, 2004; Sauermann and Roach, 2014). I assign this taste exclusively to the academic sector because employment in the industrial sector and immediate employment with a Master's degree generally lack this degree of research independence. While the human capital process is specified in logarithms, the academic taste process is defined in levels. This specification allows academic taste to take both positive and negative values. The academic taste process θ follows an AR(1) process with a constant mean:

$$\theta' = \left(1 - \varphi^{\theta}\right)\bar{\theta} + \varphi^{\theta}\theta + \varepsilon^{\theta}, \quad \varepsilon^{\theta} \sim N\left(0, \sigma^{\theta 2}\right). \tag{2}$$

Here, $\varphi^{\theta} \in (0, 1)$ is the autoregressive coefficient, $\bar{\theta}$ is the unconditional mean, and ε^{θ} is an i.i.d. shock.

I add a sector-specific productivity shock ψ to distinguish households that are better suited to A from those better suited to I. The shock follows a normal distribution with mean zero and standard deviation σ^{ψ}, and is independent of h', θ', and past values of ψ. It is redrawn each period and is not persistent across dynasties.

$$\psi' \sim N\left(0, (\sigma^{\psi})^2\right). \tag{3}$$

However, ψ affects the current income of a household in A or I.

All possible combinations of these household states are defined as the state space $\mathcal{S} := \mathcal{A} \times \mathcal{H} \times \mathcal{K} \times \Theta \times \Psi$. Here, $\mathcal{A}$, $\mathcal{H}$, $\mathcal{K} = \{M, A, I\}$, Θ, and Ψ are the respective sets for assets a, human capital h, occupation κ, academic taste θ, and sector-specific productivity ψ. The measure μ represents the proportion of households distributed across the state space $\mathcal{S}$, satisfying $\mu(\mathcal{S}) = 1$.

Each household possesses a basic level of human capital h; however, the effective utilization of this human capital depends on the chosen occupation κ. The effective human capital $\tilde{h}$ is defined as follows:

$$\tilde{h} := \begin{cases} 1 & \text{if } \kappa = M, \\ \gamma^A h & \text{if } \kappa = A, \\ \gamma^I h \exp(\psi) & \text{if } \kappa = I. \end{cases} \tag{4}$$

Under this specification, the sectors differ in income risk. The M path offers a constant productivity of one, whereas the Ph.D. paths (A and I) depend on the stochastic human capital h. Consequently, choosing D exposes the household to future income uncertainty, while the M path provides a stable baseline independent of fluctuations in h. The parameters $\gamma^A > 0$ and $\gamma^I > 0$ represent the relative productivity or return on human capital in the academic and industrial sectors, respectively, which scale human capital h into effective units.

The pre-tax labor income of the working generation is determined by the current occupation κ and effective human capital $\tilde{h}$:

$$y^\kappa = w^\kappa \tilde{h}. \tag{5}$$

The income of a household with $\kappa = M$ is $y^M = w^M$. The income of a household with $\kappa \in \{A, I\}$ depends on the realized human capital h and sector-specific productivity ψ.

$\sigma^\psi \geqslant 0$ measures the strength of sector-specific productivity between A and I. A positive value of ψ gives a sector-specific productivity in I, while a negative value gives one in A. The ratio of effective human capital across the two sectors satisfies

$$\ln\left(\frac{\tilde{h}^I}{\tilde{h}^A}\right) = \ln\left(\frac{\gamma^I}{\gamma^A}\right) + \psi. \tag{6}$$

Academic taste θ affects non-pecuniary utility, whereas h and ψ affect productivity.

Preferences A household's preferences are defined over sequences of pooled household consumption $\{c_t\}_{t=0}^{\infty}$ and the utility derived from its chosen educational path κ_{t+1}. The lifetime utility of a household is given by the expected discounted sum of period utilities:

$$\mathbb{E}_0\left[\sum_{t=0}^{\infty}\beta^t\Big(u(c_t) + \mathbb{1}_A(\kappa_{t+1})\cdot\theta_t\Big)\right]$$

where $\beta \in (0,1)$ is the discount factor. The utility from consumption c is represented by a standard CRRA utility function: $u(c) = \frac{c^{1-\rho}}{1-\rho}$. Here, $\rho > 0$ represents the coefficient of relative risk aversion. The second term captures the non-pecuniary utility (or disutility) from the household's educational choice. θ is the household's academic taste observed when this choice is made. The indicator function $\mathbb{1}_A(\kappa_{t+1})$ equals one if the household chooses the academic sector (A) after the Ph.D., and zero otherwise. This implies that the academic taste θ only contributes to the

household's utility if it chooses A. After the Ph.D., the household also receives a taste shock for the sector it chooses. I describe these shocks in Section 3.3.

3.2.2 Firms

In each period, a representative firm produces aggregate output Y using aggregate capital K and aggregate effective labor H supplied by households. Because the firm operates in perfectly competitive markets, it takes the rental rate of capital and wages as given and maximizes its profit.

Technology The production function takes a Cobb-Douglas form:

$$Y = F(K, H) = K^{\alpha} H^{1-\alpha}, \tag{7}$$

where $0 < \alpha < 1$ denotes the capital share.

Aggregate effective labor H is a composite of effective labor supplied across different occupations. For each occupation κ, effective labor is the sum of effective human capital supplied by households in that occupation:

$$H^{\kappa} = \int_{\{\kappa^i = \kappa\}} \tilde{h}^i \, d\mu, \qquad \kappa \in \{M, A, I\}. \tag{8}$$

The total effective labor is aggregated by a function that combines M additively and combines A and I through a CES structure:

$$H = H^M + \left[(H^A)^{\eta} + (H^I)^{\eta} \right]^{1/\eta}. \tag{9}$$

The parameter $1/(1-\eta)$ governs the elasticity of substitution between academic

and industrial labor. When $\eta < 1$, the marginal product of effective labor in one sector increases with effective labor in the other sector. This complementarity is a fundamental feature of the production technology. For example, basic research in the academic sector provides foundational knowledge that industrial researchers apply to develop commercial technologies (Akcigit et al., 2021), and joint R&D with universities further enhances industrial productivity (Motohashi, 2005).

3.2.3 Government

In the baseline model, the government intervenes in the economy through a subsidy policy for doctoral education, which is funded by income taxes collected from total labor income. Government expenditure is solely allocated to these subsidies. Specifically, the subsidy s^D is a lump-sum transfer to households that choose Ph.D. enrollment, intended to support education and consumption during the enrollment period. In Section 5.2, I introduce an alternative policy case that provides a hiring subsidy for Ph.D. holders in the industrial sector. Unlike s^D, which is a fixed amount per student, this hiring subsidy s^I is a proportional rate applied to the firm's wage cost of Ph.D. workers in I.

Under any policy specification, the government balances its budget every period. The total cost of these subsidies is fully financed by the uniform labor income tax τ, which adjusts endogenously.

3.3 Household's Problem

In this section, I formulate the household's optimization problem in the stationary recursive competitive equilibrium where aggregate variables and prices are constant over time.

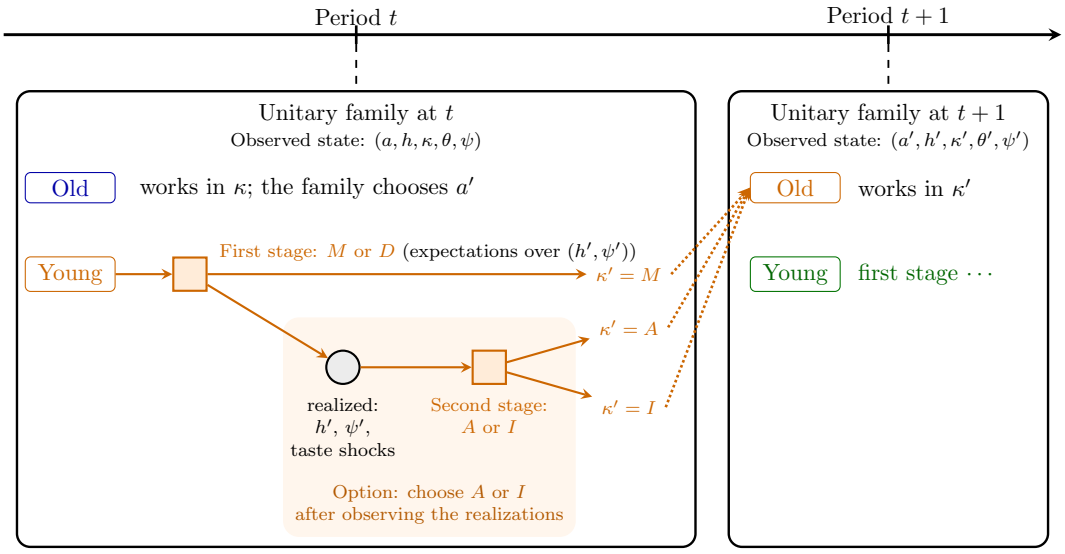


Figure 1: Two-Stage Decision and Timing of Information

Figure 1 illustrates the two-stage decision process and the timing of information for a unitary family. In period t, given the current state $(a, h, \kappa, \theta, \psi)$, the Old member works and the family chooses next period's assets a'. Concurrently, the Young member chooses between immediate employment with a Master's degree (M) and Ph.D. enrollment (D). Because this decision is made before future outcomes are known, the family forms expectations over next period's human capital (h') and sector-specific productivity (ψ').

If the Young chooses M, the next period's occupation becomes $\kappa' = M$. If the Young chooses D, the decision is irreversible. Upon graduation, the true values of h', ψ', and taste shocks are realized. In the second stage, the household has the option to choose between the academic sector (A) and the industrial sector (I) after observing these realizations. This choice sets the occupation to $\kappa' = A$ or $\kappa' = I$. In period $t+1$, the family observes the new state $(a', h', \kappa', \theta', \psi')$. The Young from period t becomes the Old and works in κ', and a new Young member begins the

first stage.

The state of the household is $(a, h, \kappa, \theta, \psi)$.

In what follows, V^M and V^D denote the values of the two options in the first stage, and V^A and V^I denote the values of the two options after the Ph.D.

First Stage: M versus D For a household that chooses M, the sector-specific productivity ψ does not affect its labor income. The value of choosing M for the Young is

$$\begin{aligned} V^M(a, h, \kappa, \theta, \psi) = \max_{c, a'} \{u(c) + \beta\, \mathbb{E}_{h', \theta', \psi'}\, V(a', h', M, \theta', \psi')\} \\ \text{s.t.} \qquad c = (1-\tau) y^\kappa + (1+r)a - a', \\ a' \geqslant 0. \end{aligned} \tag{10}$$

Second Stage: A versus I after the Ph.D. I write the values of entering A and I after the Ph.D. as

$$V^A(a', h', \theta, \psi') = \theta + \beta\, \mathbb{E}_{\theta'}\, V(a', h', A, \theta', \psi'), \tag{11}$$

$$V^I(a', h', \theta, \psi') = \beta\, \mathbb{E}_{\theta'}\, V(a', h', I, \theta', \psi'). \tag{12}$$

Academic taste θ enters only the value of A.

I add i.i.d. Gumbel taste shocks $(\varepsilon^A, \varepsilon^I)$ with mean zero to the comparison between A and I. These shocks are realized at the same time as ψ'. Their scale $\sigma^{A,I} > 0$ is measured in the same utility units as θ. The household compares $V^A + \varepsilon^A$ with $V^I + \varepsilon^I$. The value that the household obtains after the Ph.D. is the expected

maximum

$$\mathbb{E}_{\varepsilon^A,\varepsilon^I}\left[\max\{V^A+\varepsilon^A,\ V^I+\varepsilon^I\}\right]. \tag{13}$$

The probability of choosing I is

$$\Pr(I \mid \cdot) = \frac{1}{1+\exp((V^A-V^I)/\sigma^{A,I})}. \tag{14}$$

The parameter $\sigma^{A,I}$ summarizes individual differences in preferences between A and I that academic taste, human capital, and sector-specific productivity do not explain. Unlike θ, these shocks are not known at enrollment and are not persistent across generations.

Value of Ph.D. Enrollment The value of Ph.D. enrollment is

$$\begin{aligned} V^D(a,h,\kappa,\theta,\psi) = \max_{c,a'} &\left\{u(c) + \mathbb{E}_{h',\psi',\varepsilon^A,\varepsilon^I}\left[\max\{V^A+\varepsilon^A,\ V^I+\varepsilon^I\}\right]\right\} \\ \text{s.t.} \quad & c = (1-\tau)y^\kappa + (1+r)a - a' + s^D - \nu, \\ & a' \geqslant -b. \end{aligned} \tag{15}$$

Because ψ' is realized first and the household then chooses between A and I, the maximum is inside the expectation in (15). Due to this sequence of events, the possibility of choosing I in the future raises V^D before the household observes its outcomes after the Ph.D. This is the option value of I.

A household that chooses Ph.D. enrollment pays the net education cost ν, receives the subsidy s^D, and faces the borrowing limit b. The parameter b represents the student loans available to Ph.D. students.

The value of the household before the enrollment decision is

$$V(a, h, \kappa, \theta, \psi) = \max \left\{ V^M(a, h, \kappa, \theta, \psi),\ V^D(a, h, \kappa, \theta, \psi) \right\}. \tag{16}$$

Irreversibility of Ph.D. Enrollment A household that chooses D cannot return to M after the Ph.D. This assumption reflects the rigid structure of the Japanese labor market, which relies heavily on the simultaneous recruiting of new graduates. Although many firms formally place Ph.D., Master's, and Bachelor's graduates in the same recruitment category (Keidanren, 2024), a Ph.D. graduate who attempts to enter the general corporate job market faces severe disadvantages due to age premiums and firms' preference for younger, more malleable workers (Iwawaki and Kosugi, 2023). Consequently, a household cannot simply revert to the career trajectory of M if outcomes turn out to be unfavorable.

4 Calibration

This section calibrates the model to Japanese data. Section 4.1 outlines the calibration strategy. Section 4.2 evaluates the baseline model's fit to the Japanese data and examines the sorting of households.

4.1 Calibration Strategy

This section outlines the strategy used to assign values to the model parameters defined in Section 3. For the parameters that do not involve the industrial sector, I use the same external values and target moments as Hayama (2026). Below, I describe the parameters that involve the industrial sector.

Table 1 summarizes all parameters used in the model, distinguishing between

those set externally based on literature or policy data and those calibrated internally using the Simulated Method of Moments (SMM). I calibrate the eight parameters in the second group jointly to match eight target moments.

Table 1: Summary of model parameters

Parameter	Description	Value	Source / target moment
Externally set parameters			
ρ	Risk aversion	2.0	Standard literature
α	Capital income share	0.362	Hayashi and Prescott (2002)
δ	Depreciation rate (30-year)	0.930	Standard annual rate
ν	Ph.D. education cost	0.032	JPY 1.94M + forgone income; MEXT (2023b), NISTEP (2025)
s^D	Ph.D. student subsidy	0.003	JPY 3.40M; MEXT (2023a)
b	Borrowing limit (choosing D)	0.004	JPY 4.32M; JASSO (n.d.)
φ^h	Persistence of h process	0.360	Lefranc et al. (2014)
$\sigma^\theta/\sqrt{1-(\varphi^\theta)^2}$	Stationary std. dev. of θ	0.399	Hayama (2026)
η	Complementarity between A and I	0.959	Motohashi (2005)
Parameters estimated by SMM			
β	Discount factor	0.299	K/Y ratio
$\bar{\theta}$	Mean academic taste	−0.529	Ph.D. enrollment rate
σ^h	Std. dev. of h shock	0.326	Gini of academic income
φ^θ	Persistence of θ process	0.161	Academic parent gap
γ^A	Academic productivity multiplier	0.655	Lifetime income ratio Y^M/Y^A
γ^I	Industrial-sector productivity multiplier	0.877	Income ratio Y^I/Y^A
$\sigma^{A,I}$	Scale of A/I taste shocks	0.111	Industrial-sector share $I/(A+I)$
σ^ψ	Std. dev. of ψ	0.237	Gini of Ph.D. income

Note: ν, s^D, and b are measured in the money unit of the model, and the Source column reports the corresponding amounts. MEXT is the Ministry of Education, Culture, Sports, Science and Technology, NISTEP is the National Institute of Science and Technology Policy, and JASSO is the Japan Student Services Organization.

I set the exponent of the CES aggregator to $\eta = 0.959$, based on Motohashi

(2005).[2]

The target for σ^{ψ} is the Gini coefficient of the annual income of Ph.D. holders, 0.222. I compute it from the 2022 Employment Status Survey (Statistics Bureau, 2023) for regular employees aged 25–64 whose highest degree is a Ph.D. I use the midpoint of each income bin reported in the survey, and set the top bin (15 million JPY or more) to 17.5 million JPY, as in Morikawa (2025). In the model, I compute the same statistic for households in A and I.

The target for γ^{I} is the ratio of the 30-year income of researchers in private firms to the expected 30-year income of the academic path, $Y^{I}/Y^{A} = 1.440$. The expected income of the academic path combines the income of university faculty and that of postdoctoral researchers. The weight on faculty income is 0.434 (NISTEP, 2026c). This is the share of positions without a fixed term or on the tenure track among Ph.D. graduates employed in academia.[3] With both ratios measured on the same basis, the targets imply Y^{I}/Y^{M} of about 1.01–1.02. This is consistent with the reported ratio of average starting salaries for Ph.D. and Master's graduates, 1.026 (Sanro, 2026).[4]

I introduce the taste shocks to reproduce the share of Ph.D. graduates who take jobs in the industrial sector. The target for $\sigma^{A,I}$ is this share among the FY2018

[2] Motohashi (2005) finds that, among Japanese firms, the elasticity of value added with respect to in-house R&D is 0.03 higher for firms that did joint R&D with universities. Because the empirical estimate does not specify the input ratio of academic to industrial labor, I map this firm-level premium into the macro CES parameter by evaluating the marginal product at a symmetric benchmark ($H^{A} = H^{I}$). This assumption yields a 3% higher marginal product than under perfect substitution ($\eta = 1$).

[3] The two income ratios define the academic path in different ways. When I compute Y^{M}/Y^{A} for ages 30–59 on the same basis as Y^{I}/Y^{A}, the ratio is 1.41–1.42.

[4] The Sanro Research Institute (Sanro) is a private institute; its survey received responses from 294 firms. Starting salaries do not measure lifetime income. In Keidanren (2024), 51.2% of firms using a common wage scale across degrees set doctoral starting pay at the level of Master's graduates in their fourth year.

Ph.D. graduates, 32.5% (Kawamura et al., 2022). I use graduates who had no regular work experience before the Ph.D. and were not international students. I compute the share of graduates employed in private firms among those working in universities, public research institutes, or private firms.

4.2 Model Fit and Sorting

I first assess the fit of the eight moments targeted by the SMM procedure, as described in Section 4.1. Table 2 shows that the calibrated model captures the eight target moments well.

Table 2: Calibration targets and model fit

Moment	Description	Data	Model
K/Y	Capital-output ratio	3.322	3.329
Enrollment rate	Ph.D. enrollment rate	9.4%	9.2%
Gini (A)	Gini of academic income	0.188	0.188
Y^M/Y^A	Lifetime income ratio	1.395	1.394
Academic parent gap	Enrollment rate difference	4.5 pp	4.5 pp
Y^I/Y^A	30-year income ratio	1.440	1.453
Industrial-sector share	$I/(A+I)$ after the Ph.D.	32.5%	32.7%
Gini (Ph.D.)	Gini of Ph.D. income	0.222	0.226

Next, I examine patterns that the calibration does not target. First, I report the model's internal sorting pattern with respect to financial resources. Table 3 illustrates that the model endogenously generates a positive relationship between household assets and the decision to enroll in a Ph.D. program. The enrollment rate increases from 5.6% for the lowest asset quartile (Q1) to 15.4% for the highest quartile (Q4). Enrollees from households with more assets are also more likely to choose I after the Ph.D. The industrial-sector share among enrollees is 44.5% in

Q4, compared with 20.5% in Q1. Households with more assets can absorb the cost of the Ph.D. program and the income risk after it. They can therefore enroll with lower academic taste θ, and households with lower θ are more likely to choose I after the Ph.D.

Table 3: Ph.D. enrollment rate by asset quartile

Quartile	Q1	Q2	Q3	Q4
Enrollment rate (%)	5.6	7.2	8.8	15.4
Industrial-sector share of enrollees (%)	20.5	24.1	27.7	44.5

In addition to financial resources, Table 4 illustrates that the model also captures human capital sorting. The enrollment rate increases monotonically from 7.5% for the lowest human capital quartile (Q1) to 11.6% for the highest quartile (Q4). The industrial-sector share among enrollees also increases from 27.9% in Q1 to 38.2% in Q4.

Table 4: Ph.D. enrollment rate by human capital quartile

Quartile	Q1	Q2	Q3	Q4
Enrollment rate (%)	7.5	8.4	9.6	11.6
Industrial-sector share of enrollees (%)	27.9	30.1	33.2	38.2

Finally, I examine the selection mechanism with respect to non-pecuniary preferences. Table 5 reports enrollment rates conditional on quartiles of academic taste θ. Enrollment is concentrated in the highest quartile (Q4), where the rate reaches 34.4%. In the bottom three quartiles (Q1 through Q3), the enrollment rate is at most 0.4%, and almost all of these few enrollees choose I after the Ph.D.

This concentration indicates that, within the model, academic taste is the main determinant of enrollment, while assets and human capital affect the decision at

Table 5: Ph.D. enrollment rate by academic taste quartile

Quartile	Q1	Q2	Q3	Q4
Enrollment rate (%)	0.0	0.1	0.4	34.4
Industrial-sector share of enrollees (%)	99.9	99.6	96.0	31.9

the margin. Research interest is the main enrollment reason for about 80% of surveyed first-year students in humanities and social sciences, compared with 53% in engineering (Saito, 2025).[5]

5 Results

This section presents the quantitative results of the calibrated model. Section 5.1 examines the value of the industrial-sector career option and how the option changes the enrollment response to the student subsidy. Section 5.2 presents the hiring subsidy experiments and compares the hiring subsidy with the student subsidy at the same fiscal cost.

5.1 The Value of the Industrial-Sector Career Option

The Young chooses D before h', ψ', and the taste shocks are realized. Therefore, at the time of enrollment, the household does not know whether the Young will work in A or I after the Ph.D. For each enrollee, I call the sector with the higher probability at the time of enrollment the expected sector. Figure 2 groups enrollees by their expected sector. For 75.7% of enrollees, the expected sector is A. However, 22.1% of them work in I after the Ph.D. For the other 24.3%, the expected sector

[5]The sample excludes working adults and international students. I combine intellectual curiosity and a specific research question as reasons ranked first. These responses cover only enrolled students.

is I, and 34.3% of them work in A. In total, 25.0% of enrollees work in a sector different from their expected sector. Because the sector is uncertain at enrollment, the value of Ph.D. enrollment includes the value of choosing the better of A and I after the Ph.D. Roach and Sauermann (2017) also find that career preferences change during doctoral study among U.S. science and engineering students, leading some to pursue a career different from their initial aspiration.

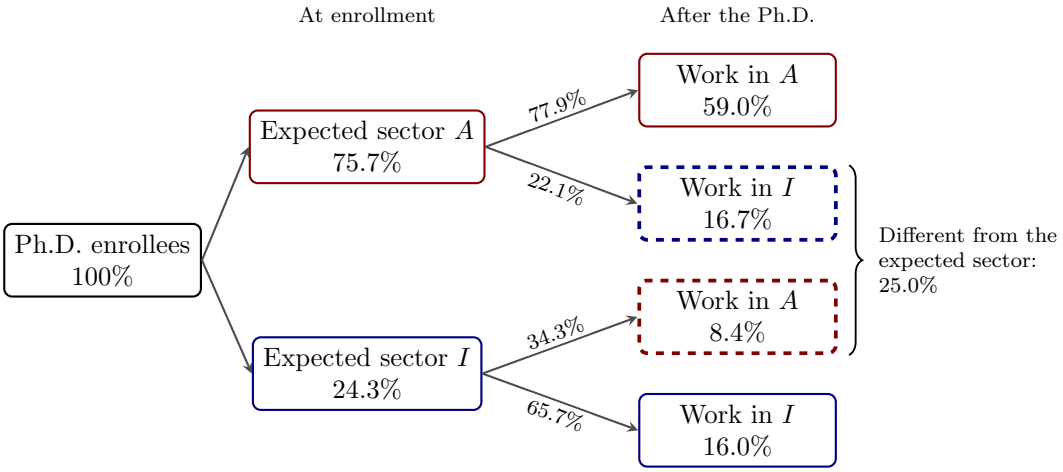


Figure 2: Expected and Realized Sectors of Ph.D. Enrollees

Note: Percentages in the boxes are shares of all enrollees. Percentages on the arrows are shares within each expected sector. Dashed boxes show enrollees who work in a sector different from their expected sector.

To measure the value of this option, I introduce the probability p^I that a Ph.D. graduate can choose I. With probability $1 - p^I$, the graduate cannot choose I and works in A. The baseline economy corresponds to $p^I = 1$. I lower p^I while keeping all other parameters at their calibrated values. This exercise examines the mechanism of the model and is not a government policy.

Figure 3 shows the enrollment rate and the population shares of A and I for each value of p^I. When $p^I = 0$, the enrollment rate decreases from 9.19% to 6.13% in gen-

eral equilibrium. This decrease of 3.06 percentage points is slightly larger than the population share of I at the baseline (3.00%). The marginal difference of 0.06 percentage points represents households that eventually work in A but enroll because of the industrial-sector career option. Therefore, while the option value supports overall Ph.D. enrollment, it has almost no effect on academia-bound households in general equilibrium; very few decide to enroll merely because this insurance exists. In partial equilibrium, where prices and taxes are fixed at the baseline, the enrollment rate drops further to 5.50%, indicating that the option does initially hold value for these households. In general equilibrium, however, this effect largely disappears, and the population share of A remains almost unchanged.

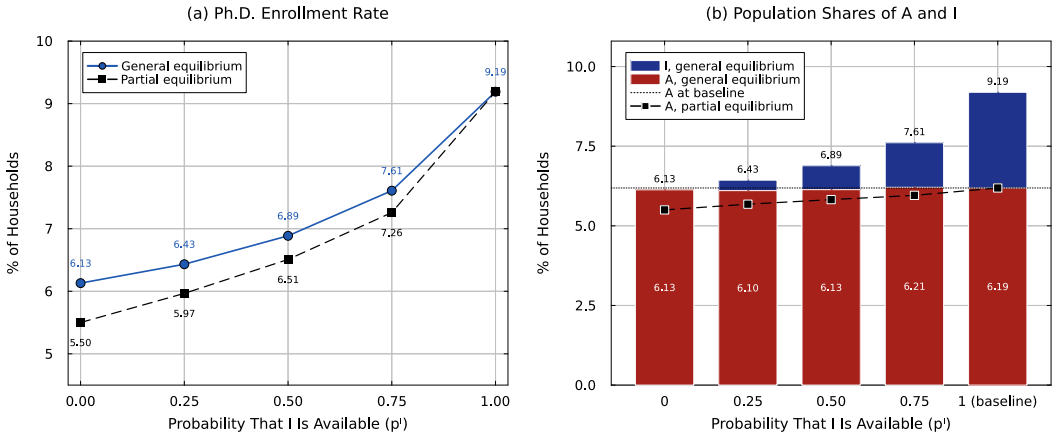


Figure 3: The Value of the Industrial-Sector Career Option

The option also changes the enrollment response to the student subsidy s^D. Figure 4 compares the enrollment response with and without the industrial-sector career option. For the economy without the option, I set $p^I = 0$ and change only $\bar{\theta}$ from -0.529 to -0.437 so that the enrollment rate equals the baseline value. In the baseline economy, the 1.5× subsidy raises the enrollment rate by 0.38 percentage points. In the economy without the option, it raises the enrollment rate by 0.13

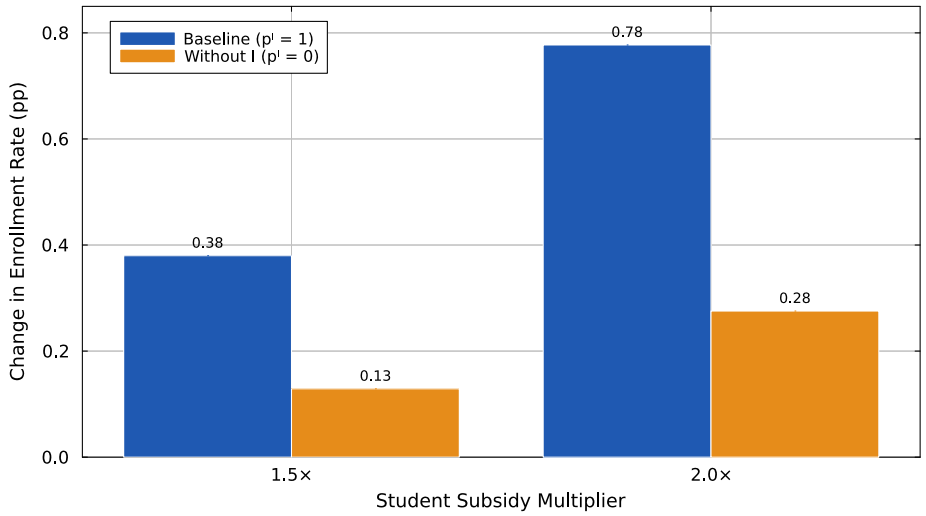


Figure 4: Enrollment Response to the Student Subsidy with and without the Industrial-Sector Career Option

percentage points. The response is larger when I is available.

The student subsidy induces new enrollment among marginal households for which the value of Ph.D. enrollment, V^D, is initially just below the value of a master's career, V^M. In the economy without I, all enrollees work in A, so a lower θ—the non-pecuniary utility of academia—directly translates to a lower V^D. Consequently, the gap between V^M and V^D widens even for households with only a slightly lower θ. In the economy with I, however, a household derives this non-pecuniary utility only if it chooses A after graduation. Thus, the impact of θ on V^D is attenuated roughly by the probability of choosing A. This attenuation keeps V^D close to V^M across a wider range of low θ, creating a larger mass of marginal households. Because the magnitude of the subsidy's effect depends on the mass of households near this enrollment margin, the same subsidy encourages significantly more enrollment in the economy with I. Indeed, the mean θ of all new enrollees under the 1.5× student subsidy is lower than that of baseline enrollees.

Furthermore, about 56% of the new enrollees work in I after graduation (Section 5.2.2). From FY2022 to FY2025, Ph.D. entrants increased by 27.2% in science and 21.1% in engineering. They decreased by 2.4% in humanities (NISTEP, 2026a; MEXT, 2025b).[6] This pattern is consistent with a larger response where industrial careers are more common, although other factors also changed across fields. These results suggest that the effect of financial support during the Ph.D. depends on the career options available after graduation.

5.2 Policy Experiments

This section examines policies in the economy where Ph.D. graduates can choose I. The main policy is the hiring subsidy s^I, which raises the value of the industrial-sector career option examined in Section 5.1. I first analyze the impact of the hiring subsidy on household enrollment decisions, the allocation of Ph.D. holders between A and I, and macroeconomic aggregates. I then compare it at the same fiscal cost with the student subsidy s^D, which acts on the supply of Ph.D. graduates rather than on the demand for their labor.

5.2.1 Hiring Subsidy

Keeping the baseline student subsidy in place, the government pays a share s^I of the firm's wage cost of Ph.D. holders in I (Section 3.2.3). The hiring subsidy raises the effective wage in I. It therefore affects the choice between A and I after the Ph.D. and the enrollment decision through the value of choosing I in the

[6]Financial support expanded during this period (MEXT, 2025a). Pooling March 2023–2025 graduates, I estimate private employment shares among employed graduates of 46.8% in science and 52.3% in engineering. The corresponding share in humanities is 15.8% (MEXT, 2025b). I pool counts and exclude education, health and welfare, public administration, research institutes, and unclassified industries.

future. I consider three rates, $s^I = 5\%$, 10%, and 20%. For each rate, I resolve the equilibrium.

Table 6: Model response to the hiring subsidy

Variable	Baseline	Hiring subsidy rate s^I		
		5%	10%	20%
Key outcomes				
Enrollment rate (%)	9.19	9.55	9.86	10.77
Population share of A (pp change)	—	+0.01	−0.05	−0.25
Population share of I (pp change)	—	+0.35	+0.72	+1.82
Industrial-sector share $I/(A+I)$ (%)	32.67	35.10	37.75	44.82
Labor income tax rate (%)	0.16	0.35	0.60	1.43
Output (Y, % change)	—	+0.11	+0.36	+1.18
Capital stock (K, % change)	—	+0.29	+0.92	+2.99
Effective labor (H, % change)	—	+0.01	+0.04	+0.17
Social welfare				
CEV (% change)	—	+0.09	−1.35	−4.28

Table 6 summarizes the results. The enrollment rate increases with s^I and reaches 10.77% at $s^I = 20\%$. The industrial-sector share among Ph.D. holders also increases and reaches 44.82%. Output and the capital stock increase as the subsidy rate increases. Effective labor hardly changes at $s^I = 5\%$ and increases at the higher rates. The CEV, which measures the welfare change as a percentage of baseline consumption, is positive at $s^I = 5\%$. It becomes negative at 10% and 20%, where the fiscal cost is larger and the labor income tax rises to 0.60% and 1.43%[7].

The population share of A hardly changes at $s^I = 5\%$ (+0.01 percentage points). It decreases by 0.05 percentage points at 10% and by 0.25 percentage points at

[7]Because the model covers only households with at least a Master's degree, these effects would be smaller still for the entire economy.

20%. Two effects explain this pattern. First, the subsidy raises the value of the industrial-sector career option and draws new households into the Ph.D. program. Some of them work in A after the Ph.D., so this effect increases the population share of A. Second, the subsidy makes the other enrollees more likely to work in I instead of A. This happens because each of them becomes more likely to choose I and because, in the new stationary equilibrium, more households are in states where this probability is high. This effect decreases the population share of A. At $s^I = 20\%$, the first effect increases the population share of A by 0.47 percentage points, and the second decreases it by 0.71 percentage points.

5.2.2 Comparison with the Student Subsidy

I compare the hiring subsidy with the student subsidy at the same fiscal cost. I choose s^I separately at two budget levels so that its additional fiscal cost equals that of the 1.5× or the 2.0× student subsidy. The additional cost includes the change in spending on the baseline student subsidy, because the hiring subsidy also changes enrollment. The resulting rates are 2.49% and 4.80% (Table 7).

At both budget levels, the student subsidy produces a larger enrollment response. It also increases the population share of I more than the hiring subsidy does, although the hiring subsidy targets I directly. This is because about 56% of the new entrants under the student subsidy work in I after the Ph.D. These new entrants have lower academic taste than baseline enrollees (mean θ of -0.003, compared with 0.123). In contrast, most of the hiring subsidy goes to Ph.D. holders who would choose I without the subsidy. The subsidy raises the wage of Ph.D. holders in I by 2.5% at the 1.5× budget. The industrial-sector share $I/(A + I)$ is slightly higher under the hiring subsidy at both budget levels.

Table 7: Student subsidy and hiring subsidy at the same cost

	Baseline	1.5× budget		2.0× budget	
		Student	Hiring	Student	Hiring
Hiring subsidy rate (%)	—	—	2.49	—	4.80
Enrollment rate (%)	9.19	9.57	9.36	9.97	9.55
Enrollment change (pp)	—	+0.38	+0.17	+0.78	+0.36
Population share of A (pp change)	—	+0.16	+0.01	+0.31	+0.01
Population share of I (pp change)	—	+0.22	+0.16	+0.46	+0.34
Industrial-sector share $I/(A+I)$ (%)	32.67	33.69	33.79	34.78	35.04
Output (Y, % change)	—	−0.02	+0.04	−0.03	+0.10
Capital stock (K, % change)	—	+0.01	+0.11	+0.05	+0.27
Effective labor (H, % change)	—	−0.04	0.00	−0.07	+0.01
Labor income tax rate (%)	0.16	0.25	0.25	0.34	0.34
CEV (%)	—	+0.20	+0.20	+0.33	+0.11

Figure 5 shows the change in the share of existing enrollees who work in I after the Ph.D. Existing enrollees refer to households whose optimal choice remains D regardless of the policy intervention. I compute this share with the baseline stationary distribution, so the change reflects only changes in their choices. Under the hiring subsidy, existing enrollees shift from A to I. At the 1.5× budget, the share working in I increases by 0.31 percentage points, from 32.67% to 32.98%. The increase is about twice as large at the 2.0× budget (0.61 percentage points). Under the student subsidy, the share decreases slightly (0.06 percentage points at the 1.5× budget). This is consistent with the 0.09% decrease in the wage in I.

The ranking of macroeconomic outcomes is the opposite. Under the student subsidy, effective labor and output decrease slightly. Under the hiring subsidy, effective labor hardly changes and output increases. The two instruments therefore involve a trade-off between Ph.D. entry and macroeconomic outcomes.

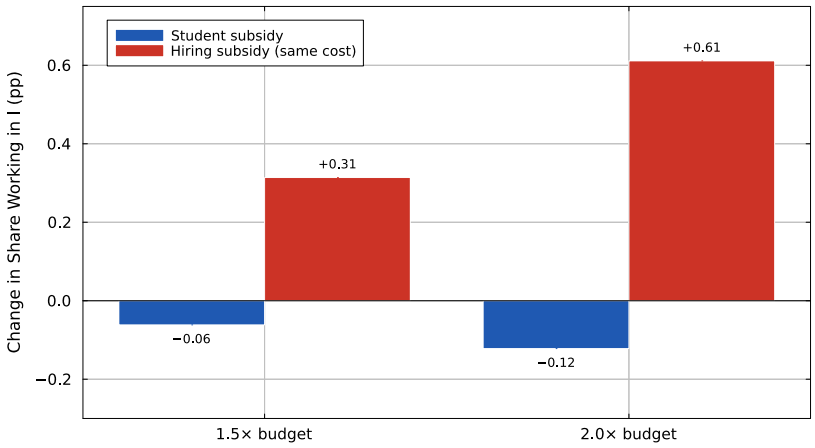


Figure 5: Career Choices of Existing Enrollees

Effective labor decreases under the student subsidy because workers in A supply less effective labor than workers in M. By (4), a worker in M supplies one unit of effective labor regardless of h, whereas a worker in A supplies $\gamma^A h$ units with $\gamma^A = 0.655$, or 0.70 units at the mean h of workers in A. Under the student subsidy, about 44% of the new entrants work in A. Because they supply only 0.70 units in A instead of the 1.00 unit they would have supplied in M, households that switch from M to D supply less effective labor on average. Under the hiring subsidy, fewer households switch. In addition, some Ph.D. graduates move from A to I, where $\gamma^I = 0.877$ is 34% higher than γ^A.

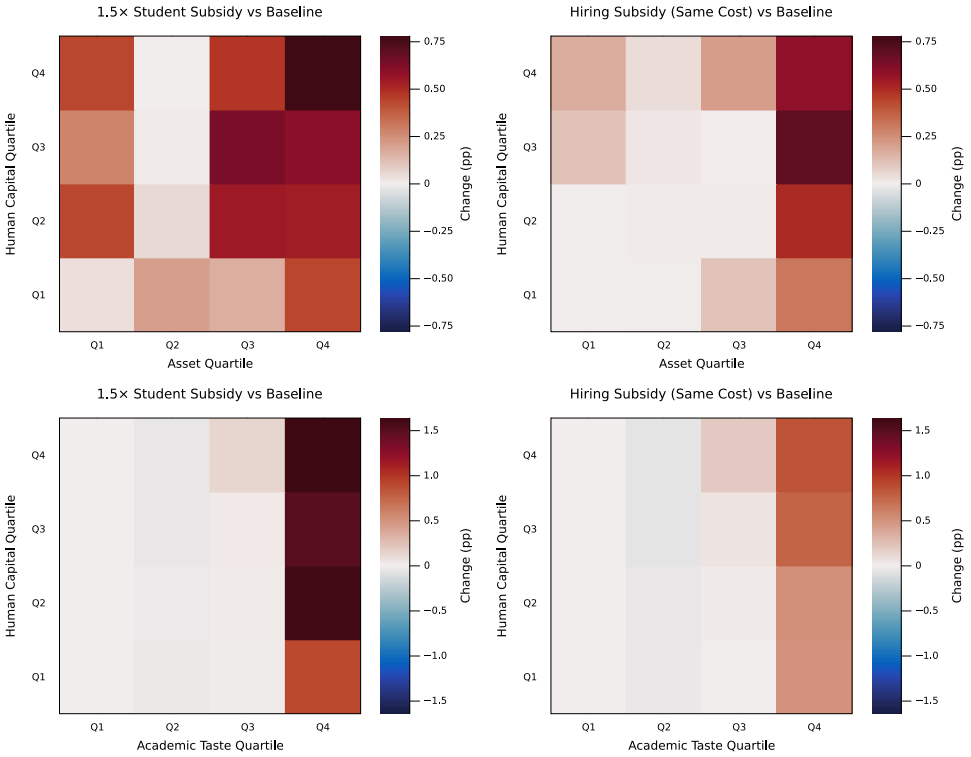


Figure 6: Changes in Ph.D. Enrollment Rate by Human Capital, Asset, and Academic Taste Quartiles

Figure 6 shows the changes in the enrollment rate by quartile cells at the 1.5× budget. Under both policies, the increase occurs almost entirely in the highest academic taste quartile (Q4). Across asset quartiles from Q1 to Q4, the student subsidy increases enrollment by 0.31, 0.06, 0.49, and 0.58 percentage points. The hiring subsidy increases it by 0.07, 0.02, 0.06, and 0.54 percentage points. In the lowest asset quartile, the student subsidy increases enrollment more than the hiring subsidy in every human capital quartile. In the highest asset quartile, enrollment increases more than in the lowest asset quartile in every human capital quartile under both subsidies.

The student subsidy directly reduces the cost of doctoral study and may help

households with few assets that are close to their borrowing limit. In contrast, the hiring subsidy raises income from employment in the industrial sector after graduation but does not directly provide financial support during doctoral study. Its smaller effect on enrollment in the lowest asset quartile is consistent with this difference in how the two subsidies work.

6 Conclusion

This paper examines how the option to choose between the academic sector and the industrial sector after the Ph.D. affects Ph.D. enrollment decisions and the effects of subsidies. An important finding is that, in general equilibrium, the industrial-sector career option as insurance does not appeal to academia-bound households facing uncertainty about their careers after graduation and gives them almost no incentive to enroll.

However, career options after graduation affect the enrollment response to financial support during the Ph.D. program. Without the industrial-sector career option, the response is much smaller. Many of the additional enrollees work in the industrial sector after graduation. The model results support the government's approach of combining financial support with the development of career paths, including employment in the industrial sector. However, academic taste still filters enrollment even when households can choose the industrial sector.

The student subsidy and the hiring subsidy involve a trade-off between different policy goals. For the same fiscal cost, the student subsidy mainly increases enrollment, while the hiring subsidy also changes the sector choices of Ph.D. graduates and increases aggregate output. The effect of the hiring subsidy also depends on its

scale. A small subsidy increases the number of Ph.D. graduates in the industrial sector without reducing the number in the academic sector, while a large subsidy moves Ph.D. graduates from the academic sector to the industrial sector. The choice of fiscal policy and its scale therefore depend on whether the policy aims to increase the total number of Ph.D. graduates or change their sector choices. Policy evaluation should also distinguish between increasing the population share of Ph.D. graduates working in the industrial sector and changing enrollees' career choices after graduation.

One limitation of the model is that it abstracts from matching frictions between Ph.D. holders and firms. In the model, all Ph.D. graduates can freely choose employment in the industrial sector. Some Japanese firms would hire new Ph.D. graduates but do not recruit them, most often because they expect few applicants (NISTEP, 2026b). Only six respondents used the tax credit for newly employed advanced research personnel in FY2024.[8] Firms' demand for Ph.D. holders may also differ across fields of specialization. Future research could introduce the matching process and field-specific differences into the model. The model could then be used to evaluate policies that combine financial incentives with direct support for matching Ph.D. holders and firms.

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[8]See NISTEP (2026b), Figure 4-16 and Table 8-3. The tax question has 1,768 respondents; the provision also covers experienced researchers without a Ph.D.

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A Stationary Recursive Competitive Equilibrium

Definition of Stationary Recursive Competitive Equilibrium. A stationary recursive competitive equilibrium is defined by the policy functions $g_c(a, h, \kappa, \theta, \psi)$, $g_a(a, h, \kappa, \theta, \psi)$, and $g_D(a, h, \kappa, \theta, \psi) \in \{0, 1\}$; the probability $\Pr(I \mid a', h', \theta, \psi')$ that a household chooses I after the Ph.D.; the probability distribution $\mu(a, h, \kappa, \theta, \psi)$ over the household state space $\mathcal{S}$; total capital K; sectoral effective labor (H^M, H^A, H^I); the interest rate r; sectoral wages (w^M, w^A, w^I); and the government policies (subsidy s^D, income tax rate τ, borrowing limit b, and hiring subsidy s^I). The baseline economy sets $s^I = 0$. I use $s^I > 0$ only in the policy experiments in Section 5.2.

Specifically, the following conditions must be satisfied:

1. Given the sectoral wages (w^M, w^A, w^I), the interest rate r, the education cost ν, and policies, the policy functions g_c, g_a, g_D, and the probability $\Pr(I \mid \cdot)$ solve the household's dynamic optimization problem in Section 3.3. This problem is defined by the Bellman equation (16) and (10)–(15). In particular, $\Pr(I \mid \cdot)$ is the logit probability in (14).

2. Factor prices are determined competitively. Given H in (9) and the production function $F(K, H) = K^{\alpha} H^{1-\alpha}$, let $\omega = (1-\alpha)Y/H$ denote the base wage per unit of effective labor. The interest rate and the sectoral wages are

$$r = \alpha \frac{Y}{K} - \delta, \tag{A.1}$$

$$w^M = \omega, \tag{A.2}$$

$$w^A = \omega \left[1 + \left(\frac{H^I}{H^A} \right)^{\eta} \right]^{\frac{1-\eta}{\eta}}, \tag{A.3}$$

$$w^I = \frac{\omega}{1 - s^I} \left[1 + \left(\frac{H^A}{H^I} \right)^{\eta} \right]^{\frac{1-\eta}{\eta}}, \tag{A.4}$$

where $0 \leqslant s^I < 1$. The firm's net cost of one unit of effective labor in I, $(1 - s^I)w^I$, equals the marginal product of effective labor in I. In the baseline economy with $s^I = 0$, w^I equals this marginal product. Because H is homogeneous of degree one in (H^M, H^A, H^I), Euler's theorem implies $w^M H^M + w^A H^A + (1 - s^I) w^I H^I = (1 - \alpha)Y$. Firms earn zero profit.

3. The government finances the total subsidies paid to all households whose Young members choose Ph.D. enrollment and the hiring subsidy through the income tax τ on total labor income. The government's budget constraint is:

$$\tau \int_{\mathcal{S}} y^{\kappa} \, d\mu = s^D \int_{\mathcal{S}} \mathbb{1}_{\{g_D(a,h,\kappa,\theta,\psi)=1\}} \, d\mu + s^I w^I H^I. \tag{A.5}$$

The hiring subsidy is a transfer financed by taxes, so I do not subtract it in the goods market clearing condition below.

4. In the market, the following clearing conditions must hold:

(a) Total capital demand by firms equals total asset supply by households:

$$K = \int_{\mathcal{S}} g_a(a, h, \kappa, \theta, \psi)\, d\mu. \tag{A.6}$$

(b) For each sector, effective labor demand by firms equals effective labor supply by households, H^κ in (8), for $\kappa \in \{M, A, I\}$.

(c) Total output is allocated to aggregate consumption C, replacement investment δK, and the total resource cost of Ph.D. education:

$$\begin{aligned} F(K, H) = &\underbrace{\int_{\mathcal{S}} g_c(a, h, \kappa, \theta, \psi)\, d\mu}_{C} + \delta K \\ &+ \nu \int_{\mathcal{S}} \mathbb{1}_{\{g_D(a,h,\kappa,\theta,\psi)=1\}}\, d\mu. \end{aligned} \tag{A.7}$$

5. The probability distribution μ is stationary. It must be consistent with the household's policy functions (g_a, g_D), the probability $\Pr(I \mid \cdot)$, the stochastic transition processes (1) and (2), and the distribution of ψ' in (3). That is, μ is the fixed point of the transition function Γ generated by the economy's laws of motion:

$$\mu = \Gamma(\mu). \tag{A.8}$$