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【要旨】

・Japan is experiencing a continuous decline in Ph.D. enrollment
・Develops a dynamic heterogeneous-agent model with non-pecuniary preference
・Heterogeneity in “academic taste” drives Ph.D. enrollment decisions
・Ignoring this heterogeneity overestimates the effects of financial aid
・Financial aid has a limited impact on Ph.D. enrollment

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A Macroeconomic Model of Ph.D. Enrollment with Income Risk and Non-Pecuniary Preferences*

Airi Hayama†

Abstract

While the number of Ph.D. holders is increasing globally, Japan is experiencing a continuous decline in Ph.D. enrollment. To evaluate potential policy interventions, this paper constructs a dynamic heterogeneous agent model that explicitly incorporates non-pecuniary "academic taste" alongside human capital heterogeneity and asset constraints. Based on the model calibrated using the Japanese macroeconomic data, I find that current subsidy policies and their expansions are sub-optimal in terms of social welfare compared to a no-subsidy regime. The aggregate elasticity of enrollment remains low because subsidies cover only contemporaneous costs without mitigating the substantial post-graduation income risks. As a result, rather than an efficient investment in aggregate human capital, the policy works primarily as a tax-funded transfer for consumption amenities, encouraging enrollment mainly among relatively wealthy households who possess strong academic taste and enough assets to buffer the post-graduation income risks. Because pursuing a Ph.D. in Japan offers no expected lifetime wage premium, counterfactual analysis demonstrates that omitting this non-pecuniary preference heterogeneity falsely predicts unrealistically high, financially driven enrollment surges. These findings highlight the critical role of non-pecuniary preference heterogeneity in educational selection at the doctoral stage; policy designs that ignore this non-pecuniary self-selection mechanism will fail to achieve broad expansions in enrollment or generate meaningful macroeconomic returns.

Keywords: Ph.D. Enrollment, Heterogeneous-Agent Macroeconomic Model, Non-Pecuniary Preferences, Human Capital, Financial Aid, Income Risk
JEL Codes: D15, E24, I22, I23, J24

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1 Introduction

While the number of Ph.D. holders per capita has been increasing in many major countries, Japan has seen a continuous decline in Ph.D. program enrollment, diverging from this global trend.[1] To respond to this global shift, the Japanese government has been promoting policies to encourage Ph.D. enrollment, focusing on expanding financial support during the program.

This paper emphasizes that explicitly incorporating non-pecuniary "academic taste" is indispensable for accurately analyzing the decision to enroll in a Ph.D. program. In Japan, opting for immediate employment after a Master's degree yields an expected lifetime income that is approximately 40% higher than pursuing a Ph.D. for an academic career.[2] Consequently, the standard human capital framework, which assumes agents maximize lifetime earnings, fails to rationalize any Ph.D. enrollment in Japan, given these significant financial disincentives and substantial post-graduation income risks. In fact, a survey conducted in Japan by Kawamura and Watanabe (2023) reveals that approximately 66% of Master's students who opted for employment instead of a Ph.D. cited the desire for financial independence as their reason. In contrast, about 80% of students who chose to enroll in a Ph.D. program identified their interest in research (which this paper conceptualizes as academic taste) as the primary motivating factor. By focusing on this critical but often overlooked non-pecuniary factor, this paper quantitatively evaluates the first of the government's policy pillars: the expansion of financial support (subsidies) during the program. This approach allows for a more nuanced evaluation of how non-pecuniary motives interact with financial constraints to shape enrollment patterns

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[1] National Institute of Science and Technology Policy (2025).

[2] See Section 4 for details.

and respond to policy interventions.

This paper constructs a dynamic heterogeneous-agent model that explicitly incorporates "academic taste" alongside financial factors to analyze Ph.D. enrollment decisions.[3] Households in this economy are heterogeneous in their assets, human capital, and academic taste, all of which are assumed to follow intergenerationally persistent stochastic processes. Individuals live for two periods: during the "young" period, they decide whether to enroll in a Ph.D. program, and during the "old" period, they supply labor based on that educational choice. The model captures a fundamental career trade-off where the academic path provides non-pecuniary utility from research but entails significant income risks and potential wage penalties compared to the industrial sector. Consequently, this structure allows the model to characterize how academic taste acts as a decisive filter in educational selection, particularly for households navigating financial constraints.

I calibrate the model parameters to match the structural features of the Japanese economy and empirical evidence on Ph.D. enrollment. The framework is disciplined to replicate key targets, including the capital-output ratio and the baseline Ph.D. enrollment rate.

Using the calibrated model, I perform policy experiments to analyze the impact of varying the doctoral subsidy level. The simulation results reveal that while enrollment rates among households with strong academic taste are already relatively high, further promotion is difficult to achieve except for those with high assets who can leverage their wealth to buffer post-graduation income risks. For households without such strong non-pecuniary preferences, the current subsidy levels are not

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[3] Formalizes and extends the analysis in Hayama (2026).

attractive enough to offset the substantial financial disincentives of the doctoral path. Consequently, the aggregate response of enrollment remains remarkably limited because the policy fails to resolve the underlying income risks; specifically, an annual increase of 100,000 JPY in support raises the enrollment rate by a mere 0.015 percentage points. To underscore the significance of these results, I contrast them with a counterfactual model that omits academic taste heterogeneity, where the same subsidy increase leads to an unrealistically high 6.88 percentage point rise in enrollment. This stark discrepancy demonstrates that explicitly incorporating non-pecuniary preferences is indispensable for capturing the actual nature of Ph.D. enrollment decisions, where intrinsic motivation, rather than pure financial optimization, acts as a decisive filter. Crucially, I find that current subsidy policies and their expansions are sub-optimal compared to a no-subsidy regime in terms of social welfare. This outcome is driven by the fact that the policy works primarily as a tax-funded transfer for consumption amenities rather than an efficient investment in aggregate human capital. These findings suggest that policy designs focusing solely on contemporaneous costs may struggle to yield significant macroeconomic impact.

The remainder of this paper is organized as follows. Section 2 reviews the related literature and situates this study within the existing research on human capital and occupational choice. Section 3 presents the dynamic heterogeneous-agent model, which explicitly introduces "academic taste" into household preferences. Section 4 presents the quantitative model analysis, outlining the calibration strategy and discussing the simulation results of the policy experiments and counterfactual scenarios. Section 5 concludes the paper and discusses avenues for future research. Finally, Appendices A, B and C provide technical details on the formal definition of the equilibrium, the numerical implementation, and the calibration procedure, respectively.

2 Literature Review

This paper is situated at the intersection of three distinct strands of literature: (1) the labor market dynamics and career risks associated with Ph.D. programs, (2) the policy evaluation of higher education subsidies, and (3) the role of non-pecuniary preferences in human capital investment decisions.

Global structural changes in academia have significantly heightened the career risks for Ph.D. graduates. The increasing reliance on external funding has prioritized short-term results, expanding the demand for precarious, temporary postdoctoral labor (Cantwell and Taylor, 2015). Consequently, opportunities for stable academic positions have diminished, making holding a doctorate no longer a guarantee of tenure (Cantwell, 2011). In contrast to these academic risks, evidence from other developed nations (Auriol, Misu and Freeman, 2013) demonstrates that choosing a business career generally offers relatively lower employment risks and higher income (Auriol et al., 2013). Amidst these shifts, doctoral education is evolving toward interdisciplinary and industry-oriented models (Sarrico, 2022). This high-risk environment underscores the need to analyze Ph.D. enrollment beyond simple career-path choices, focusing on the fundamental trade-off between academic aspirations and financial precariousness.

Second, the literature on higher education subsidies emphasizes their dual role in alleviating liquidity constraints and providing insurance against future uncertainty. While standard human capital theory justifies subsidies to ensure equality of opportunity, empirical effects vary significantly across contexts (Dynarski, 2003; Nielsen, Sørensen and Taber, 2010; Lochner and Monge-Naranjo, 2011). In Japan, the response to financial aid is mediated by rigid labor markets and future income prospects (Sano, 2019; Kane, 1994). Recent studies suggest that early financial commitments can act as "insurance" against income risk (Dynarski, Libassi, Michelmore and Owen, 2021; Mateen, Stiglitz and Yun, 2021). However, excessive expansion may lead to "over-education" or labor market mismatches, potentially depressing economic growth (Freeman, 1976; Duncan and Hoffman, 1981; Horii, Kitagawa and Futagami, 2008; Alon, 2019). This paper positions itself by addressing the "high-risk" Japanese environment where subsidies fail to mitigate substantial post-graduation risks, requiring a model that incorporates non-pecuniary factors (Renée, 2025; Becker, 1964).

Third, educational investment decisions are driven by multi-faceted utility functions that include non-pecuniary "psychic costs" and "consumption amenities" (Cunha, Heckman and Navarro, 2005; Jacob, McCall and Stange, 2018; Beffy, Fougere and Maurel, 2012). The specific components of these utilities depend heavily on national characteristics and ideologies (Delavande and Zafar, 2019; McAlpine, Skakni and Inouye, 2021). In Japan, postgraduate education is often motivated by higher job satisfaction rather than wage premiums (Suga, 2017). Despite risks of skill mismatch, wage penalties, and psychological distress associated with doctoral studies (Paolo and Mañé, 2016; Gaeta, Lavadera and Pastore, 2017; Bender and Heywood, 2011; Levecque, Anseel, De Beuckelaer, Van der Heyden and Gisle, 2017), many individuals are "pulled" into Ph.D. programs by academic taste (Bloch, Graversen and Pedersen, 2015; Di Paolo, 2016). While these preferences may shift toward industrial priorities in STEM fields (Roach and Sauermann, 2010, 2017) or be influenced by industry contact (Mangematin, 2000), academic taste remains the primary filter. By modeling this unobserved heterogeneity, this paper contributes to a more credible evaluation of doctoral policy and its macroeconomic consequences.

3 Model Economy

I develop a heterogeneous-agent dynasty model. The economy consists of three types of agents: households, firms, and a government. I begin by describing the demographic structure and the economic environment. I then define the technology and, finally, the stationary recursive competitive equilibrium.

3.1 Demography

Time is discrete and given by $t = 0, 1, 2, \dots$, and persists over an infinite horizon. The economy is populated by a continuum of households (dynasties), indexed by i. In each household i, altruistic individuals who live for two periods are born in every period. While each individual has a finite lifespan, the household lineage is perpetual due to altruism.

The lifecycle and timing of events for individuals within a household are described as follows:

1. The "Young" (Period 1 of life): In any period t, a new individual (generation t) is born. During this period, the household makes an educational choice $\kappa^i_{t+1} \in \{I, A\}$, where I denotes the industrial sector (e.g., private firms) and A denotes the academic sector. If the household chooses to enroll its generation in a Ph.D. program ($\kappa^i_{t+1} = A$), it incurs an education cost v during the "young" period. There is a one to one mapping between the educational choice and the occupation in the next period.

2. The “Old” (Period 2 of life): In period $t+1$, this individual (now “old”) supplies labor. Their occupation is the one they chose in t, and the levels of human capital h^i_{t+1} and academic taste θ^i_{t+1} they utilize are realized in period $t+1$. After this period, the individual exits the economy.

I interpret each period t as corresponding to 30 years in real time. This implies that the “young” period (education choice) and the “old” period (labor supply) each last for 30 years respectively.

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 their assets, human capital, occupation, and academic taste. They make decisions regarding consumption, saving, and enrollment in Ph.D. programs. Each household i has a state defined by assets a, human capital h, occupation κ, and academic taste θ.

In each period t, h^i_t and θ^i_t represent the human capital and academic taste of the “old” generation who supplies labor. These attributes are inherited from the previous generation and define the current household state. I assume that both household level stochastic processes are intergenerationally persistent.

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

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

Here, $\varphi^h \in (0,1)$ is the autoregressive coefficient, and $\varepsilon^{h,i}_{t+1}$ is an i.i.d. shock.

In contrast to the human capital process which 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^i_t follows an AR(1) process with a constant mean:

$$\theta^i_{t+1} = \left(1 - \varphi^\theta\right)\bar{\theta} + \varphi^\theta \theta^i_t + \varepsilon^{\theta,i}_{t+1}, \quad \varepsilon^{\theta,i}_{t+1} \sim N\Big(0, {\sigma^{\theta}}^2\Big). \tag{2}$$

where $\varphi^\theta \in (0,1)$ is the autoregressive coefficient, $\bar{\theta}$ is the unconditional mean, and $\varepsilon^{\theta,i}_{t+1}$ is an i.i.d. shock. This structure implies that the household makes an educational choice for the individual born in period t based on the current household state $(a^i_t, h^i_t, \kappa^i_t, \theta^i_t)$, where this decision determines the occupation in period $t+1$ and the other state variables $(a^i_{t+1}, h^i_{t+1}, \theta^i_{t+1})$ are stochastic realizations which depend on the current state. All possible combinations of these household states are defined as the state space $\mathcal{S} := \mathcal{A} \times \mathcal{H} \times \mathcal{K} \times \Theta$. Here, $\mathcal{A}$, $\mathcal{H}$, $\mathcal{K} = \{I, A\}$, and Θ are the respective sets for assets a, human capital h, occupation κ, and academic taste θ. The measure μ represents the proportion of households distributed across the state space $\mathcal{S}$, satisfying $\mu(\mathcal{S}) = 1$.

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

$$\tilde{h}^i_t := \begin{cases} 1 & \text{if } \kappa^i_t = I, \\ \gamma h^i_t & \text{if } \kappa^i_t = A. \end{cases} \tag{3}$$

This specification highlights the distinct risk profile of each sector. The industrial sector offers a constant productivity of one, whereas the academic path depends on the stochastic human capital stock h_t^i. Consequently, choosing academia exposes the household to future income uncertainty, while the industrial sector provides a stable baseline independent of fluctuations in h_t^i. The parameter $\gamma > 0$ represents the relative productivity or return on human capital in the academic sector, which scales the raw human capital h into effective units.

Preferences Household i's preferences are defined over sequences of consumption $\{c_t^i\}_{t=0}^{\infty}$ and the utility derived from their chosen occupation κ_t^i.

The lifetime utility of household i is given by the expected discounted sum of period utilities:

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

where $\beta \in (0,1)$ is the discount factor. The utility from consumption c_t^i is represented by a standard CRRA utility function: $u(c_t^i) = \frac{{c_t^i}^{1-\rho}}{1-\rho}$. Here, $\rho > 0$ represents the coefficient of relative risk aversion. The second term captures the non-pecuniary utility (or disutility) from the household's occupation. θ_t^i is the household's academic taste. The indicator function $\mathbb{1}_A(\kappa_t^i)$ equals one if the household's occupation κ_t^i is in academia (A), and zero otherwise. This implies that the academic taste θ_t^i only contributes to the household's utility if they are engaged in an academic occupation.

3.2.2 Firms and Aggregation

Firms produce goods using aggregate capital $K > 0$ and aggregate effective human capital $H > 0$ supplied by households.

Technology In period t, firms produce aggregate output Y_t using aggregate capital K_t and aggregate effective human capital H_t supplied by households. I assume the technology follows a Cobb–Douglas form,

$$Y_t = F(K_t, H_t) = K_t^{\alpha} H_t^{1-\alpha},$$

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

3.2.3 Government

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 represents a transfer provided to "young" individuals who enroll in a Ph.D. program, intended to support their education and consumption during the enrollment period.

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. 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.

This state is characterized by a vector (a, h, κ, θ), which represents assets a, human capital h, the current occupation of the "old" generation κ, and academic taste θ. As defined in Section 3.1, the household makes choices for the next period. This educational choice is synonymous with the choice of the next period's occupation, $\kappa' \in \{I, A\}$. The household's problem is to choose consumption c, next period's assets a', and this next period's occupation κ' to maximize its lifetime utility (defined in Section 3.2.1). Let $V(a, h, \kappa, \theta)$ be the value function for a household in state (a, h, κ, θ). The problem can be expressed recursively by the following Bellman equation:

$$V\Big(a, h, \kappa, \theta\Big) = \max_{c, a', \kappa'} \Big\{ \Big(u\left(c\right) + \mathbb{1}_A(\kappa) \cdot \theta \Big) + \beta \mathbb{E}_{h', \theta'} V'\Big(a', h', \kappa', \theta'\Big) \Big\} \tag{4}$$

subject to the following constraints: The flow budget constraint is:

$$c = \begin{cases} (1-\tau)y + (1+r)a - a' & \text{if } \kappa' = I, \\ (1-\tau)y + (1+r)a - a' + s - \nu & \text{if } \kappa' = A. \end{cases} \tag{5}$$

The labor income y earned by the working generation is determined by the current occupation κ and human capital h. Specifically, the income is $y = w$ if the household is in the industrial sector ($\kappa = I$), while it is $y = w\gamma h$ if it is in academia ($\kappa = A$). Here, w denotes the wage and r represents the real interest rate, both of which are determined in the factor markets. This formulation implies that the industrial sector provides a stable income, whereas the academic path depends on the stochastic human capital stock h and thus entails income risk. Additionally, s denotes the subsidy received during doctoral studies, and ν represents the cost of education, including tuition and forgone earnings. The constraints on next period's assets a' depend on the occupational choice κ' and a borrowing limit $b \geqslant 0$:

$$\begin{cases} a' \geqslant 0 & \text{if } \kappa' = I, \\ a' \geqslant -b & \text{if } \kappa' = A. \end{cases} \tag{6}$$

Here, $u(c)$ is the utility from consumption, and $\mathbb{1}_A(\kappa)\theta$ is the non-pecuniary utility. This term, consistent with the preference definition in Section 3.2.1, indicates that the academic taste θ contributes to utility only when the "old" generation's current occupation κ is academia (A). β is the discount factor. The expectation $\mathbb{E}_{h',\theta'}$ is taken over the stochastic realization of the next period's state (h', θ'), which follows the transition processes defined in Section 3.2.1. The budget constraint (5) allocates income from labor $(1-\tau)y$ and assets $(1+r)a$ to consumption c, next period's assets a', and the net cost of education $(s - \nu)$, which is incurred only if the household selects the doctoral path for the "young" generation ($\kappa' = A$). The constraints (6) on next period's assets a' are state-dependent. For the industrial sector ($\kappa' = I$), households face a no-borrowing constraint. For the doctoral path ($\kappa' = A$), the constraint allows households to borrow up to an exogenous limit b. This parameter b represents the student loans available to students during the Ph.D. program, which enables households to finance their education and consumption during their studies even with limited current assets.

3.4 Stationary Recursive Competitive Equilibrium

I define a recursive competitive equilibrium, or stationary recursive competitive equilibrium, as the state in which households, firms, and the government all behave optimally and the market-clearing conditions are simultaneously satisfied. In the steady state, although each household i continues to face uncertainty, the aggregate distribution of all possible states that households may encounter remains constant over time.

The formal definition of the equilibrium and the market-clearing conditions are provided in Appendix A.

4 Model Analysis

This section conducts a quantitative analysis of the model to evaluate the policy interventions. First, Section 4.1 outlines the calibration strategy. Section 4.2 validates the baseline model's fit to the Japanese data and examines the model's implications regarding endogenous selection mechanisms. Section 4.3 then presents the macroeconomic and welfare impacts of the policy experiments. Finally, Section 4.4 provides a counterfactual analysis to highlight the critical role of non-pecuniary preferences in the Ph.D. enrollment decision.

4.1 Calibration Strategy

This section outlines the strategy used to assign values to the model parameters defined in Section 3. My strategy is to choose parameters such that the model matches key characteristics of the Japanese economy and empirical evidence on Ph.D. enrollment. A detailed description of the data sources and the calibration procedure is relegated to Appendix C.

Table 1 summarizes all parameters used in the model, distinguishing between those set externally based on literature or policy data (Appendix C.1) and those calibrated internally using SMM (Appendix C.2).

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	Based on ann. rate $\delta \approx 0.085$
ν	Ph.D. educational cost	0.328	MEXT (2023), NISTEP (2024)
s	Government subsidy rate	0.032	MEXT data
b	Borrowing limit ($\kappa' = A$)	0.040	JASSO student loan (type I)
φ^h	Persistence of h process	0.360	Lefranc, Ojima and Yoshida (2014)
Internally Calibrated Parameters (SMM)			
β	Discount factor	0.296	K/Y ratio
$\bar{\theta}$	Mean academic taste	-0.619	Ph.D. enrollment rate
σ^h	Std. dev. of h shock	0.315	Gini coeff. (Academia)
σ^θ	Std. dev. of θ shock	0.528	Childhood household income†
φ^θ	Persistence of θ process	0.366	Share of parents with Ph.D.†
γ	Academic human capital return	0.693	Lifetime income ratio (Y^I/Y^A)

Note: † Targets taken from Morgan, LaBerge, Larremore, Galesic, Brand and Clauset (2022). Values for parameters are rounded.

4.2 Model Implications

This section evaluates the performance and empirical plausibility of the calibrated model. I first assess the fit of the six moments explicitly targeted by the SMM procedure, as described in Appendix C.2. Table 2 summarizes the results. As shown, the calibrated model closely reproduces the key empirical moments observed in the data.

Table 2: Fit of Targeted Moments

Moment	Description	Data	Model
K/Y	Capital-output ratio	3.322	3.309
Enrollment Rate	Ph.D. enrollment (% of Master's grads)	9.4%	9.4%
Gini (A)	Gini coefficient of academic income	0.188	0.182
Y^I/Y^A	Lifetime income ratio (Ind. / Acad.)	1.395	1.361
Parent Ph.D.	Share of faculty with a Ph.D. parent	22.2%	20.7%
Childhood Income	Relative childhood household income†	1.237	1.235

Note: Data sources are described in Appendix C.2. †Ratio relative to the general public.

The primary implications of the model come from examining key patterns and responses that were not explicitly targeted during the calibration. First, I validate the model's internal mechanism regarding financial constraints. Although the SMM procedure only targeted the total Ph.D. enrollment rate (9.4%), Table 3 illustrates that the model endogenously generates a positive relationship between household assets and the decision to enroll in a Ph.D. program. As shown in Table 3, the enrollment rate increases from 7.0% for the lowest asset quartile (Q1) to 13.6% for the highest quartile (Q4). This pattern confirms that the model correctly captures the effect of liquidity constraints, where wealthier households can more easily finance the educational costs and endure the income risks associated with doctoral studies.

Table 3: Ph.D. Enrollment Rate by Asset Quartile

Quartile	Q1	Q2	Q3	Q4
Enrollment Rate (%)	7.0	7.2	9.2	13.6

In addition to financial wealth, Table 4 illustrates that the model also captures human capital sorting. As shown in Table 4, the enrollment rate increases monotonically from 8.7% for the lowest human capital quartile (Q1) to 9.8% for the highest quartile (Q4). This pattern confirms the positive selection mechanism, where individuals with higher academic aptitude, and thus higher expected returns in academia, are more likely to pursue a doctoral degree.

Table 4: Ph.D. Enrollment Rate by Human Capital Quartile

Quartile	Q1	Q2	Q3	Q4
Enrollment Rate (%)	8.7	9.4	9.7	9.8

Furthermore, I examine the selection mechanism with respect to non-pecuniary preferences. Table 5 reports the enrollment rates conditional on the academic taste quartiles (θ). The model generates a distinct "corner solution" behavior: for households in the bottom three quartiles (Q1 through Q3), the enrollment rate is zero. Enrollment occurs only among those in the highest quartile (Q4), where the rate reaches 37.7%.

Table 5: Ph.D. Enrollment Rate by Academic Taste Quartile

Quartile	Q1	Q2	Q3	Q4
Enrollment Rate (%)	0.0	0.0	0.0	37.7

This stark selection indicates that in the model, academic taste acts as a necessary condition for enrollment, while human capital influences the decision at the margin. This finding mirrors the survey results of Kawamura and Watanabe (2023), who report that approximately 80% of Ph.D. entrants cite an interest in research as their primary motivation. These consistencies validate the model's suitability for policy analysis.

Second, I verify that the model responds directionally as expected to policy interventions. I simulate the model by varying the government subsidy level s to assess the sensitivity of enrollment decisions. Quantitatively, when the annual subsidy is increased by 100,000 JPY, the enrollment rate increases by approximately 0.015 percentage points. Regardless of the magnitude of the elasticity estimates or the specific form of financial aid considered, the positive behavioral response is consistent with prior studies (Dynarski, 2003; Nielsen et al., 2010; Sano, 2019).

4.3 Policy Experiments

This section presents the quantitative results of the policy experiments. I analyze the impact of varying the doctoral subsidy level s on household enrollment decisions, macroeconomic aggregates, and social welfare. The simulation results, summarized in Table 6, reveal a nuanced mechanism: while the macro-level expansion of enrollment and GDP is highly inelastic, the subsidy generates substantial welfare gains by enabling a specific subset of households to pursue non-pecuniary utility.

Table 6: Model Response to Subsidy Policy

Variable	No Subsidy	Baseline	1.5×	2.0×
Key Outcomes				
Enrollment Rate	9.3%	9.4%	9.5%	9.5%
Output (Y, % change)	+1.4	—	+0.9	+0.9
Capital Stock (K, % change)	+3.8	—	+2.6	+2.4
Eff. Human Capital (H, % change)	+0.0	—	−0.0	−0.0
Social Welfare				
CEV (% change)	+0.9	—	+0.5	+0.4

First, I examine the macro-level response of the economy to changes in the subsidy level. The results summarized in Table 6 indicate that the aggregate enrollment rate is remarkably inelastic with respect to the subsidy. Quantitatively, when the annual subsidy is increased by 100,000 JPY, the enrollment rate increases by only approximately 0.015 percentage points. Furthermore, this highly inelastic response is consistent with recent empirical data. Between FY2021 and FY2023, while the number of students receiving government financial support expanded by approximately 20.3%, the Ph.D. enrollment rate among Master's graduates increased by a mere 0.032 percentage points.[4] Simulating a comparable subsidy expansion within the full model yields a similarly negligible increase of just 0.016 percentage points, capturing this structural stagnation.

Similarly, the impact on macroeconomic variables is limited. Within the modeled economy, output and capital stock grow by only 0.9% and 2.4–2.6% respectively under the expanded policies, and aggregate effective human capital remains virtually unchanged. It is important to note that this model focuses exclusively on households with at least a Master's degree, which constitute approximately 5.6% of the overall Japanese economy.[5] Consequently, when scaled to the entire macroeconomy, the impact of the 1.5× policy translates to a mere 0.05% increase in total GDP and a 0.03% improvement in overall social welfare. More importantly, Table 6 reveals that the baseline policy and its expansions are actually sub-optimal compared to a no-subsidy regime. Abolishing the subsidy entirely yields the highest gains in

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[4] Since FY2021, the Japanese government has implemented comprehensive policies for doctoral students, which include expanding financial support during their enrollment and strengthening career path development post-graduation (MEXT, 2025; available at: `https://www.mext.go.jp/content/20250626-mxt_kiban01-000043384_09.pdf`).

[5] This figure is calculated based on the averages of the university enrollment rate from 2009 to 2013 and the enrollment rate among undergraduate students from 2013 to 2017 (using data from the School Basic Survey (MEXT, 2025)), as well as the Ph.D. enrollment rate among Master's graduates from 2015 to 2019 (using data from the Japanese Science and Technology Indicators (NISTEP, 2025)).

output and social welfare. However, it should be noted that these figures likely underestimate the true macroeconomic impact. Because the current model abstracts from the positive externalities of advanced research, such as knowledge spillovers and TFP gains, the broader economic returns of doctoral education are not fully captured. Nevertheless, the limited behavioral response in enrollment aligns with the structural reality that the subsidy addresses only the contemporaneous financial burden during the program, leaving the substantial post-graduation income risk unresolved. This finding is consistent with recent literature highlighting the importance of insuring future income risk (e.g., Mateen et al. (2021)).

To understand the mechanism driving these behind the unresponsive macro aggregates, I decompose the change in the aggregate enrollment rate into a *within-quartile* component and a *composition* component, plus an interaction term. Let the aggregate enrollment rate be $ER = \sum_{q=1}^{4} p_q \, ER_q$, where ER_q is the enrollment rate conditional on belonging to asset quartile q, and p_q is the stationary population share of quartile q. Following the baseline stationary distribution, I hold the asset quartile assignments fixed across policy experiments to perform the following decomposition:

$$\Delta ER \; = \; \sum_q p_q^0 \, \Delta ER_q \; + \; \sum_q ER_q^0 \, \Delta p_q \; + \; \sum_q \Delta p_q \, \Delta ER_q \tag{7}$$

where p_q^0 and ER_q^0 denote baseline values. The "within effect" captures pure behavioral responses within fixed groups, while the "composition effect" represents shifts in the population distribution across quartiles. Table 7 reports the resulting decomposition relative to the baseline.

As shown in Table 7, the small positive aggregate changes (+0.039 p.p. for

Table 7: Decomposition of Changes in Ph.D. Enrollment Rate

Scenario	Total change	Within effect	Composition effect	Interaction
No Subsidy vs. Baseline	−0.138 p.p.	−0.684 p.p.	+0.664 p.p.	−0.119 p.p.
1.5× vs. Baseline	+0.039 p.p.	−0.551 p.p.	+0.673 p.p.	−0.083 p.p.
2.0× vs. Baseline	+0.089 p.p.	−0.503 p.p.	+0.660 p.p.	−0.069 p.p.

1.5× and +0.089 p.p. for 2.0×) mask a complex general-equilibrium trade-off. Surprisingly, the pure behavioral response within fixed groups (the within effect) is negative, which is offset by a strongly positive composition effect. This indicates that the subsidy induces endogenous shifts in the stationary wealth distribution, making the aggregate numbers difficult to interpret directly.[6]

To isolate the pure behavioral responses of households while abstracting from the composition effects caused by endogenous shifts in the asset distribution, I hold the baseline quartile assignments fixed and examine the within-group policy responses. Figure 1 presents the resulting enrollment rates across asset quartiles. Specifically, Figure 1 illustrates the enrollment rates under four distinct scenarios: the baseline subsidy level (orange bars), the complete removal of the subsidy (blue bars), and two expansionary scenarios—a 1.5× increase (green bars) and a 2.0× increase (purple bars). The results demonstrate that the expansion of subsidies primarily enhances enrollment opportunities for households in the higher asset quartiles. In contrast, the policy expansion appears to have a negligible impact on the enrollment decisions of households in the lower asset quartiles.

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[6] To understand why the within effect can be negative, consider a household in the lowest asset group (Q1) that already intended to enroll. If the subsidy increases their assets enough to move them into Q2, they are no longer counted in the Q1 average. Since an “enrolling” household has left the group, the enrollment rate for those remaining in Q1 appears to decrease, even though no one’s behavior actually worsened. Figure 1 addresses this by tracking households based on their original baseline status.

While Figure 2 highlights the marginal changes relative to the baseline across both human capital and asset dimensions.

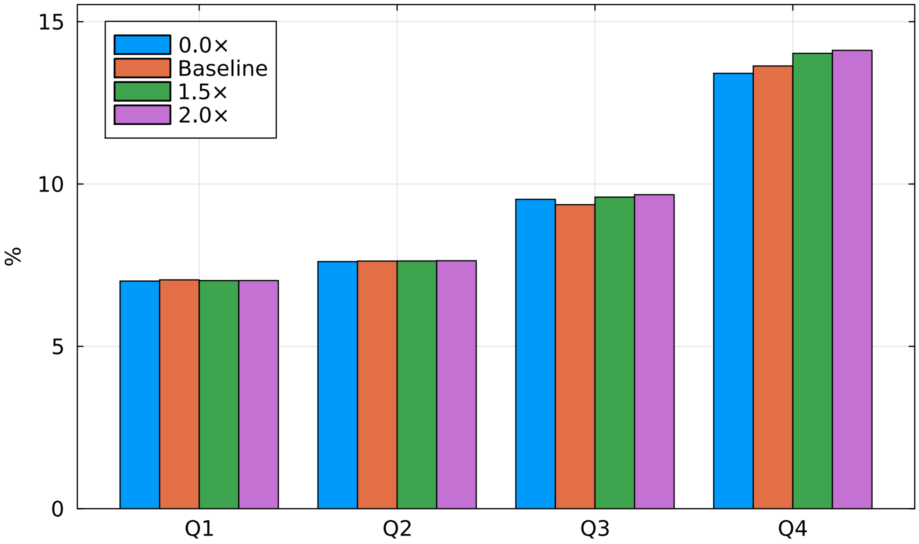

Figure 1: Ph.D. Enrollment Rate by Asset Quartile

A conventional human capital perspective might predict that subsidies primarily boost enrollment among students with high ability who face liquidity constraints, specifically those in asset quartile Q1 and human capital quartile Q4. However, Figure 2 reveals a strikingly different reality, even though the absolute change in the enrollment rate is small and remains within plus or minus one percentage point. In other words, the subsidy primarily influences enrollment decisions for households with high assets, particularly those with low human capital, while having almost no impact on households with low assets. The agents who marginally change their behavior are those who possess enough household wealth to buffer income risks but previously hesitated to enroll because their expected financial returns in academia were low.

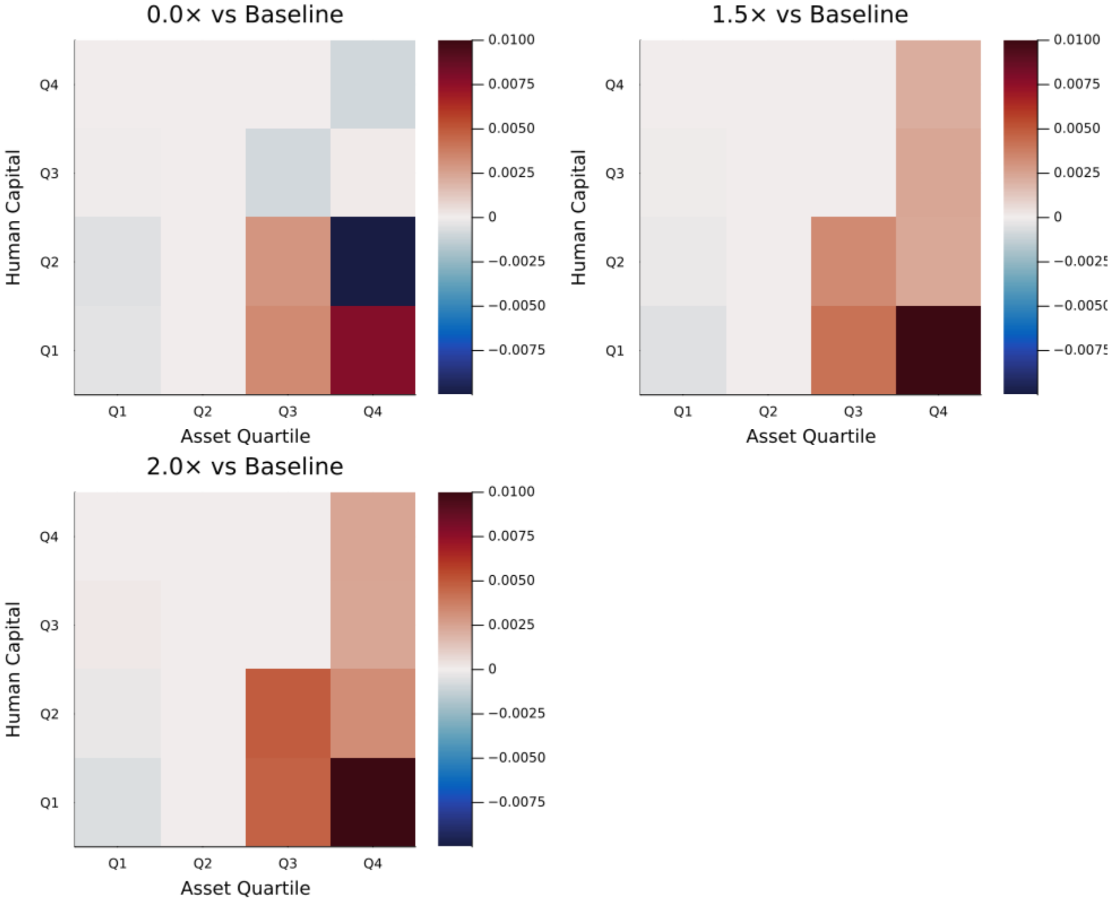

Figure 2: Changes in Ph.D. Enrollment Rate by Human Capital and Asset Quartiles

Finally, if their expected financial return is low, why do these wealthier, lower-human capital households choose to enroll when the subsidy expands? The answer lies in the non-pecuniary preferences, specifically academic taste θ. Figure 3 presents the enrollment changes across the human capital and academic taste dimensions. The heatmap clearly demonstrates that the subsidy-induced increases are exclusively concentrated in the highest academic taste quartile (Q4), completely dominating the lower human capital segments.

This stark selection pattern is justifiable because the expected lifetime financial return of the doctoral path remains lower than that of the industrial path even with

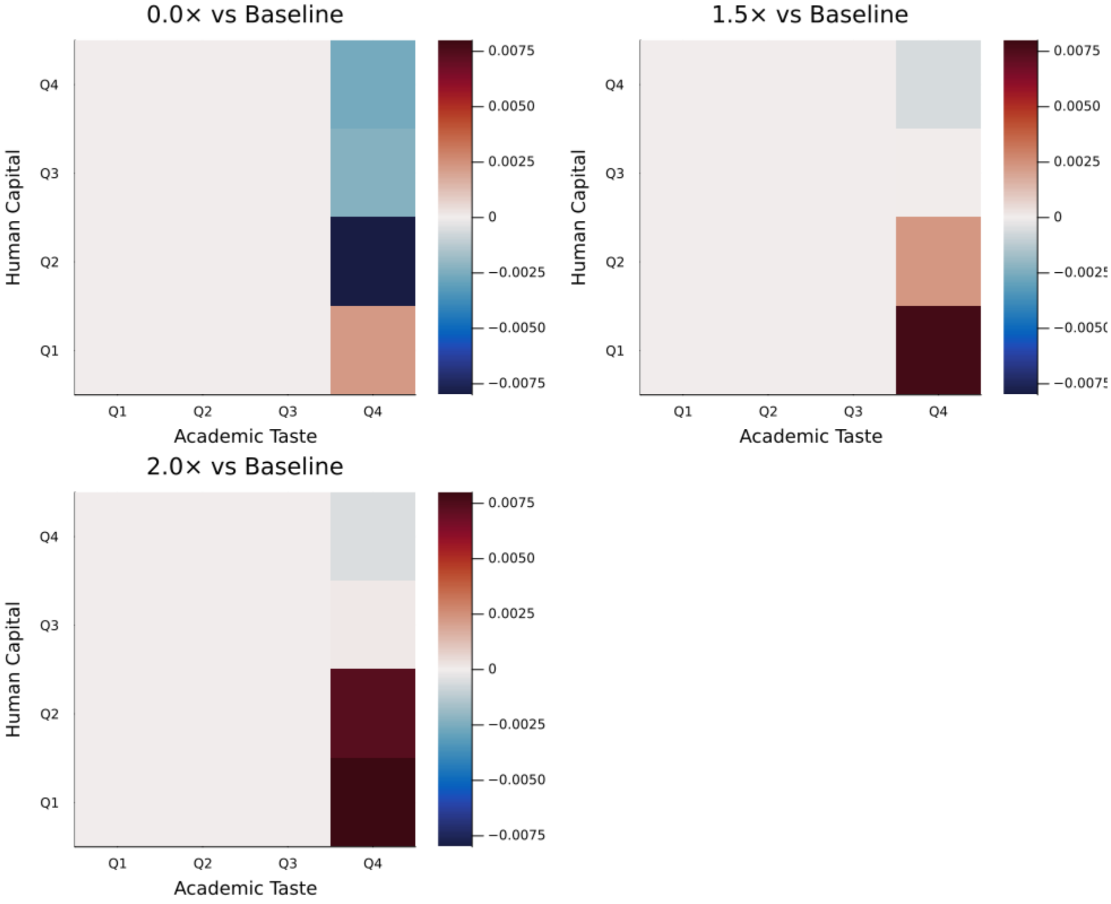

Figure 3: Changes in Ph.D. Enrollment Rate by Human Capital and Academic Taste Quartiles

expanded subsidies. Consequently, the policy is insufficient to incentivize enrollment among purely financially motivated households; instead, it functions as an enabler of consumption amenities. It provides just enough financial margin for households with strong academic taste but lower expected financial returns (low h) to leverage their existing assets and select their preferred career path. This conclusion is strongly supported by empirical evidence. For instance, Suga (2017) finds that the motivation for postgraduate education in Japan is significantly driven by job satisfaction rather than wage premiums. Furthermore, it aligns with survey data from Kawamura and Watanabe (2023), which reports that 80% of Ph.D. students enroll due to “academic taste.” However, while the subsidy successfully satisfies the non-pecuniary preferences of this specific demographic, it comes at a significant macroeconomic cost. This is because the expansion of the subsidy, funded by a higher tax burden on households, primarily induces enrollment among individuals whose productivity would actually be higher had they chosen not to enroll.

4.4 Counterfactual Analysis

To underscore the significance of incorporating heterogeneous non-pecuniary “academic taste” into the model, I perform a counterfactual analysis by assuming a homogeneous level of academic taste across all households (i.e., $N_\theta = 1$). By removing the preference heterogeneity, I isolate how θ acts as a buffer for financial incentives.

Calibration for the Counterfactual Model First, the model is re-calibrated to match key empirical moments, including the baseline Ph.D. enrollment rate and the capital-output ratio. While I attempted to calibrate the model to match the empirical baseline Ph.D. enrollment rate of 9.4%, the simplified structure of the homogeneous θ model resulted in a best-fit rate of 8.7%. Table 8 summarizes the calibrated parameters for this homogeneous θ case. It should be noted that, given the absence of non-pecuniary preference heterogeneity, this counterfactual model abstracts from the dynastic links observed in the data, such as the proportion of academic workers whose parents hold a Ph.D. Instead, this simpler framework serves as a benchmark to focus on the pure elasticity of enrollment behavior.

Table 8: Internally Calibrated Parameters for the Counterfactual Model

Parameter	Description	Value	Source / Target Moment
β	Discount factor	0.324	K/Y ratio
$\bar{\theta}$	Mean academic taste	0.124	Ph.D. enrollment rate
σ^h	Std. dev. of h shock	0.323	Gini coeff. (Academia)
γ	Academic human capital return	0.690	Lifetime income ratio (Y^I/Y^A)

Policy Responsiveness Table 9 compares the aggregate outcomes of the full model with those of the counterfactual homogeneous θ model.

Table 9: Comparison of Subsidy Effects (Full Model vs. Counterfactual Model)

Variable	No Subsidy	Baseline	1.5×	2.0×
Key Outcomes				
Enrollment Rate	8.7%	8.7%	25.8%	39.3%
Output (Y, % change)	−0.1	—	−4.3	−3.6
Capital Stock (K, % change)	−0.2	—	−5.0	+2.6
Eff. Human Capital (H, % change)	+0.0	—	−3.8	−7.0
Social Welfare				
CEV (% change)	−0.1	—	−6.7	−8.7

As shown in Table 9, the model without preference heterogeneity exhibits an unrealistically high response to the subsidy. In the absence of the θ filter, the Ph.D. enrollment rate jumps to 25.8% under the 1.5× subsidy and nearly 40% under the 2.0× scenario. This stands in stark contrast to the stagnant enrollment rates captured in the full model. Furthermore, as an additional metric of this sensitivity, an annual increase of 100,000 JPY in the subsidy raises the enrollment rate by approximately 6.88 percentage points in this setting. This response is nearly 450 times larger than the 0.015 percentage point increase observed in the full model, where academic taste acts as a decisive determinant.

The counterfactual results also reveal that omitting heterogeneity of θ leads to a severe misallocation of human capital and biased welfare evaluations. Under the 1.5× subsidy, aggregate output Y drops by 4.3% and social welfare decreases by 6.7%, representing much more severe declines compared to the full model.

The critical role of θ is further illuminated by comparing the underlying selection mechanisms. In the full model, Figure 2 demonstrates that the behavioral response to subsidies is concentrated among relatively wealthy households (asset Q3-Q4) with lower human capital (human capital Q1-Q2), as these agents use their assets to buffer the income risks of pursuing their academic tastes.

In sharp contrast, as illustrated in Figure 4, the counterfactual model predicts a strictly meritocratic selection pattern where the subsidy primarily boosts enrollment among liquidity-constrained, high-ability students in the lowest asset quartiles (asset Q1-Q2 and human capital Q4).

Without the non-pecuniary "academic taste" filter, households make career choices based purely on a financial trade-off. Consequently, households with high academic aptitude become unrealistically responsive to the subsidy in pursuit of higher lifetime earnings. However, such pure financial optimization is inconsistent with the Japanese reality, where opting for a Ph.D. results in a lower expected lifetime income. Because the full model captures an entirely different selection pattern, in which intrinsic motivation overrides the lack of a financial premium, it clearly demonstrates that omitting θ fails to characterize the true behavioral reality of Ph.D. enrollment decisions in Japan.

In conclusion, these findings demonstrate that a model omitting the heterogeneity of academic taste tends to overestimate policy responsiveness while producing

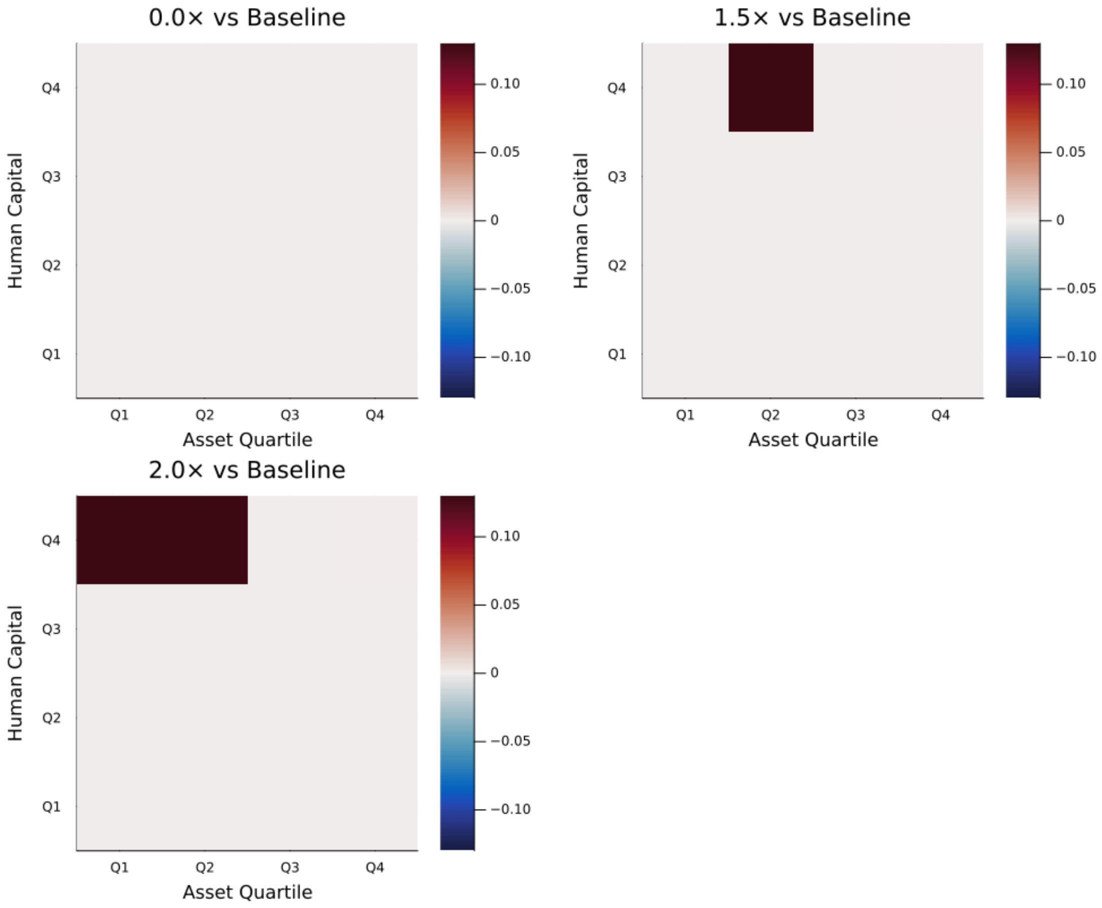

Figure 4: Changes in Ph.D. Enrollment Rate: Full Model vs. Counterfactual Selection Patterns

biased assessments of social welfare. Therefore, explicitly incorporating the unobserved heterogeneity of non-pecuniary benefits (θ) is crucial for a credible quantitative evaluation of Ph.D. enrollment policies and their macroeconomic consequences.

5 Conclusion

This paper constructed a dynamic heterogeneous-agent model to analyze Ph.D. enrollment decisions in Japan. Decisions at the doctoral stage are characterized by a unique nature, in which non-pecuniary motives—specifically "academic taste" —play a decisive role in the enrollment process. By explicitly incorporating this preference heterogeneity alongside standard financial factors, this study underscores the necessity and importance of developing a model uniquely tailored to doctoral education, departing from conventional human capital frameworks that primarily focus on pecuniary returns.

While job insecurity in academia, such as the precariousness of postdoctoral positions, is a globally shared challenge, many countries have seen a continued increase in Ph.D. holders, largely driven by rising demand in the private sector. Although a detailed discussion is beyond the scope of this paper, this trend suggests that in many countries, households originally aiming for academia can pivot to non-academic careers, or new households are drawn to doctoral studies by these outside options. Japan, however, presents a particularly constrained environment where doctoral talent is disproportionately concentrated in universities. For instance, approximately 75% of Ph.D.s in Japan work in academia compared to 43% in the U.S., whereas only 14% in Japan enter industry versus 42% in the U.S.[7] Furthermore, choosing to pursue a Ph.D. often entails forfeiting the traditional "membership-type" new-graduate employment opportunities in the private sector, which acts as a severe structural penalty. By incorporating these severe, Japan-specific career risks into the model, my findings highlight that intrinsic academic taste acts as the most critical determinant of enrollment. Consequently, the doctoral subsidy functions not merely as a standard educational investment, but primarily as an enabler that allows households with high academic taste to overcome liquidity constraints and pursue their preferred careers. Indeed, the simulation results suggest that although such support is limited to the period of enrollment and does not lead to a dramatic surge in enrollment rates, it nonetheless lowers the entry barrier for spe-

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[7] National Institute of Science and Technology Policy (2025).

cific households, thereby contributing to a modest increase in the aggregate Ph.D. enrollment rate. Regarding the recent policy initiatives in Japan aimed at expanding the doctoral population, these findings indicate that such subsidies partially achieve their primary objective by supporting a specific demographic, even if the quantitative impact remains constrained by the unresolved post-graduation risks.

The current model shows that uniformly expanding this limited subsidy yields relatively muted positive impacts on the macroeconomy. However, because the model abstracts from externalities such as the impact on TFP from an increase in Ph.D. holders, the true macroeconomic benefits of expanding the subsidy might be underestimated. One potential extension of this study is to incorporate these positive externalities to provide a broader evaluation of doctoral support policies.

Additionally, although this paper analyzed subsidies provided during enrollment, the results suggest that income risk after graduation remains a key factor. Therefore, another direction for future research is to examine policies that directly mitigate career risks after completion. Examples include the introduction of Income-Contingent Loans (ICL) or measures to improve matching with the private sector, which has recently become an active policy area. It remains an important task to compare and analyze the effects of such policies against the enrollment subsidy analyzed herein. In addition, while future uncertainty significantly affects students' university choices, as pointed out by Dynarski et al. (2021), the timing of financial aid commitments warrants further discussion. Early commitment to financial aid is expected to encourage students who wish to enroll in a Ph.D. program but hesitate due to financial risks. Such an analysis clarifies whether subsidy policies should target "newly entering households" or "households on the verge of giving up," thereby contributing to more effective policy design.

Finally, in reality, motivations for Ph.D. enrollment and subsequent career paths vary significantly across academic disciplines. Future analysis should, therefore, also focus on analyzing these field-specific differences in risks and incentives.

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A Definition of Equilibrium

Definition of Stationary Recursive Competitive Equilibrium. A stationary recursive competitive equilibrium is defined by the policy functions $g_c(a,h,\kappa,\theta)$, $g_a(a,h,\kappa,\theta)$, and $g_\kappa(a,h,\kappa,\theta)$; the probability distribution $\mu(a,h,\kappa,\theta)$ over the household state space; total capital K; total effective human capital H; the interest rate r; the wage w; the government policies (subsidy rate s, income tax rate τ, and borrowing limit b).

Specifically, the following conditions must be satisfied:

1. Given interest rate r, the wage w, the education cost ν, and policies, the policy functions g_c, g_a, and g_κ solve the household's dynamic optimization problem defined by the Bellman equation (4) and constraints (5)-(6) in Section 3.3.

2. Factor prices are determined competitively, and in a stationary recursive competitive equilibrium, the interest rate r and the wage w coincide with the solutions to the firm's optimization problem:

$$r = F_K(K,H) - \delta, \tag{A.1}$$

$$w = F_H(K,H). \tag{A.2}$$

3. The government finances the total subsidies s paid to all households selecting the doctoral path for their young members ($\kappa' = A$) through the income tax τ on total labor income wH. The government's budget constraint is:

$$\tau w H = s \int_{\mathcal{S}} \mathbb{1}_{\{g_\kappa(a,h,\kappa,\theta)=A\}} \, d\mu(a,h,\kappa,\theta). \tag{A.3}$$

4. In the market, the following clearing conditions must hold:
    (a) Total capital demand by firms equals total asset supply by households:

        $$K = \int_{\mathcal{S}} g_a(a, h, \kappa, \theta)\, d\mu(a, h, \kappa, \theta). \tag{A.4}$$

        Moreover, total labor demand by firms equals total effective human capital supply by households (using $\tilde{h}$ from (3)):

        $$H = \int_{\mathcal{S}} \tilde{h}\, d\mu(a, h, \kappa, \theta). \tag{A.5}$$

    (b) Total output is allocated to aggregate consumption C, replacement investment δK, and the total resource cost of education ν:

        $$F(K, H) = \underbrace{\int_{\mathcal{S}} g_c(a, h, \kappa, \theta)\, d\mu(a, h, \kappa, \theta)}_{C} + \delta K + \nu \int_{\mathcal{S}} \mathbb{1}_{\{g_\kappa(a,h,\kappa,\theta)=A\}}\, d\mu(a, h, \kappa, \theta). \tag{A.6}$$

5. The probability distribution μ is stationary. It must be consistent with the household's policy functions (g_a, g_κ) and the stochastic transition processes ((1), (2)). That is, μ is the fixed point of the transition function Γ generated by the economy's laws of motion:

    $$\mu = \Gamma(\mu). \tag{A.7}$$

B Numerical Implementation

To solve the model numerically, I approximate these continuous AR(1) processes using finite-state Markov chains based on the Tauchen (1986) method. I approximate both the human capital process and the latent academic taste process using $N_h = 10$ and $N_\theta = 10$ grid points, respectively. In the numerical computation, the units of both human capital and of labor productivity in the industrial sector are scaled by a factor of 10 to ensure numerical stability. Since the structural parameters are jointly calibrated to match the empirical moments conditional on this scaling, and because the model targets are dimensionless ratios, this choice of scaling unit does not affect the equilibrium properties or the results.

C Calibration

I follow the standard practice of dividing the parameters into two groups. The first group, described in Appendix C.1, consists of parameters set externally based on established literature or institutional data. These parameters are fixed prior to the internal calibration described in Appendix C.2. The second group, described in Appendix C.2, consists of parameters calibrated internally using the Simulated Method of Moments (SMM) to match key target moments. Table 1 (in Section 4) provides a complete summary of all parameters and their values.

C.1 Externally Set Parameters

I begin by setting the parameters that are determined exogenously, based on established literature or directly from institutional data. Following Hayashi and Prescott (2002), I set the capital share of income, α, to 0.362. The capital depreciation rate, δ, is set to 0.085 annually to match a standard annual rate used in quantitative macro models for Japan. For preferences, I set the coefficient of relative risk aversion, ρ, to 2.0. This is a standard value in the quantitative macroeconomics literature and is consistent with the CRRA value used in related studies, such as Matsuda and Mazur (2022).

I calibrate the parameters related to educational costs and financial constraints based on Japanese institutional data. The education cost, ν, is comprised of two components: direct costs (tuition and fees) and opportunity costs (foregone income). For direct costs, I calculate the average cost of a three-year Ph.D. program in Japan. Using FY2023 data on tuition and entrance fees and FY2023 enrollment data from Japanese Science and Technology Indicators 2024 (National Institute of Science and Technology Policy, 2024), I compute a weighted average cost across national, public, and private universities, resulting in a value of approximately 1.94 million JPY.[8] I assume no tuition is incurred during the extended enrollment period or the post-completion period before securing employment. For the time-related costs, I assume the Ph.D. program takes 5 years. Since one model period corresponds to 30 years, the program duration occupies 1/6 of the period. Regarding the opportunity cost included in ν, I estimate the foregone income during this 5-year period. As this income would have been earned if the individual had chosen the non-doctoral path, I measure this cost relative to the income of the industrial sector ($\kappa = I$). Finally, ν is set as the sum of these direct and opportunity costs, normalized by the model's unit of income.

The government subsidy, s, is calibrated based on national data on financial support for doctoral students (e.g., Japan Student Services Organization (JASSO), Japan Society for the Promotion of Science (JSPS)).[9] I set s to match the average support received during the standard three years of enrollment, which corresponds to approximately 1.2% of the lifetime income of an industrial sector worker. For those pursuing the doctoral path ($\kappa' = A$), I set the borrowing limit b to 4.32 million JPY, which corresponds to the JASSO interest-free student loan (Type I). This parameter b defines the lower bound of the asset constraint (6).

I also fix the parameters related to the persistence of the stochastic processes and the numerical method before the internal calibration. The human capital process, defined in equation (1), is assumed to follow AR(1) process in logs. I set the persistence parameter $\varphi^h = 0.360$, following the estimates for intergenerational

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[8] Based on the data from MEXT:
`https://www.mext.go.jp/a_menu/koutou/shinkou/07021403/1412031_00005.htm`.

[9] Based on the data from MEXT:
`https://www.mext.go.jp/content/20230905-mxt_daigakuc01-000031747_01.pdf`.

persistence in Lefranc et al. (2014).

Details on the numerical implementation, including grid settings and the scaling procedure, are described in Appendix B.

C.2 Internally Calibrated Parameters

This section describes the parameters calibrated internally to minimize the distance between key statistical moments observed in Japanese data and those generated by the model's simulation using the Simulated Method of Moments (SMM).

Let $\Psi = (\beta, \bar{\theta}, \gamma, \sigma^h, \sigma^\theta, \varphi^\theta)$ denote the vector of six structural parameters to be estimated. I define M_{data} as the vector of target moments from the data and $M_{model}(\Psi)$ as the corresponding vector of simulated moments generated by the model given parameters Ψ. The target moments M_{data} consist of the following six statistics: (1) the capital-output ratio (K/Y), (2) the Ph.D. enrollment rate, (3) the lifetime income ratio between industrial and academic paths (Y^I/Y^A), (4) the Gini coefficient of income for academic workers, and following Morgan et al. (2022), (5) the household income associated with the childhood location of academic workers, and (6) the proportion of academic workers whose parents hold a Ph.D.

The estimated parameter vector $\hat{\Psi}$ is obtained by minimizing the weighted sum of squared percentage deviations between the model and data moments. Formally, the minimization problem is defined as:

$$\hat{\Psi} = \arg\min_{\Psi} \sum_{j=1}^{6} \omega_j \left(\frac{M_{model,j}(\Psi) - M_{data,j}}{M_{data,j}} \right)^2 \tag{C.1}$$

where ω_j represents the weight assigned to moment j. Using relative (percentage) squared errors rather than absolute errors ensures that moments with larger absolute values (e.g., $K/Y \approx 3.322$) do not disproportionately influence the estimation compared to moments with smaller values (e.g., Enrollment rate ≈ 0.094). In addition to this scaling, I assign specific weights to prioritize the fit of aggregate macroeconomic ratios and key sorting statistics. Specifically, I set $\omega = 3.0$ for the capital-output ratio and Ph.D. enrollment rate; $\omega = 2.0$ for the childhood household income and the share of parents with a Ph.D.; and $\omega = 1.5$ for the Gini coefficient and the lifetime income ratio.

Although the parameters in Ψ are estimated jointly, each parameter tends to have a dominant influence on a specific moment. The following paragraphs describe the identification of each parameter in relation to its corresponding target moment.

Discount Factor (β) The discount factor, β, is calibrated to match the aggregate capital-output ratio (K/Y) of the Japanese economy. Specifically, I target an annual K/Y ratio of 3.322. This target is calculated using the 2015–2019 average of the aggregate capital stock from the JIP Database 2023 (RIETI and Hitotsubashi University, 2023) and the corresponding average of annual real GDP from the National Accounts of Japan. The discount factor β is set such that the model's steady-state ratio of capital stock to annualized output (i.e., total 30-year output divided by 30) matches this macroeconomic target.

Mean Academic Taste ($\bar{\theta}$) The mean-shift parameter, $\bar{\theta}$, which determines the average level of academic taste, is calibrated internally to match the average Ph.D. enrollment rate of 9.4% among Master's program graduates from 2015 to 2019. This target is taken from Japanese Science and Technology Indicators 2025 (National

Institute of Science and Technology Policy, 2025).

Academic Human Capital Return (γ) The academic human capital return, γ, which scales the human capital of academic workers (Occupation A), is set to match the expected lifetime income ratio between the industrial and academic paths (wH^I/wH^A). I calibrate γ to match my calculated ratio of 1.395 (i.e., the industrial path yields a 39.5% higher expected lifetime income).[10]

Variance of Human Capital (σ^{h^2}) The variance of human capital, σ^{h^2}, which governs income heterogeneity, is calibrated to match the Gini coefficient of income for academic workers (0.188). I calculate this target using data from the Basic Survey on Wage Structure (MHLW, 2023) and the Survey on Postdoctoral Fellows Regarding Employment and Careers (MEXT, 2022).

Variance of Academic Taste (σ^{θ^2}) The variance of academic taste, σ^{θ^2}, drives the sorting pattern based on socio-economic background. Ideally, this parameter would be calibrated using Japanese data; however, available income data for Ph.D. students in Japan mixes individuals who are financially independent with those who co-reside with their parents, making it difficult to consistently identify their socio-economic backgrounds.[11] Therefore, as an alternative, I calibrate this parameter to

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[10] This ratio is calculated as follows: The expected lifetime income for the industrial sector (wH^I) is computed using data from the School Basic Survey (MEXT, 2023) for career path distributions, the Basic Survey on Wage Structure (MHLW, 2023), and the Employment Status Survey (MHLW, 2023). Due to data limitations, I assume that "post-graduate" workers in these datasets primarily represent Master's graduates who did not enroll in a Ph.D. program. The expected lifetime income for the academic path (wH^A) additionally incorporates data from the Survey on Postdoctoral Fellows (MEXT, 2022).

[11] Japan Student Services Organization (JASSO), "FY2022 Student Life Survey" [Reiwa 4-nendo Gakusei Seikatsu Chosa], available at:
`https://www.jasso.go.jp/statistics/gakusei_chosa/2022.html`.

match the average household income of the childhood neighborhoods of academic workers, using US data as reported in Morgan et al. (2022). Targeting this moment strictly disciplines the degree of heterogeneity in the non-pecuniary motivation required to pursue a Ph.D. despite the substantial income risks involved. Ultimately, this moment captures the crucial correlation between an individual's background resources and their selection into academia.

Intergenerational Persistence (φ^θ) The persistence parameter, φ^θ, governs the intergenerational transmission of academic taste. This parameter is identified by matching the proportion of academic workers whose parents hold a Ph.D. As shown in Morgan et al. (2022), this share serves as a proxy for the strong dynastic link observed in the Japanese academic sector.