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所得リスクと非金銭的選好を考慮した博士課程進学のマクロ経済分析

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キーワード: Ph.D. Enrollment, Heterogeneous-Agent Macroeconomic Model, Non-Pecuniary Preferences, Human Capital, Financial Aid, Income Risk

【要旨】

・Japan is expanding doctoral financial aid amid declining Ph.D. enrollment.
・Models Ph.D. enrollment decisions with heterogeneous “academic taste.”
・Heterogeneity in “academic taste” drives Ph.D. enrollment decisions.
・Ignoring this heterogeneity overestimates the effects of financial aid.
・At equal cost, financial aid raises enrollment more; income insurance raises welfare more.

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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 doctorate recipients per million population has increased in many major countries, Japan has seen a continued decline in Ph.D. enrollment. Against this background, recent policy efforts in Japan have focused on expanding financial support during doctoral study. This paper constructs a dynamic heterogeneous agent model that incorporates non-pecuniary "academic taste" alongside household assets and human capital to analyze Ph.D. enrollment in Japan. Using the calibrated model, I find that enrollment responds only modestly to larger enrollment subsidies, with additional enrollment concentrated among households with strong academic taste and sufficient assets. A recalibrated benchmark with common academic taste produces a much larger subsidy response, showing that preference heterogeneity materially affects the model's policy predictions. The limited aggregate response and the concentration of entrants in the highest academic taste quartile remain under alternative income ratio calibrations, although the asset margin and the output and welfare results vary. In the baseline income ratio calibration, expanding the subsidy slightly lowers stationary welfare, whereas partial income insurance at the same fiscal cost raises welfare despite producing a smaller enrollment response. These results highlight the importance of preference heterogeneity and post-graduation income risk for evaluating recent doctoral support policies in Japan.

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 doctorate recipients per million population has increased in many major countries, Japan has seen a continued decline in Ph.D. enrollment, diverging from the broader international pattern.[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 doctoral study.

The policy problem in Japan is not limited to tuition and living costs during doctoral study. A Master's graduate can immediately use Japan's conventional new graduate recruitment system, an important route into stable employment and training provided by firms. Entering a Ph.D. program means forgoing this opportunity at the Master's stage, while later entry into private sector employment can be more difficult under existing Japanese hiring practices.[2] At the same time, those pursuing an academic career face the more general risks of fixed-term postdoctoral and academic employment, with uncertain access to permanent positions. Thus, doctoral study in Japan combines an opportunity cost specific to Japan's private sector with the employment risk of an academic career.

Kawamura and Watanabe (2023) report similar concerns in survey responses. Among Master's students who chose employment rather than Ph.D. enrollment, many cited uncertainty about their economic outlook during doctoral study and employment after completion. At the same time, about 80% of students who chose

[1] NISTEP (2025).

[2] Iwawaki and Kosugi (2023) document that Japan's new-graduate hiring system continues to concentrate opportunities for stable employment at graduation. Ministry of Education, Culture, Sports, Science and Technology and Ministry of Economy, Trade and Industry (2025, p. 13) explain that doctoral recruitment is not governed by a uniform schedule and that firms may use cohort-based hiring, career hiring, or both. Human Resources Committee, Council for Science and Technology (2017, p. 11) identify employment-practice barriers to hiring older doctoral graduates.

to enroll in a Ph.D. program identified their interest in research as the primary motivating factor. These responses motivate a framework in which financial risks and non-pecuniary motives jointly shape Ph.D. enrollment.

This paper studies how heterogeneity in non-pecuniary "academic taste" shapes Ph.D. enrollment and its response to financial aid. Non-pecuniary factors are already standard in quantitative models of educational choice. The contribution here is to model Ph.D. enrollment in Japan with heterogeneous academic taste at the household level and to quantify how this heterogeneity interacts with household assets, human capital, and post-graduation income risk. This framework allows the paper to evaluate how financial support affects enrollment when households differ both in their financial capacity and in the value they attach to an academic career.

This paper constructs a dynamic heterogeneous agent model of Ph.D. enrollment. Households differ in assets, human capital, and academic taste, all of which are intergenerationally persistent. The household chooses between immediate employment and Ph.D. enrollment, with the academic path providing non-pecuniary utility from research but exposing the household to post-graduation income risk. I calibrate the model to Japanese macroeconomic data and empirical evidence on Ph.D. enrollment.

Using the calibrated model, I find that enrollment responds only modestly to larger enrollment subsidies, with additional enrollment concentrated among households with strong academic taste and sufficient assets. Under a stylized 20.3% increase in the subsidy amount, enrollment rises by 0.07 percentage points in the full model, compared with 14.6 percentage points in a recalibrated benchmark with common academic taste. The limited aggregate response and the concentration of

entrants in the highest academic taste quartile remain under alternative income ratio calibrations, although the asset margin and the output and welfare results vary. In the baseline income ratio calibration, expanding the subsidy slightly lowers stationary welfare, whereas partial income insurance at the same fiscal cost raises welfare despite producing a smaller enrollment response.

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 sensitivity analyses and policy experiments. 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 and sensitivity analyses, respectively.

2 Literature Review

This paper relates to three strands: the labor market risks of doctoral education, quantitative analyses of higher education investment and financial support, and non-pecuniary motives in educational choice.

First, the doctoral-to-academic path can involve substantial post-completion earnings and employment risk. Academic labor markets in many countries have increasingly relied on temporary and postdoctoral positions, while access to stable academic employment has become more uncertain (Cantwell (2011); Cantwell and Taylor (2015); Auriol, Misu and Freeman (2013); Sarrico (2022)). These risks

are particularly relevant in Japan, where doctoral study entails forgoing the conventional new-graduate hiring opportunity available upon completion of a Master's degree; survey respondents also identify rigid cohort-based hiring as a source of disadvantage for later entry into the labor market (Kawamura and Watanabe (2023)). The relevant ex ante margin is therefore whether the household will bear current educational costs and future career risk to enter the doctoral-to-academic path, not simply whether additional schooling raises expected earnings.

Second, this paper is related to quantitative models of higher-education investment and education policy. These models emphasize expected returns, ability or preparedness, family resources, borrowing constraints, and financial aid as important determinants of educational investment and college attendance (Lochner and Monge-Naranjo (2011); Abbott, Gallipoli, Meghir and Violante (2019)). Empirical studies likewise show that tuition, student aid, family background, and uncertainty about net college prices can shape enrollment decisions (Kane (1994); Dynarski (2003); Nielsen, Sørensen and Taber (2010); Sano (2019); Dynarski, Libassi, Michelmore and Owen (2021)). Several of these mechanisms remain important in the present model through household assets, human capital, borrowing limits, and the direct cost of doctoral study. The distinction is that the doctoral-to-academic path modeled here need not offer the clear earnings advantage typically associated with higher educational attainment. Financial resources therefore shape which households can bear the cost and risk of doctoral study, but they need not by themselves explain why households choose the doctoral path.

Third, non-pecuniary motives are already well established in models and empirical studies of educational choice. Structural models allow heterogeneous consump-

tion values or psychic costs to affect schooling decisions (Keane and Wolpin (1997); Abbott et al. (2019)), and Gong, Lochner, Stinebrickner and Stinebrickner (2019) directly estimate the consumption value of college. A prominent empirical literature further shows that non-pecuniary considerations shape choices among universities and fields of study (Beffy, Fougère and Maurel (2012); Delavande and Zafar (2019); Wiswall and Zafar (2015)). The contribution of this paper is therefore not the introduction of a non-pecuniary preference itself. Rather, the distinctive margin is doctoral entry after substantial prior educational selection. In the empirical studies cited immediately above, the relevant non-pecuniary margin is conditional on higher-education participation, such as which institution or field of study an individual chooses. In the Japanese doctoral setting considered here, by contrast, interest in academic research can operate directly on the extensive margin of whether to enter doctoral study at all, particularly when the modeled doctoral-to-academic path offers no clear financial advantage over immediate employment after a Master's degree. This enrollment margin also differs from work on scientists' career preferences and job choices after entry into doctoral or postdoctoral training (Stern (2004); Roach and Sauermann (2010)).

For comparison, Lochner and Monge-Naranjo (2011) and Horii, Kitagawa and Futagami (2008) model higher education investment without a direct non-pecuniary payoff from schooling, focusing respectively on individual credit constraints and aggregate human capital investment and growth. Neither analyzes Ph.D. entry. Under the baseline career path calibration here, a version of the present model based only on earnings cannot reproduce the observed positive rate of doctoral entry without another pecuniary wedge. Accordingly, this paper studies how academic taste at the household level interacts with assets, human capital, and post-completion in-

come risk to shape doctoral entry and its response to financial support in general equilibrium.

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 $t = 0, 1, 2, \ldots$, and persists over an infinite horizon. The economy is populated by a continuum of households (dynasties), indexed by i.

Throughout the model, 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. The Ph.D. enrollment decision is centered on the Young but is represented formally as a household choice. Each individual moves from Young to Old, while the dynasty continues indefinitely.

1. The "Young" is the co-resident child whose educational path $\kappa_{t+1}^i \in \{I, A\}$ is chosen within the unitary family before h_{t+1}^i and θ_{t+1}^i are realized. Choosing A means enrollment in a Ph.D. program and incurs the net education cost in period t.

2. The "Old" is the working parent, who supplies labor in occupation κ_t^i and contributes labor income to the pooled household budget. In period $t + 1$,

the current Young becomes the Old, works in the occupation κ_{t+1}^i selected in period t, and exits the economy after the Old stage.

After defining these roles, I refer to the unitary family as the household and describe its choices at the household level. I interpret one model period as a 30-year generational interval.

Figure 1 shows that the period-t household (the unitary family) chooses the child's path κ_{t+1} before h_{t+1} and θ_{t+1} are realized under equations (1)–(2).

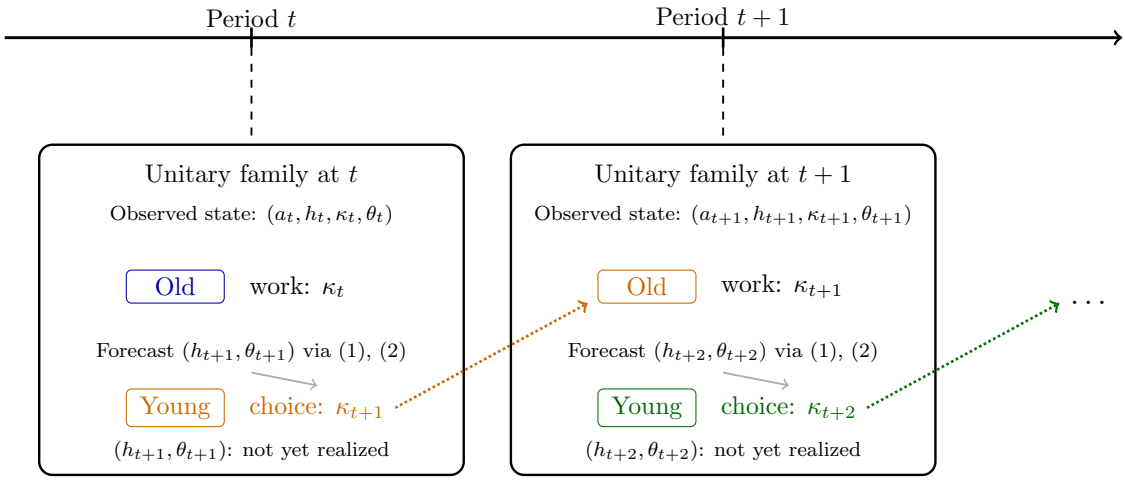


Figure 1: Decision Maker, Information, and Intergenerational Timing

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, and academic taste. The state of household i is $(a_t^i, h_t^i, \kappa_t^i, \theta_t^i)$. Both human capital and academic

taste are persistent across dynasties.

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

$$\ln h_{t+1}^i = \varphi^h \ln h_t^i + \varepsilon_{t+1}^{h,i}, \quad \varepsilon_{t+1}^{h,i} \sim N\Big(0, \sigma^{h^2}\Big). \tag{1}$$

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

Academic taste θ_t^i is the non-pecuniary value that the household attaches to the doctoral-to-academic path. 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_t^i follows an AR(1) process with a constant mean:

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

Here, $\varphi^\theta \in (0,1)$ is the autoregressive coefficient, $\bar{\theta}$ is the unconditional mean, and $\varepsilon_{t+1}^{\theta,i}$ is an i.i.d. shock. 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_t^i; however, the effective utilization of this human capital depends on the chosen occupation κ_t^i. The

effective human capital $\tilde{h}_t^i$ is defined as follows:

$$\tilde{h}_t^i := \begin{cases} 1 & \text{if } \kappa_t^i = I, \\ \gamma h_t^i & \text{if } \kappa_t^i = A. \end{cases} \tag{3}$$

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 pooled household consumption $\{c_t^i\}_{t=0}^{\infty}$ and the utility derived from its chosen educational path κ_{t+1}^i. The lifetime utility of household i is given by the expected discounted sum of period utilities:

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

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 educational choice. θ_t^i is the household's academic taste observed when this choice is made. The indicator function $\mathbb{1}_A(\kappa_{t+1}^i)$ equals one if the household chooses the doctoral-to-academic path (A), and zero oth-

erwise. This implies that the academic taste θ_t^i only contributes to the household's utility if it chooses the doctoral-to-academic path.

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

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 is a transfer to households that choose Ph.D. enrollment, intended to support 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, h, κ, θ). As defined in Section 3.1, the household chooses consumption c, next-period assets a', and the educational path $\kappa' \in \{I, A\}$. 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:

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

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. Relative earnings vary across households because academic income depends on h, whereas industrial income is constant. The model therefore allows a restricted form of comparative advantage, with homogeneous industrial productivity. 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 $b \geqslant 0$:

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

Here, $u(c)$ is the utility from consumption, and $\mathbb{1}_A(\kappa')\theta$ is the non-pecuniary utility from the household's educational choice. 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 $(\nu - s)$, which is incurred only if the household selects the doctoral path ($\kappa' = A$). 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 evaluates the baseline model's fit to the Japanese data and examines its implications for endogenous selection. Section 4.3 presents the subsidy experiments and uses partial income insurance as a counterfactual benchmark. Section 4.4 examines a homogeneous academic taste benchmark. Section 4.5 then examines sensitivity to alternative income ratio targets. Finally, Section 4.6 discusses limitations of the quantitative policy interpretation.

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	Standard annual rate
ν	Ph.D. education cost	0.328	MEXT, NISTEP
s	Government subsidy rate	0.032	MEXT
b	Borrowing limit ($\kappa' = A$)	0.040	JASSO
φ^h	Persistence of h process	0.360	Lefranc, Ojima and Yoshida (2014)
Parameters estimated by SMM			
β	Discount factor	0.307	K/Y ratio
$\bar{\theta}$	Mean shared academic taste	−0.400	Ph.D. enrollment rate
σ^h	Std. dev. of h shock	0.326	Gini of academic income
σ^θ	Std. dev. of θ shock	0.395	Economic resources
φ^θ	Persistence of θ process	0.138	Academic parent gap
γ	Academic productivity multiplier	0.674	Lifetime income ratio

The model analyzes the Ph.D. enrollment decision made before future academic income is realized. The relevant object is therefore the expected income and risk associated with the career paths available at the time of enrollment. The baseline industrial-to-academic lifetime income ratio, Y^I/Y^A, compares immediate employment after a Master's degree with a path that begins with doctoral study and leads to an academic career. The academic path includes postdoctoral employment, delays in moving to stable academic employment, and the possibility of never making that transition. Giving positive probability to these paths lowers expected income relative to a calculation based only on workers who obtain stable university positions.

On the Master's side, I use published employment statistics to estimate the share

of Master's graduates in each occupation and apply these shares to the number of graduate school graduates by age and occupation in the Basic Survey on Wage Structure. The wage data do not distinguish Master's and doctoral graduates within the same age and occupation cells, so they cannot identify wage differences by degree within those cells. On the academic side, I combine postdoctoral income and contract duration with the transition rate to stable academic employment and university faculty earnings by age and rank. Appendix C.2 documents the data sources, sample construction, and calculation. Lifetime income from immediate employment is 33,144.9540 in units of JPY 10,000, while expected lifetime income from the academic path is 23,755.9464. Their ratio is 1.3952277, which I round to 1.395 for the baseline calibration target. I therefore interpret 1.395 as a baseline value for the specific academic career represented in the model, not as an estimate of the earnings disadvantage of doctoral graduates in general.

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.

The primary implications of the model come from examining key patterns that were not explicitly targeted during the calibration. 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 8.7% for the lowest asset quartile (Q1) to 10.9% for the highest quartile (Q4). This pattern captures the role of accumulated resources in buffering tuition, forgone

Table 2: Calibration targets and model fit

Moment	Description	Data	Model
K/Y	Capital-output ratio	3.322	3.322
Enrollment rate	Ph.D. enrollment rate	9.4%	9.4%
Gini (A)	Gini of academic income	0.188	0.188
Y^I/Y^A	Lifetime income ratio	1.395	1.397
Academic parent gap	Enrollment rate difference	4.5 pp	4.5 pp
Economic resources	Academic group / population	1.237	1.090

Note: The economic resources target is the childhood ZIP-code income ratio for U.S. tenure-track faculty in Morgan, LaBerge, Larremore, Galesic, Brand and Clauset (2022); its model counterpart is the asset ratio for Ph.D. entrants. See Appendix C.2 for details.

earnings, and the lower and uncertain income of the doctoral-to-academic path.

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

Quartile	Q1	Q2	Q3	Q4
Enrollment rate (%)	8.7	8.9	9.2	10.9

In addition to financial resources, Table 4 illustrates that the model also captures human capital sorting. As shown in Table 4, the enrollment rate increases monotonically from 9.0% 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 (%)	9.0	9.3	9.5	9.8

Furthermore, I examine the selection mechanism with respect to non-pecuniary preferences. Table 5 reports enrollment rates conditional on quartiles of academic taste θ, which is shared within the household. 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 37.6%.

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

Quartile	Q1	Q2	Q3	Q4
Enrollment rate (%)	0.0	0.0	0.0	37.6

This concentration indicates that, within the model, academic taste strongly structures enrollment, while human capital influences the decision at the margin. This pattern is consistent with 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. This qualitative consistency motivates the taste mechanism, while the concentration also makes sensitivity analysis of the taste distribution important for the policy conclusions.

Appendix C.3 shows that the weak subsidy response, positive asset sorting, and strong selection by academic taste remain under substantial variation in the dispersion of academic taste, holding its persistence fixed at the baseline value. This sensitivity exercise establishes qualitative robustness to the calibrated dispersion but does not identify the relative contributions of academic taste and financial constraints.

4.3 Policy Experiments

This section presents the quantitative results of the policy experiments. I first analyze the impact of varying the enrollment subsidy s on household enrollment decisions, macroeconomic aggregates, and social welfare. The subsidy is the main policy experiment because recent Japanese policy expansions have focused on grant-based financial support during doctoral enrollment.[3] I then use partial income insurance as a counterfactual benchmark at the same fiscal cost.

4.3.1 Enrollment Subsidy

The simulation results, summarized in Table 6, show that enrollment and macroeconomic aggregates respond only weakly to the subsidy. Relative to the baseline policy, subsidy expansions slightly reduce output, effective human capital, and stationary welfare, whereas the allocation without a subsidy has the highest welfare among the reported cases.

Table 6: Model response to subsidy policy

Variable	No subsidy	Baseline	1.5×	2.0×
Key outcomes				
Enrollment rate	9.20%	9.40%	9.53%	9.68%
Labor income tax rate	0.00%	0.16%	0.25%	0.34%
Output (Y, % change)	+0.10	—	−0.03	−0.05
Capital stock (K, % change)	+0.16	—	−0.04	−0.01
Eff. human capital (H, % change)	+0.06	—	−0.03	−0.07
Social welfare				
CEV (% change)	+0.40	—	−0.36	−0.74

[3] MEXT (2025)

The baseline subsidy requires a proportional labor income tax of 0.16%, which rises to 0.25% under the 1.5× subsidy and to 0.34% under the 2.0× subsidy. To separate the direct effect of the subsidy from the marginal tax burden, I also recompute the stationary distribution and market clearing while holding the tax rate at its baseline value. Because this diagnostic does not impose government budget balance, it is not an equilibrium with a balanced budget, and the resulting deficit is reported explicitly in Table 7.

Table 7: Fixed tax diagnostic

	1.5× subsidy		2.0× subsidy	
	Balanced	Fixed tax	Balanced	Fixed tax
Enrollment rate (%)	9.53	9.53	9.68	9.68
CEV (%)	−0.36	−0.28	−0.74	−0.61
Deficit / Y (%)	—	0.05	—	0.11

Holding the labor income tax at its baseline value leaves enrollment unchanged at the reported precision and attenuates, but does not reverse, the welfare losses. The CEV changes from −0.36% to −0.28% under the 1.5× subsidy and from −0.74% to −0.61% under the 2.0× subsidy. Thus, the additional tax burden contributes to the welfare loss but does not explain the small enrollment response or the welfare ranking.

To relate the aggregate enrollment response to recent Japanese policy changes, I consider two additional subsidy expansions. When the annual subsidy is increased by 100,000 JPY, the enrollment rate increases by approximately 0.05 percentage points. This positive behavioral response is consistent with prior studies of financial aid and enrollment (Dynarski (2003); Nielsen et al. (2010); Sano (2019)). 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 0.03 percentage points.[4] To represent this observed expansion of support within the model, I implement a stylized experiment that increases the per-student subsidy amount by the same 20.3%; the model therefore captures the expansion through the amount of support per student rather than through the number of recipients. Under this experiment, the enrollment rate increases by 0.07 percentage points.

Similarly, the impact on macroeconomic variables is limited. Within the modeled economy, output falls by only 0.03% and 0.05% under the 1.5× and 2.0× policies, respectively. The capital stock changes by −0.04% and −0.01%, while effective human capital falls by 0.03% and 0.07%, respectively. The 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, these already small effects would become smaller still. Abolishing the subsidy entirely yields the highest output and social welfare among the four reported stationary allocations.

Figure 2 highlights the marginal changes relative to the baseline across both human capital and asset dimensions. A conventional human capital perspective combined with liquidity constraints might predict the largest subsidy response among households with high human capital and low assets. Figure 2 shows a different

[4]Since FY2021, the Japanese government has implemented comprehensive policies for doctoral students, including expanded financial support during enrollment and strengthened post-graduation career development (MEXT (2025)).

[5]This figure is calculated from the average university enrollment rate over 2009–2013 and the average graduate school enrollment rate among university graduates over 2013–2017 using MEXT (2025), and the average Ph.D. enrollment rate among Master's graduates over 2015–2019 using NISTEP (2025).

pattern. The response remains small among low asset households, including those with high human capital, whereas high asset households respond across the human capital distribution. Within the highest asset quartile, the largest responses occur among households with middle-to-high or high human capital. Thus, the cross-sectional response to the subsidy is more clearly concentrated by household assets than by human capital.

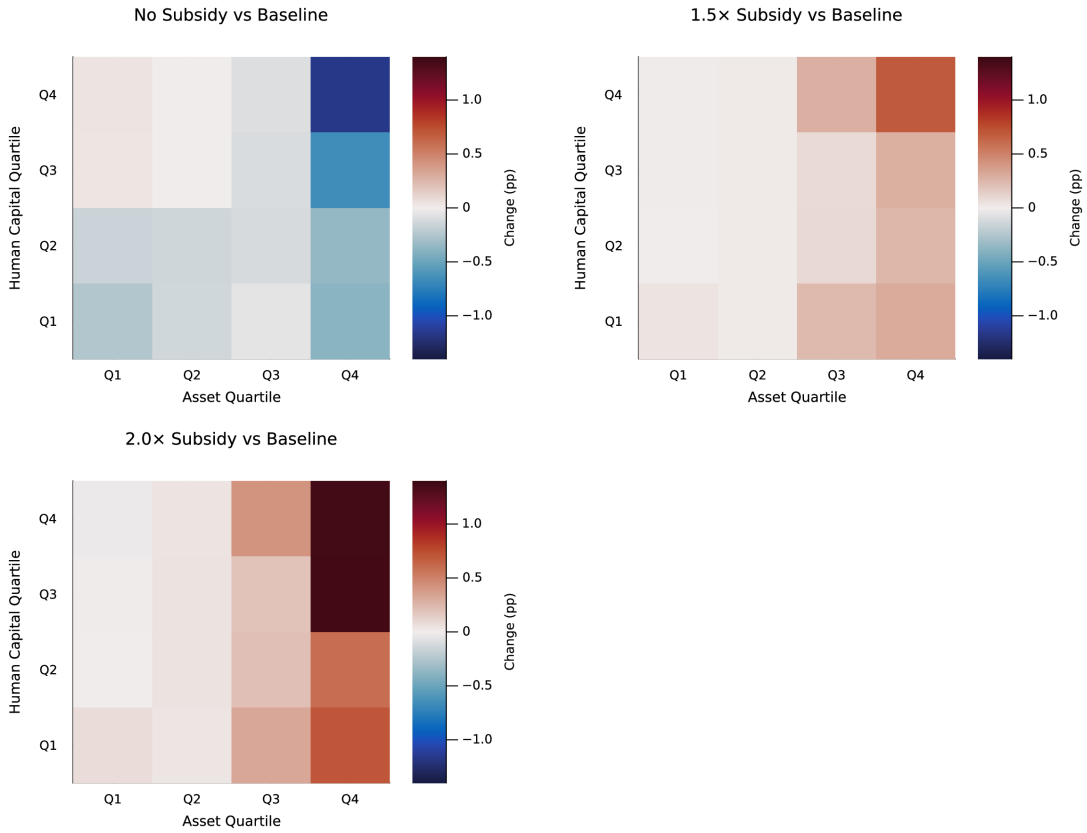


Figure 2: Changes in Ph.D. Enrollment Rate by Human Capital and Asset Quartiles

Finally, why is the increase in enrollment induced by the subsidy relatively larger among households with high assets even though the Ph.D. path has a lower expected lifetime financial return than the industrial path? The answer in the model lies

in non-pecuniary preferences, specifically academic taste θ. Figure 3 presents the enrollment changes across the human capital and academic taste dimensions.

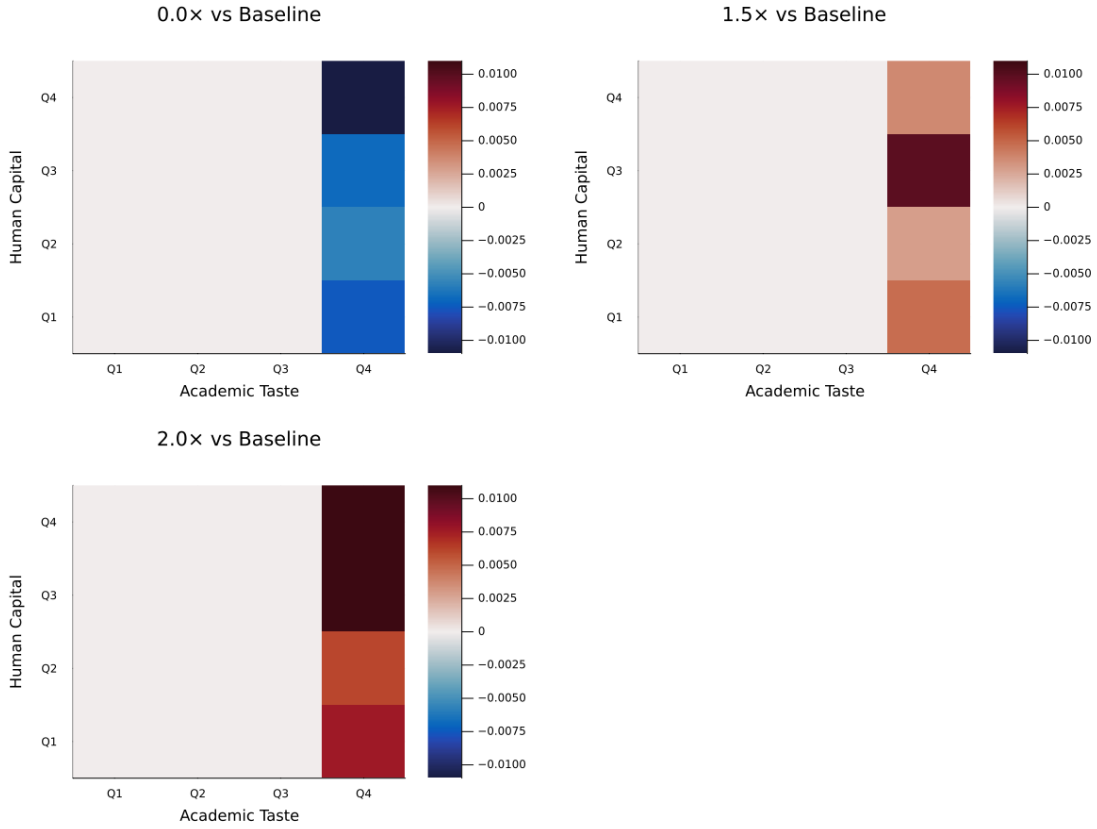


Figure 3: Changes in Ph.D. Enrollment Rate by Human Capital and Academic Taste Quartiles

The heatmap shows that the increases induced by the subsidy occur only in the highest academic taste quartile (Q4); the lower three taste quartiles do not respond. This selection pattern can be understood within the model because the expected lifetime financial return of the Ph.D. path remains lower than that of the industrial path even under expanded subsidies. The subsidy therefore affects enrollment only among households with sufficiently strong academic taste, for whom it provides additional financial margin to choose the Ph.D. path. This interpretation is qualitatively consistent with the evidence on research motivation discussed above

and with Suga (2017), who finds evidence that postgraduate education raises job satisfaction for male workers, consistent with a non-pecuniary return. The recent Japanese policy expansions considered here provide financial support during doctoral enrollment and therefore reduce current enrollment costs, but they do not directly insure households against post-graduation income risk. This motivates the partial income insurance counterfactual considered next.

4.3.2 Partial Income Insurance

Keeping the baseline subsidy in place, an academic worker with realized human capital h' receives the non-taxable transfer

$$T^{\lambda}(h') = \lambda \max\{0, y^{I}(h') - y^{A}(h')\}, \tag{7}$$

where $y^{I}(h')$ and $y^{A}(h')$ are industrial and academic labor income at the same human capital state. The rule is known when the household makes its doctoral enrollment decision, but the transfer is paid after the child's occupation and income are realized in the following model period. I choose the replacement rate λ separately at two budget levels so that the baseline subsidy plus insurance payments costs the same as either the 1.5× or the 2.0× subsidy. At each budget level, I resolve the equilibrium under each policy by recomputing the invariant distribution, the proportional labor income tax, and market clearing.

Table 8 compares the subsidy and partial income insurance at the same fiscal cost. Matching the 1.5× and 2.0× subsidy budgets requires insurance replacement rates of 2.85% and 5.86%, respectively. At both budget levels, the subsidy produces a larger enrollment response but lowers stationary welfare, whereas partial income

Table 8: Subsidies and partial income insurance at the same cost

	Baseline	1.5× budget		2.0× budget	
		Subsidy	Insurance	Subsidy	Insurance
Insurance replacement rate (%)	—	—	2.85	—	5.86
Enrollment rate (%)	9.40	9.53	9.42	9.68	9.39
Enrollment change (pp)	—	+0.12	+0.02	+0.28	−0.01
Labor income tax rate (%)	0.16	0.25	0.25	0.34	0.34
CEV (%)	—	−0.36	+0.12	−0.74	+0.22

insurance has little effect on enrollment and raises welfare. About 90.8% of academic workers receive a positive insurance transfer at either budget level, so the transfer predominantly benefits academic workers whose enrollment decision is unchanged. Because the replacement rate applies only to the shortfall of academic income relative to industrial income, the policy provides partial rather than comprehensive income protection.

Holding the labor income tax at its baseline value and financing the additional insurance spending with a deficit leaves the enrollment responses unchanged at the reported precision: 0.02 percentage points at the 1.5× budget and −0.01 percentage points at the 2.0× budget. The corresponding deficits are 0.05% and 0.11% of output. Thus, the marginal tax increase does not explain the near-zero enrollment response under insurance.

Figure 4 reports the joint enrollment changes under partial income insurance. The responses are small in absolute magnitude and mixed in sign across cells defined by asset and human capital quartiles. Unlike the subsidy response, they do not show a stable concentration in the highest asset quartile. The figure should therefore be interpreted primarily as showing that partial income insurance generates only small

changes at the enrollment margin.

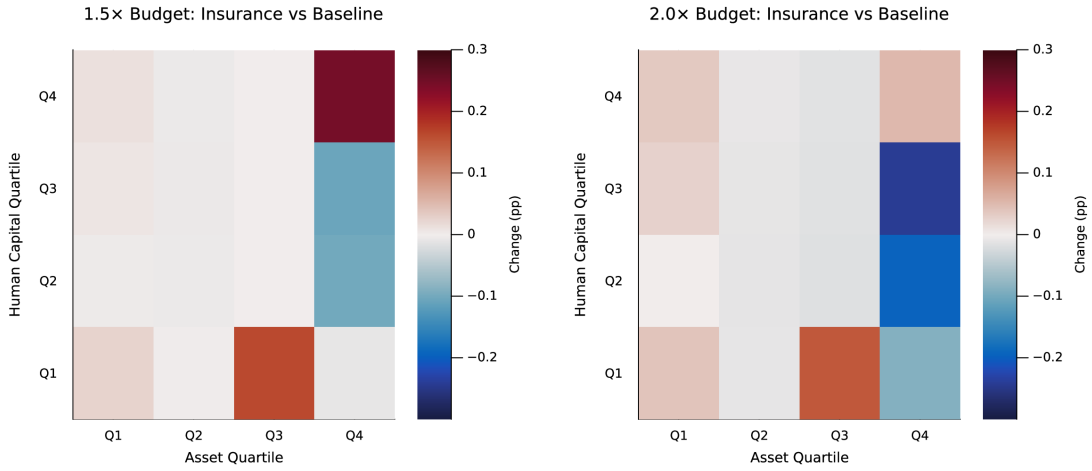


Figure 4: Changes in Ph.D. Enrollment Rate under Partial Income Insurance by Human Capital and Asset Quartiles

This limited enrollment response contrasts with the positive welfare effects reported in Table 8, which arise mainly through consumption smoothing among academic workers rather than through additional doctoral entry. To examine the human capital dimension of the difference in enrollment responses, Table 9 compares the subsidy and partial income insurance across human capital quartiles.

Table 9: Enrollment changes by human capital (pp)

Budget	Policy	Human capital			
		Q1	Q2	Q3	Q4
1.5×	Subsidy	+0.13	+0.07	+0.08	+0.22
	Insurance	+0.05	−0.02	−0.02	+0.07
2.0×	Subsidy	+0.22	+0.15	+0.34	+0.38
	Insurance	+0.04	−0.05	−0.05	+0.02

The subsidy response is positive in every human capital quartile and is largest

in Q4 at both budget levels, whereas the insurance response is smaller and non-monotone across human capital quartiles. One possible reason for the smaller enrollment response under insurance is the timing of the transfer. The enrollment subsidy reduces the current cost of doctoral study, whereas the insurance transfer is paid only after future academic income is realized and cannot be used to finance the current cost of enrollment or borrowed against. Because one model period represents 30 years, the model captures this timing only coarsely. The present exercise therefore does not separately identify the quantitative contribution of payment timing.

Human capital provides another possible explanation. Because human capital is persistent, households with higher current human capital tend to expect higher future academic income, reducing the expected value of the insurance transfer. The enrollment subsidy, by contrast, is received by every Ph.D. entrant regardless of human capital. Since households with higher human capital, particularly those in Q3 and Q4, are among those most responsive to the subsidy, this difference may contribute to the smaller aggregate enrollment response under insurance.

The -0.01 percentage point aggregate response at the $2.0\times$ budget should therefore be interpreted as essentially no net response in general equilibrium rather than as evidence that insurance reduces enrollment. Overall, the two instruments involve a trade-off across policy objectives: the subsidy has a larger effect on doctoral entry, whereas partial income insurance has little effect on entry but improves welfare by smoothing consumption when academic income is low. This welfare mechanism is consistent with related work on income-contingent loans in unemployment and education (Mateen, Stiglitz and Yun (2021); Matsuda and Mazur (2022)).

4.4 Counterfactual Analysis with Homogeneous Academic Taste

To examine the role of heterogeneous non-pecuniary "academic taste" in the model, I perform a counterfactual analysis by assuming a homogeneous level of academic taste across all households (i.e., $N_\theta = 1$). I recalibrate the common level of academic taste and the remaining internally determined parameters and examine how predicted enrollment and policy responses change in the absence of preference heterogeneity.

Calibration of the Benchmark First, the model is recalibrated to match key empirical moments, including the baseline Ph.D. enrollment rate and the capital-output ratio. The recalibrated homogeneous-θ model matches the empirical baseline Ph.D. enrollment rate and capital-output ratio closely, although its fit to the Gini coefficient of academic income and lifetime income ratio is worse than that of the full model. Table 10 summarizes the calibrated parameters for this homogeneous θ case. Given the absence of non-pecuniary preference heterogeneity, this benchmark cannot reproduce the academic parent enrollment gap targeted in the full model. Instead, this simpler framework serves as a benchmark for enrollment responsiveness in the absence of taste heterogeneity.

Table 10: Calibrated parameters for the homogeneous academic taste benchmark

Parameter	Description	Value	Source / target moment
β	Discount factor	0.290	K/Y ratio
$\bar{\theta}$	Homogeneous academic taste	0.132	Ph.D. enrollment rate
σ^h	Std. dev. of h shock	0.360	Gini coeff. (Academia)
γ	Academic productivity multiplier	0.650	Lifetime income ratio

At the recalibrated parameters, the homogeneous-θ model produces $K/Y =$

3.32, an enrollment rate of 9.4%, a Gini coefficient of academic income of 0.21, and a lifetime income ratio of 1.43. Thus, the benchmark matches the capital-output ratio and baseline enrollment rate closely, while its fit to income dispersion and the lifetime income ratio is weaker than that of the full model.

Policy Responses For comparison with the full model, Table 11 reports the aggregate outcomes of the homogeneous academic taste benchmark.

Table 11: Subsidy effects in the homogeneous academic taste benchmark

Variable	No subsidy	Baseline	1.5×	2.0×
Key outcomes				
Enrollment rate	3.2%	9.4%	25.1%	35.1%
Labor income tax rate	0.00%	0.16%	0.68%	1.29%
Output (Y, % change)	+1.0	—	−3.3	−5.3
Capital stock (K, % change)	−0.6	—	−2.0	−3.3
Eff. human capital (H, % change)	+1.9	—	−4.0	−6.4
Social welfare				
CEV (% change)	−6.1	—	+6.8	+8.5

The homogeneous academic taste benchmark requires a labor income tax of 0.68% under the 1.5× subsidy and 1.29% under the 2.0× subsidy. I therefore repeat the fixed-tax diagnostic using the benchmark's baseline tax rate of 0.16%.

Table 12 shows that, unlike in the full model, holding the tax rate fixed materially increases both enrollment and CEV in this benchmark. Thus, the homogeneous academic taste benchmark is sensitive not only to the subsidy but also to its fiscal financing, while its unusually large policy response remains under either fiscal closure.

Table 12: Fixed-tax diagnostic for the homogeneous academic taste benchmark

	1.5× subsidy		2.0× subsidy	
	Balanced	Fixed tax	Balanced	Fixed tax
Enrollment rate (%)	25.12	26.71	35.10	39.18
CEV (%)	+6.79	+7.90	+8.54	+10.96
Deficit / Y (%)	—	0.36	—	0.82

As shown in Table 11, the homogeneous academic taste benchmark produces an unusually large response to the subsidy. With θ held at a common calibrated value, the Ph.D. enrollment rate rises to 25.1% under the 1.5× subsidy and 35.1% under the 2.0× scenario. For a common 20.3% increase in the subsidy amount, the benchmark's enrollment rate rises by 14.6 percentage points, whereas the full model rises by only 0.07 percentage points. The implied elasticities are 7.64 and 0.04, respectively.

The benchmark results also show substantially different patterns of human capital allocation and welfare. Under the 1.5× subsidy, aggregate output Y falls by 3.29%, while the calculated CEV rises by 6.79%. This positive welfare response should not be read as a direct policy prediction. When all households share the same positive academic taste, the increase in non-pecuniary utility dominates the decline in consumption and output. I therefore interpret this result as a diagnostic of the homogeneous academic taste benchmark.

I next compare the underlying selection mechanisms. In the full model, Figure 2 shows that the subsidy response is more clearly concentrated by household assets than by human capital, with larger responses among high-asset households. Figure 5 shows that the homogeneous academic taste benchmark instead produces large

threshold responses among households with high human capital. Under the 1.5× subsidy, the largest cell response occurs in the highest human capital and asset quartiles.

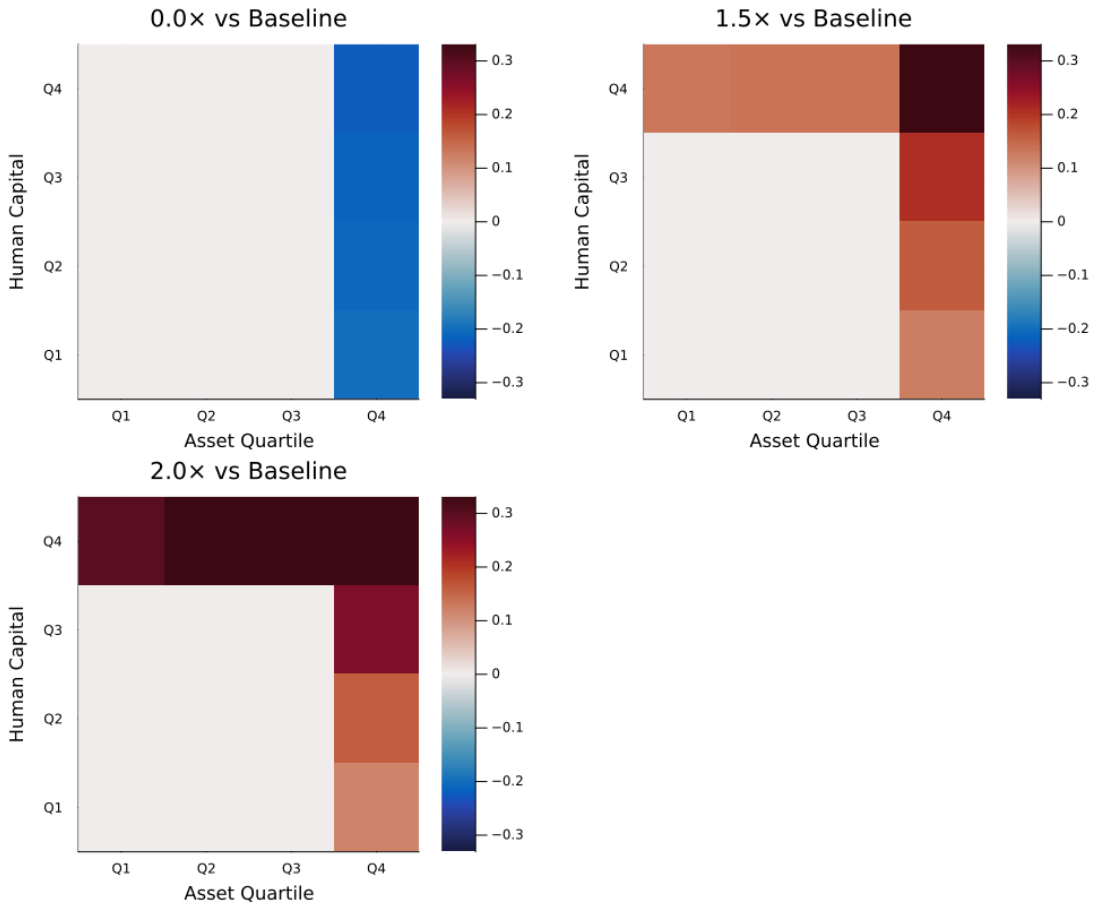


Figure 5: Changes in Ph.D. Enrollment Rate: Full Model vs. Homogeneous Academic Taste Benchmark

With academic taste held at a common calibrated value, households no longer differ in their non-pecuniary motives, so selection across households is driven by financial states and human capital. Consequently, the homogeneous academic taste benchmark generates large threshold responses among households with high human capital as the subsidy changes the financial trade-off. This benchmark deliberately

removes heterogeneity in non-pecuniary preferences by assigning the same academic taste to every household. Because the homogeneous academic taste comparison produces a qualitatively different selection pattern and a much larger enrollment response, it shows that the model's policy predictions depend materially on preference heterogeneity. Together with the survey evidence on research motivation, this comparison supports retaining heterogeneous non-pecuniary academic taste in the quantitative framework. This does not imply that financial constraints are unimportant.

4.5 Sensitivity Analysis of the Lifetime Income Ratio

Morikawa (2025) provides a complementary perspective by comparing realized labor market outcomes among people classified by the graduate school course from which they report graduating in the 2022 Employment Status Survey.[6] The study reports an unconditional annual earnings difference of approximately 40%, which falls to approximately 10% after detailed industry and occupation controls. These annual earnings comparisons are not identical to the sex specific discounted lifetime income estimates in the same study or to the ex ante career sequences in the baseline calibration. I therefore translate these annual earnings differences into the model's Y^I/Y^A ratio by taking the reciprocals of 1.40 and 1.10, yielding 0.714 and 0.909, respectively, and use these values for the sensitivity analysis.

For each alternative ratio, I recalibrate all six internally determined parameters, retain the same family background moment and academic parent enrollment

[6]Because the survey classification is based on the graduate school course from which a respondent graduated rather than on enrollment history, a person who entered but did not graduate from a doctoral program may remain classified by an earlier completed Master's course. This distinction reflects the different timing and populations of the realized outcome and enrollment decision perspectives.

target, and resolve every subsidy equilibrium and fixed tax diagnostic. Table 13 reports these parameters together with the household enrollment responses and the aggregate outcomes.

Table 13: Sensitivity to the industrial-to-academic lifetime income ratio

Measure		Baseline	Morikawa (2025) scenarios	
			Unconditional	Conditional
Lifetime income ratio, Y^I/Y^A		1.395	0.714	0.909
Calibration and household selection				
Enrollment rate (%)		9.40	9.43	9.41
Mean shared academic taste, $\bar{\theta}$		−0.400	−0.445	−0.432
Std. dev. of θ shock, σ^θ		0.395	0.396	0.396
Persistence of θ process, φ^θ		0.138	0.124	0.130
Entrants in taste Q4 (%)		100	100	100
Entrant-to-population asset ratio		1.09	1.02	1.11
Household enrollment responses				
1.5× subsidy	Enrollment change (pp)	+ 0.12	+ 0.13	+ 0.04
2.0× subsidy	Enrollment change (pp)	+ 0.28	+ 0.17	+ 0.25
Aggregate outcomes				
No subsidy	CEV (% change)	+ 0.40	+ 0.50	− 0.47
1.5× subsidy	Output (Y, % change)	− 0.03	+ 0.06	+ 0.15
	CEV (% change)	− 0.36	− 0.23	+ 0.20
2.0× subsidy	Output (Y, % change)	− 0.05	+ 0.04	+ 0.30
	CEV (% change)	− 0.74	− 0.43	+ 0.36

Notes: The second and third blocks report changes relative to the equilibrium under each calibration's baseline subsidy.

In the alternative calibrations, the mean of academic taste is lower, while its dispersion changes very little and entrants remain concentrated in the highest quartile

of academic taste. Because each calibration matches the same aggregate enrollment target, the lower mean offsets the greater financial attractiveness of the doctoral path under the baseline subsidy. For the subsidy response, the dispersion of taste is particularly important because it helps determine how many households are close to the enrollment margin. Since this dispersion changes very little across the calibrations, the aggregate enrollment response remains small: even doubling the subsidy raises enrollment by less than 0.3 percentage points in all three cases.

These results support the importance of heterogeneity in academic taste for selection into Ph.D. study and for the limited aggregate response to enrollment subsidies. They do not imply that financial circumstances are unimportant. The entrant-to-population asset ratio changes across the three calibrations, and the effects on output and welfare also differ. In particular, under the 0.909 ratio, subsidy expansion raises both output and CEV, while subsidy removal lowers welfare, reversing the baseline welfare ranking.

Thus, the conclusions that remain common across the alternative income ratios are the concentration of entrants in the highest academic taste quartile and the small aggregate enrollment response to larger subsidies, while the asset margin and the output and welfare results depend on the assumed relative income of the two career paths.

4.6 Limitations of the Quantitative Policy Interpretation

The quantitative policy results are subject to three important limitations. First, the education cost combines tuition and forgone earnings as a fixed cost, so the model omits choices over outside work, research time, completion effort, and completion probability. Financial aid can affect enrollment but cannot operate through

these margins during doctoral study. Adding them could raise the enrollment response if aid reduces the need for outside work or other costly adjustments during doctoral study, or lower it if outside work provides alternative financing and aid mainly reduces work among students who would enroll anyway.

Second, comparative advantage is restricted: industrial effective human capital is one for every household, whereas academic productivity is γh. With separate abilities, an individual with modest academic productivity could still have an academic comparative advantage if that individual's industrial productivity were lower. A subsidy could then induce enrollment even when academic taste is insufficient to justify doctoral study without support, weakening the inferred role of taste and the concentration of additional entrants in the highest academic taste quartile. Such entry would not necessarily imply occupational misallocation or a productivity loss. Calibrated academic taste may therefore absorb omitted variation in outside opportunities, which the model does not separately identify. The selection and welfare results are thus conditional on homogeneous industrial productivity. Quantifying this extension would require a joint ability distribution, an information structure, and moments that distinguish relative productivity from preferences.

Third, the production side of the model omits external returns from advanced research, such as knowledge spillovers and TFP gains. The reported output effects therefore reflect only changes in aggregate capital and effective human capital within the model. If doctoral education generates positive externalities, the model may understate the macroeconomic benefits of enrollment subsidies, but their magnitude is not quantified here.

5 Conclusion

This paper constructs a dynamic heterogeneous agent model to analyze Ph.D. enrollment decisions in Japan. The results show that, within the current specification, heterogeneity in the non-pecuniary motive called "academic taste" materially shapes selection into doctoral study and the aggregate response to enrollment subsidies. Across both the sensitivity analysis of the dispersion of academic taste and the alternative income ratio calibrations, entrants remain concentrated in the highest academic taste quartile and the aggregate enrollment response remains small. Household assets and human capital also affect which households with strong academic taste are at the enrollment margin, although the asset margin varies across income calibrations.

Furthermore, choosing to pursue a Ph.D. can mean forgoing the conventional new graduate recruitment opportunity available after a Master's degree, while later entry into private sector employment can be more difficult. By incorporating these career risks specific to Japan, the model shows why financial support during doctoral study need not generate a large aggregate enrollment response. The doctoral subsidy lowers the entry barrier for some households with strong academic taste, but it does not directly address income risk after graduation. Accordingly, the model suggests that recent efforts to expand doctoral support can modestly increase enrollment, although the quantitative impact remains limited.

In the baseline income ratio calibration, expanding the enrollment subsidy has little effect on output and slightly lowers stationary welfare. These macroeconomic and welfare results are sensitive to the assumed relative income of the two career paths, and the welfare ranking reverses under the alternative income ratio of 0.909.

In the baseline calibration, partial income insurance at the same fiscal cost produces a smaller enrollment response than the subsidy but raises stationary welfare through consumption smoothing.

The quantitative results should be interpreted within the model's abstractions. In particular, the model does not incorporate within-program time allocation, sector-specific comparative advantage, or external returns to doctoral research. Future work incorporating these margins, as well as differences across fields of study, could provide a broader evaluation of doctoral support policies.

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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; and the government policies (subsidy 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:

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

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 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.

Current assets lie on a finite grid, but assets for the next period can be chosen between grid nodes. On each feasible interval, I linearly interpolate the expected continuation value and compare the endpoints with the interior candidate implied by the first order condition. Choices between grid nodes are allocated to adjacent nodes using linear lottery weights when constructing the stationary distribution. This avoids stepwise changes in asset supply caused by the grid while preserving the discrete Ph.D. enrollment decision.

C Calibration

I divide the parameters into two groups. Appendix C.1 describes the parameters set externally based on established literature or institutional data, while Appendix C.2 describes the parameters calibrated internally using the Simulated Method of Moments (SMM) to match key target moments. Table 1 in Section 4 summarizes all parameters and their values.

C.1 Externally Set Parameters

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.

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 NISTEP (2025), I compute a weighted average cost across national, public, and private universities, resulting in a value of approximately 1.94 million JPY.[7] 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,

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

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)).[8] 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 an AR(1) process in logs. I set the persistence parameter $\varphi^h = 0.360$, following the estimates for intergenerational persistence in Lefranc et al. (2014).

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

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

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, (5) the family background ratio in Morgan et al. (2022), and (6) the academic parent enrollment gap in Kato and Tsunoda (2009).

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 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 weights to prioritize the fit of aggregate macroeconomic ratios and

key sorting statistics.

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 RIETI and Hitotsubashi University (2023) and the corresponding average of annual real GDP from ESRI (2024). 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 shared within the household, 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 NISTEP (2025).

Academic Productivity Multiplier (γ) The academic human capital return, γ, which scales the human capital of academic workers (Occupation A), is calibrated to match the expected lifetime income ratio between the industrial and academic paths (Y^I/Y^A). I calibrate γ to match the calculated ratio of 1.395. The lifetime income target is constructed as follows.

All monetary amounts in this calculation are measured in units of JPY 10,000. The numerator, Y^I, represents immediate employment after completing a Master's

program. The underlying age–occupation tabulation reports graduate school graduates as a combined group. I therefore use the occupation-specific Master's share among new graduates,

$$m_o = \frac{N_o^M}{N_o^M + N_o^D}, \qquad \widetilde{N}_{ao}^M = N_{ao}^{GS} m_o, \qquad \pi_{ao}^M = \frac{\widetilde{N}_{ao}^M}{\sum_{o'} \widetilde{N}_{ao'}^M}, \tag{C.2}$$

where a indexes age groups, o occupations, and GS, M, and D denote graduate school, Master's, and doctoral graduates. Using the mean annual income of graduate school graduates, y_{ao}^{GS}, and the number of years n_a represented by each age group gives

$$Y^I = \sum_a \sum_o y_{ao}^{GS} \pi_{ao}^M n_a = 33{,}144.9540. \tag{C.3}$$

The sum covers ages 24–64.

The denominator, $E[Y^A]$, represents the modeled sequence from doctoral study to an academic career. The wage and employment tabulations are from MHLW (2024), while the postdoctoral income, contract, and transition inputs come from Kawamura, Watanabe and Knowledge Infrastructure Policy Division, Science and Technology Policy Bureau, Ministry of Education, Culture, Sports, Science and Technology (2024).

Here, PD and Fac denote postdoctoral and stable university faculty positions, respectively. For postdoctoral researchers, income bin shares π_j^y and representative annual incomes z_j imply $\bar{y}^{\mathrm{PD}} = \sum_j \pi_j^y z_j = 324.5604$. Contract duration shares π_j^d and representative durations d_j imply $\bar{d}^{\mathrm{PD}} = \sum_j \pi_j^d d_j = 1.6499$ years.

For a stable university faculty position, age–rank income y_{ar}, the within-age rank

share w_{ar}, years n_a, and the continuation weight v_a give

$$Y^{A,\text{Fac}} = \sum_a \sum_r y_{ar} w_{ar} n_a v_a = 34{,}092.4576. \tag{C.4}$$

The transition probability to stable academic employment is proxied by the number of postdoctoral researchers who move to tenure-track or permanent positions relative to the relevant postdoctoral sample:

$$p = \frac{782}{10{,}544} = 0.0741654. \tag{C.5}$$

Let $L = 22$ be the number of transition periods, $I^{\text{PD}} = \bar{y}^{\text{PD}} \bar{d}^{\text{PD}} = 535.4937$, and $I^{\text{Fac}} = Y^{A,\text{Fac}}/L = 1{,}549.6572$. If the first stable match occurs in period ℓ, lifetime income is $Y_\ell^A = (\ell - 1) I^{\text{PD}} + [L - (\ell - 1)] I^{\text{Fac}}$ and its probability is $p(1-p)^{\ell-1}$. If no match occurs, $Y_\varnothing^A = L I^{\text{PD}}$ with probability $(1-p)^L$.

Hence,

$$E[Y^A] = \sum_{\ell=1}^{L} p(1-p)^{\ell-1} Y_\ell^A + (1-p)^L Y_\varnothing^A = 23{,}755.9464, \tag{C.6}$$

$$\frac{Y^I}{E[Y^A]} = \frac{33{,}144.9540}{23{,}755.9464} = 1.3952277 \simeq 1.395. \tag{C.7}$$

This target concerns two specific career sequences and is not intended to measure the causal return to actually obtaining a doctoral degree, as distinct from enrolling in a doctoral program. All fields of study are included, but after the academic path is chosen its income states are restricted to precarious academic employment and university faculty; income earned as a physician or other medical practitioner

is not an income state on the academic path. The numerator uses income for all graduate school graduates rather than income specific to Master's graduates within age–occupation cells, with Master's shares used to adjust the occupational composition. Moreover, the numerator of p pools transitions to positions on the tenure track and permanent positions across reported destination occupations, rather than a university-only cross-tabulation, and the approximately annual transition probability is applied once per average contract duration of 1.6499 years.

Standard Deviation of the Human Capital Shock (σ^h) The standard deviation of the human capital shock, σ^h, which governs income heterogeneity, is calibrated to match the Gini coefficient of income for academic workers (0.188). I calculate this target using MHLW (2024) and Kawamura et al. (2024).

Standard Deviation of the Academic Taste Shock (σ^θ) The standard deviation σ^θ of the academic taste shock governs heterogeneity in shared academic taste across households and affects sorting by socioeconomic background. I use the family background ratio reported by Morgan et al. (2022) to calibrate σ^θ. They report that the median childhood ZIP code income of U.S. tenure-track faculty is 1.237 times the median across U.S. ZIP codes. Its model counterpart is the ratio of mean household assets among Ph.D. entrants to mean assets in the model population. The resulting model ratio is 1.09. Because these measures refer to different populations and economic environments, I use the Morgan statistic as an indicator of socioeconomic background rather than as a direct estimate of the gradient of Ph.D. enrollment with respect to parental income or wealth. The implied stationary standard deviation is 0.399 in the baseline, and I vary the stationary dispersion in

the sensitivity analysis.

Intergenerational Persistence (φ^θ) The persistence parameter, φ^θ, governs how academic taste is transmitted to the successor household. I calibrate this parameter to an academic parent enrollment gap constructed from Kato and Tsunoda (2009). They report a Ph.D. enrollment rate of 16.9% for Master's students in science and engineering whose fathers work in education or academic research; using the reported table counts, I calculate an enrollment rate of 12.4% for the complementary group. The resulting 4.48 percentage point gap has a closer conceptual counterpart in the model's academic parent state than does parental doctoral education. The calibrated model generates a 4.48 percentage point academic parent gap.

C.3 Sensitivity to the Dispersion of Academic Taste

I assess whether the main quantitative conclusions depend on the calibrated dispersion of academic taste. I hold its intergenerational persistence φ^θ at the baseline value of 0.138 and vary the stationary standard deviation of θ from 0.50 to 1.50 times its baseline value. For each of the five cases, I adjust σ^θ to produce the specified stationary dispersion and adjust the mean academic taste parameter to reproduce the baseline Ph.D. enrollment rate of approximately 9.4%. All other structural parameters remain fixed.

Table C.1 summarizes the resulting stationary equilibria. Across the five dispersion values, the 20.3% subsidy increase raises enrollment by 0.02–0.08 percentage points, compared with 0.07 percentage points in the case with baseline dispersion. The asset Q4–Q1 enrollment gap remains positive at 1.92–5.28 percentage points,

Table C.1: Sensitivity to the dispersion of academic taste

	Stationary s.d. multiplier				
	0.50	0.75	1.00	1.25	1.50
Enrollment response (pp)	+0.08	+0.06	+0.07	+0.03	+0.02
Asset Q4–Q1 gap (pp)	+5.28	+2.90	+2.22	+2.01	+1.92
Entrants in taste Q4 (%)	100	100	100	100	100

Notes: $\varphi^{\theta} = 0.138$ in all cases. Mean academic taste is adjusted to keep enrollment near 9.4%. The enrollment response is for a 20.3% subsidy increase.

and all entrants remain in the highest academic taste quartile in every specification. The exercise therefore shows that the weak subsidy response, positive asset sorting, and strong selection by academic taste are qualitatively robust to substantial variation in the dispersion of academic taste. This exercise does not identify the relative contributions of academic taste and financial constraints, and the results do not imply that financial constraints are unimportant.