Talent Hoarding, Misallocation, and Innovation: A Dynamic Model of Labor Market Distortions by Large Incumbents

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Abstract

Why do large incumbent firms choose to hoard high-skilled talents? We develop a formal applied-theory model of incumbent-led, labor-market talent hoarding in innovative sectors. A large incumbent and specialized research firms compete dynamically for frontier researchers whose effort raises the probability of discovery rather than contemporaneous output. The incumbent rationally overhires and underdeploys specialized talent through four channels: (i) maintaining parallel teams to preserve real-option flexibility under technological uncertainty; (ii) attracting risk-averse workers via firm-wide equity that shares risk across projects; and, when specialized firms face financing frictions, additionally (iii) leveraging deep pockets to outbid rivals, and (iv) preemptively hiring to block rival R&D. These forces misallocate talents away from higher-fit specialized uses, depress human-capital accumulation and career progression for hoarded workers, and can shift technology paths even before market deployment. Comparing competitive equilibrium to a constrained social-planner allocation, we show a welfare wedge attributable specifically to talent hoarding, distinct from standard product-market monopoly losses, and characterize how it scales with uncertainty, cannibalization risk, and liquidity constraints. Because discovery is uncertain and researcher effort shifts success probabilities rather than immediate output, hoarding naturally arises upstream. By placing hoarding upstream, at stages (1) research and (2) technology development, rather than downstream production, our framework complements work on post-development acquisitions and production-stage labor hoarding. This upstream perspective clarifies how incumbent hiring can redirect technology trajectories and slow diffusion well before market entry.

JEL classification: J24, O31, D4, D61, L1, L26

Keywords: Talent hoarding, Labor misallocation, Innovation strategy, Large incumbents, Talent Competition, Labor dynamics, Market Equilibrium

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1 Introduction

Why would large incumbents firms deliberately hire more highly talented advanced talents than needed? In a well-functioning labor market where advanced talent is costly and scarce, the standard economic theory predicts that firms hire precisely the number of workers needed to maximize marginal returns on R&D. At first glance, surplus hiring, paying high wages to recruits who end up underemployed, appears wasteful even for financially abundant incumbents. Yet in practice, leading technology and finance companies frequently employ large cohorts of specialized researchers who remain underutilized. Reports document systematic overhiring and "benching" of technical staff at major technology firms even after large layoffs (Francis and Pipe [2024], Chen [2022]). Popular accounts note that such practices are not mere managerial errors but deliberate strategies that shape the innovation landscape.

Our paper develops a formal model that isolates the economic logic behind this phenomenon of talent hoarding. We show how an incumbent's private incentives to stockpile specialized researchers diverge from the socially efficient allocation that maximizes aggregate innovation. The inefficiency we highlight is distinct from the standard welfare costs of monopoly pricing: it arises specifically in the allocation of human capital during the research and development stage. When incumbents absorb scarce researchers, potentially more productive specialized firms are deprived of the human capital they need, resulting in under-innovation and under-diffusion of new technologies.

We identify four channels through which hoarding emerges. Two arise generically: First, under uncertainty about which technology or project will ultimately prove lucrative, incumbents may maintain multiple specialized teams but deploy only one or two. From the firm's perspective, sustaining parallel teams provides an option-like value: the ability to pivot or expand along the most promising R&D path once its potential becomes clear. Second, incumbents attract risk-averse or liquidity-constrained workers by offering equity-based compensation that facilitates risk-sharing. Many talented researchers knowingly accept uncertain or loosely defined roles at large firms to gain a certainty premium. Even if their own specialized technology underperforms, they still share in the broader returns of the firm and benefit from employment stability. Third, incumbents with deeper cash reserves or stronger equity-financing channels can outbid smaller entrants for scarce talent, even when those researchers might have been more productive and engaged in a specialized startup environment. Fourth, by hiring star researchers preemptively, before it is clear whether a technology will succeed, incumbents can hinder potential rivals from pursuing innovative projects, thereby safeguarding monopoly or oligopoly positions.

Formally, we analyze a dynamic model of R&D competition between one large incumbent and specialized firms. Technologies are subject to stochastic profitability ('trendiness') and potential cannibalization when two in-house projects overlap. In equilibrium, incumbents may optimally hoard talent, preempt rivals, and leave some researchers underutilized. We compare this private outcome to a constrained social planner's allocation that internalizes the innovation externality, thereby quantifying the welfare loss attributable to talent hoarding.

To build intuition, we first present a simplified three-period model that captures the core trade-offs between human capital accumulation, cannibalization risk, and liquidity constraints. We then extend to the full dynamic framework.

The rest of the paper proceeds as follows. Section 2 reviews related literature in organizational economics and industrial organization. Section 4 introduces the motivating case studies that illustrate talent hoarding in practice. Section 5 introduces the full model components. Section 6 develops a three-period benchmark model with one technology, which delivers closed-form conditions and clarifies the sources of talent hoarding. Section 7 characterizes the competitive equilibrium, while Section 8 presents the social planner allocation. Section 9 derives analytical solutions under linear functional forms, and Section 10 provides comparative statics based on these solutions. Section 11 then extends the analysis to an infinite-horizon dynamic model with two technologies. Section 12 shows our equilibrium analysis regarding how large firms' private incentives to block or preempt smaller rivals can drive systematic over-hiring of specialized talent. Section 13 discusses the comparison between private and social planner outcomes. Section 14 shows the simulation of the solutions using different sets of parameters. Section 15 discusses future research, and Section 17 concludes.

2 Literature Review

Our analysis builds on and connects several literatures on strategic human-capital management, labor-market dynamics, and innovation.

2.1 Talent Allocation, Promotion Incentives, and Talent Hoarding

Early studies of employment relationships (e.g., Kahn and Huberman [1988]) model "up-or-out" as an incentive scheme for firm-specific effort, while more recent work highlights signaling frictions in promotion (Waldman and Zax [2016]). Connecting these themes to talent hoarding, we note that when large firms pay premia to attract top researchers, internal advancement may become a bottleneck and yield a modern "up-or-idle" outcome.

In comparison to other notable papers from around the same time that address talent hoarding, our contribution is to shift the locus of hoarding upstream and outside the firm. He and Waldman [2024] analyzes how managers learn about subordinates' ability and may withhold or delay recommendations to keep stars in their own unit, with commitment tools that can mitigate hoarding at a cost. This is a personnel problem inside the firm, as there is no external labor market game over scarce researchers. Haegele [2024] provides causal evidence that hoarding within a large firm suppresses mobility using quasi-random manager rotations and documents distributional and efficiency effects. Benkert et al. [2024] presents that an incumbent may buy and shut down a startup to hire the team.

By contrast, we analyze ex-ante competition for frontier researchers before technologies are developed or deployed. Incumbents overhire to keep real-option flexibility under uncertainty, share risk via equity,

and preempt rival R&D without buying the firm when rivals are cash-constrained. This intra-firm hoarding at the market level in stages (1)-(2) helps explain the misallocation of talents in R&D, and our planner comparison quantifies the welfare wedge separate from the monopoly power of the product market.

2.2 Firm Heterogeneity and Market Frictions in Innovation and Resource Allocation

A related literature explores how firm-level productivity and market frictions drive resource misallocation and highlights that incumbent firms sometimes stifle reallocation unintentionally or strategically. The framework of Greenwald and Stiglitz [1986] shows that under imperfect information private equilibria may deviate from socially optimal allocations. Likewise, Cabral and Riordan [1994] and Tirole [1988] examine how dynamic competition and entry deterrence can yield increasing dominance by larger incumbents. In our setting, large and cash-abundant employers can outbid smaller rivals for specialized labor, thereby soaking up more talent than they ultimately use and locking human capital into less productive roles. More recently, in empirical contexts of emerging technologies, the hiring has become a key process of intangible human capital investment and acquisition of strategic assets Babina et al. [2024].

2.3 Strategic Hiring under Uncertainty: Killer Acquisitions and Patent Trolls

Recent work in industrial organization shows that incumbents may acquire nascent rivals and then shelve their innovations to protect market power and preserve monopoly rents (Cunningham et al. [2021]). A related strategy involves non-practicing entities, known as 'patent trolls', that stockpile patents and assert them aggressively without producing goods or advancing the underlying technology (Cohen et al. [2019]). We emphasize a distinct, ex-ante labor-market channel: by hiring star personnel and maintaining excess capacity, incumbents can preempt rival R&D even when those hires are underutilized. Unlike killer acquisitions or patent-troll enforcement, which are largely ex post and relatively low-risk, our mechanism operates before technologies are realized. We analyze the boundary conditions under which firms accumulate talent early to secure human capital, sustain advantage, and impede competitors' innovation trajectories. Whereas prior literatures focus on hoarding after development or at the production stage, our model offers, to our knowledge, the first formal applied-theory framework for hoarding in the research and early-development stages, where blocking rivals can reshape not only market shares but also the timing and direction of technological progress.

Fernández-Villaverde et al. [2025] document 'defensive hiring', whereby incumbents over-recruit researchers at above-market wages to deter competitors and slow creative destruction, especially when the supply of research labor is inelastic. In their evidence, the incumbent effectively clears the market, which is an empirical corner solution that appears in our model. We go beyond this by linking strategic hiring to persistent labor-market distortions. Our dynamic model of talent hoarding and misallocation embeds additional ex-ante commitment channels: (i) real options under technological uncertainty, (ii) risk-sharing

via equity-based compensation, which is now increasingly common among high-skill earners (Eisfeldt et al. [2023]), and (iii) competitive blocking of specialized research teams.

We build on real-options theory (Dixit [1994]; Kulatilaka and Perotti [1998]), which emphasizes the value of investing in multiple uncertain projects to preserve the flexibility to scale whichever proves most profitable. In our setting, hoarding specialized researchers ensures the incumbent can pivot among several technological trajectories as uncertainty resolves, thereby increasing the private value of preemptive hiring.

2.4 Skill-Biased Technological Change and Labor Mismatch

Research on skill-biased technological change (Acemoglu [2002]) shows that innovations tend to complement high-skill labor. When large incumbents hoard such talent, mismatch and underutilization become especially acute. Financing and information frictions likewise push workers into suboptimal roles (Banerjee and Duflo [2007]; Banerjee et al. [2024]; Midrigan and Xu [2014]). If hoarded hires forgo more entrepreneurial or specialized research development, knowledge diffusion, and the total innovation and competitiveness of the economy may suffer.

This paper also connects to canonical job-search and matching models (McCall [1972]) and to personnel-economics frameworks on incentives, promotions, and job design (Lazear and Shaw [2007]). We how deep-pocketed incumbents use wage premia to attract pivotal talent and impede entrants, creating externalities that distort the efficient flow of human capital. Beyond static search and matching models, Postel-Vinay and Robin [2002] highlight how equilibrium wage dispersion arises when workers accept lower wages today in exchange for the option value of higher offers tomorrow. We draw on this insight, but extend it to an innovation setting where the option value embedded in employment at large incumbents is tied not to future wage offers, but to risk-sharing and human capital dynamics that shape the allocation of R&D talent.

2.5 Policy Interventions and Welfare Considerations

A large literature emphasizes that private equilibrium rarely coincides with the social optimum under asymmetric information or incomplete markets. Market interventions, such as taxes, subsidies, or related policies, can realign incentives and improve allocation of talent, for instance by shifting researchers toward smaller startups (Arnosti et al. [2016]). These considerations link to broader debates in organizational economics over how the concentration of human capital within large incumbents shapes aggregate innovation and growth (Acemoglu et al. [2018]) as well as wage distributions (Abowd et al. [1999]).

3 Motivation and Contributions

Economists, statisticians, biologists, and physicists frequently report that their skills are "shelved" after moving to large technology or finance firms. Yet talent hoarding long predates modern tech. A memorable

example from Major League Baseball[1] shows how a powerful incumbent can secure promising talent largely to keep rivals from benefiting. In the 1950s, the Brooklyn Dodgers signed Roberto Clemente, highly rated by their scouts, then stashed him in Triple-A Montreal without a real chance at the Major League roster. By limiting his playing time, they hoped other clubs would overlook him. The plan backfired when the Pittsburgh Pirates claimed Clemente in the Rule 5 draft for $4,000; he became a Hall of Famer in Pittsburgh. Locking up an exceptional prospect without deploying him illustrates how incumbents may seize (and under-deploy) top talent to foreclose competitors' access. Having seen how over-hiring or "stockpiling" arises across contexts, we turn to a formal model that details the channels through which large, resource-rich incumbents hoard specialized labor.

Sometimes, talent stockpiling directly aims to choke off potential competitors. Amazon's 2012 acquisition of Kiva Systems for $775 million, followed by ceasing sales of Kiva robots to third parties, effectively locked up the technology for Amazon's own use.[2] Similarly, Google has acquired and discontinued products such as Sparrow Mail and reMail while retaining the engineering teams.[3] These cases suggest that hoarding talent is not mere managerial slack but, at times, an intentional strategy to foreclose rivals' access to human capital and technologies (Biddle [2014]).

While it is impossible to interrogate corporate leaders en masse about whether they intentionally over hire and their strategic motivations, a growing body of evidence is consistent with hoarding. For example, the productivity of star inventors often declines after they leave smaller or younger firms to join large incumbents, suggesting that once these hires are absorbed by dominant players, they may be underutilized or placed on idle benches (Akcigit and Goldschlag [2023]). These findings resonate with numerous accounts of advanced researchers being brought on primarily to block rival firms or as an option on future projects, rather than to fill immediate R&D needs. For example, a surge of press coverage and industry commentary (e.g., Bain Insights[4] and The Economist[5]) captures the fierce competition for tech firms to aggressively get talents. By hiring large numbers of masters and PhD-level personnel, sometimes well beyond what current projects demand, firms not only insulate themselves from skill shortages but also deny competitors ready access to top specialists.

Beyond firm-level impacts, the aggregate stakes are large even if only a subset of firms hoard. Training a single STEM PhD at elite private universities like MIT, Harvard, and Stanford can approach $500,000 funding from the university endowments, National Institute of Health (NIH), and National Science Foundation (NSF) when considering stipends, tuition coverage, research grants, and institutional overheads,[6] so underutilization

[1] Based on David Schoenfield, "How the Pirates stole Roberto Clemente from the Dodgers," ESPN, Sept. 16, 2015.

[2] https://www.industryweek.com/technology-and-iiot/robotics/article/\protect\penalty\z@21974332/beyond-kiva-how-amazon-triggered-a-robotic-arms-race

[3] https://www.npr.org/sections/alltechconsidered/2012/09/25/\protect\penalty\z@161573307/employee-shopping-acqui-hire-is-the-new-normal-in-silicon-valley

[4] https://www.bain.com/insights/tech-talent-war-tech-report-2021

[5] https://www.economist.com/business/2016/11/05/tech-firms-shell-out-to-hire-and-hoard-talent

[6] Back-of-the-envelope totals using published cost-of-attendance figures for typical 5–6 year programs: https://sfs.mit.edu/graduate-students/cost-of-attendance/grad-cost-of-attendance/; https://gsas.harvard.edu/financial-support/cost-attendance; https://studentservices.stanford.edu/tuition-rates/2024-2025-graduate-and-professional-tuition-rates.

wastes scarce human capital and may reduce innovation and productivity Akcigit et al. [2024]. Early-career mismatches can also depress promotion prospects and earnings trajectories. Startups, unable to match incumbent compensation, may struggle to assemble the specialized teams needed to bring new ideas to market, dampening entrepreneurship and slowing technological progress. These considerations sharpen questions about how public resources (grants, fellowships) are translated into social value.

We highlight implications for three key stakeholders:

First, university–industry coordination. Doctoral education in scientific and technical fields is heavily subsidized by government agencies, philanthropic grants, or university resources. When graduates move into roles where advanced training goes largely untapped, it raises questions about placement practices and information flows. More structured internships or co-ops could help students calibrate expectations about corporate R&D and innovation, and funding models might be revisited to encourage better skill–job matching.

Second, managerial and organizational design.. Over-hiring—especially when capital is cheap, can reflect agency problems or empire-building. Oversized teams dilute incentives, slow decisions, and relegate strong talent to holding areas, eroding motivation and bottom-up innovation. HR and senior leaders should align headcount with strategic needs rather than engage in headcount inflation.

Third, regulation and policy. Systematic preemption of specialized labor by incumbents can generate negative spillovers for industry-wide innovation. One question is whether existing mobility policies, non-compete laws, or other labor regulations inadvertently enable talent hoarding. Another question concerns public funding: should policymakers who subsidize doctoral training require more transparent commitments from private employers about how specialized hires will be utilized? Although such interventions may prove controversial, they highlight the broader societal interest in ensuring that advanced human capital is deployed productively.

It is important to realize that talent hoarding is not just the result of a transient managerial mistake or error. In equilibrium, firms may choose payrolls heavier in advanced talent than productive needs justify and then place some hires in less productive roles. This misallocation is socially costly and prevents talent from flowing to uses that maximize innovative output. Our paper contributes to the intersection of innovation strategy and labor by helping to understand the ongoing phenomenon, such as AI talent war.

4 From Reality to Framework: a Motivating Case

We consider a motivating example of Google (Alphabet) to illustrate we abstract from the typical real world observations of talent hoarding behavior to our model. Over the 2010s, Google's massive financial resources enabled it to systematically hire or buy out teams, often not purely for their productivity but also to preempt competitors' access to that human capital. This behavior maps onto the four channels of our model: retaining parallel teams under uncertainty, offering risk-sharing to recruits, leveraging deep pockets

for key hires, and blocking competitors before they can scale.

Parallel Teams and Option-Like Flexibility. One well-known instance was Google's parallel AI labs, Google Brain in California and DeepMind in London, both working at the frontier of machine learning. Operating two top labs in parallel let Google treat R&D as a set of real options: if one group's approach stalled, the other might succeed. In 2023, Alphabet merged them, noting each had pushed independent large-scale breakthroughs. Another illustration is Google's spree of robotics-focused hiring—eight small robotics outfits in six months[7]. Industry observers noted Google's vast resources made these team purchases trivial in cost, allowing multiple robotics lines to proceed without betting on any single one.

Risk-Sharing and a Failure-Tolerant Culture. Google also fosters an internal environment that mitigates employees' risk. For instance, its X innovation lab[8] rewards teams that shut down unviable projects, meaning workers do not pay the price if their R&D fails. By contrast, starting or joining a small firm means one flop can end everything financially. Moreover, Google X exemplifies the strategy to hoard all the talents when facing uncertainty of future technological states: the firm deliberately keeps a substantial number of highly skilled scientists and engineers on the payroll, even if their current projects are not immediately productive, as a hedge against significant technological uncertainty. This practice follows an "options" logic, in which the firm invests in a spectrum of high-risk "moonshot" ideas across multiple fields (from renewable energy to artificial intelligence), only a fraction of which transition into full-fledged ventures such as Waymo. While this approach is beneficial for Google's internal risk-sharing (and may eventually yield the next world-changing technology), it further tightens the labor market for startups, who face both technical risk in developing new products and product market risk in selling them. In short, the same conditions that motivate Google to stockpile talent under uncertainty simultaneously amplify the second mechanism of depriving small firms of the skilled workforce they need to innovate.

Financial Firepower to Outbid Others. On the open job market, Google made headlines outbidding rivals for specialized engineering talent. A notable example: its 2014 purchase of DeepMind, which outbid Facebook[9]. Similar stories played out with smaller teams in e-mail and consumer apps, where Google simply placed lavish packages on the table [10].

Preemptive Team Hires to Block Competitors. Beyond acquiring people it wanted, Google also closed off those teams to other potential acquirers. For instance, with the small firm Milk (eight employees), Google reportedly outbid a competitor, folded Milk's product, and kept the team inside. A similar

[7] https://www.cbsnews.com/news/google-buys-8-robotics-companies-in-6-months-why/

[8] https://www.theatlantic.com/magazine/archive/2017/11/x-google-moonshot-factory/540648/

[9] https://timesofindia.indiatimes.com/technology/tech-news/respect-facebook-founder-mark-zuckerberg-on-\how-google-deepmind-ceo-negotiated-with-google-playing-him-off/articleshow/112411902.cms

[10] https://www.npr.org/sections/alltechconsidered/2012/09/25/161573307/\protect\penalty\z@employee-shopping-acqui-hire-is-the-new-normal-in-silicon-valley

pattern emerged with Sparrow and reMail, both shuttered soon after their developers joined Google. This is effectively the "locking-up" of talent preempted potential rivals from scaling.

5 Core Model Components

Now we translate these real-world observations into the core theoretical components of our model. We define (i) large incumbents, (ii) specialized research firms, (iii) the talents they compete to hire, and (iv) the characteristics of technology and product. These components serve as the building blocks for the dynamic model of talent allocation developed in Section 11. Unlike prior studies that measure productivity in terms of output quantities given an existing technology, we focus on settings where the technology itself is not yet developed, and talent's contribution is instead to the probability of discovery. This framing aligns our model with innovation-sector realities such as AI, biotech, or quantum computing, where individual researchers directly shift the likelihood of breakthrough rather than immediate output levels.

5.1 Large Incumbent Firms

Large incumbent firms in our model are defined as leading corporations typically featured in major indices such as the S&P 500 or the Fortune 500. These firms include dominant technology companies like Apple, Microsoft, Google, and Amazon, which have established significant market presence and possess substantial financial resources. Unlike startups, large incumbent firms have surpassed the initial growth stages and can raise extensive financing through mechanisms such as equity issuance, debt financing, and retained earnings. Their financial robustness allows them to manage liquidity strategically to navigate financing constraints, optimize investment decisions, and maintain resilience against external shocks Bolton et al. [2011]. Additionally, these firms have the infrastructure and market influence to attract and retain top talent, thereby creating high entry barriers for smaller competitors. By leveraging their deep pockets, large incumbents can invest in research and development, acquire innovative startups, and secure key personnel, thereby maintaining their competitive edge and hindering the growth of new entrants in the industry.

A distinctive feature of large incumbents is the potential for cannibalization between their existing business lines and new technologies. When both types of R&D succeed, it may be privately optimal for the firm to commercialize only the more profitable project, leaving the other team's expertise idle. This possibility (Jungbauer et al. [2021]) creates incentives for incumbents to over-hire even when they know that part of the talent pool may be underutilized.

Additionally, large incumbent firms frequently incorporate equity-based compensation into their talent packages, supplementing fixed salaries with firm-wide profit-sharing incentives. Unlike performance-based equity tied to an employee's specific team or project, such as in boutique consulting firms, these equity payoffs at these large incumbent firms are linked to the firm's financial performance.

In practice, large incumbent firms like Google or Microsoft frequently maintain multiple, sometimes

disparate, lines of research and development, reflecting their broader scope and financial capacity to invest across technologies. In contrast, smaller or specialized research outfits (e.g., a quantum computing startup) typically concentrate on a single core technology. To capture this fundamental difference in breadth, we assume throughout the model that the incumbent has two distinct technologies under development whereas each specialized firm focuses on only one. This simplification aligns with empirical observations that well-established incumbents often possess the resources and the strategic motivation to sustain parallel R&D paths, whereas smaller specialized players usually channel their limited resources into a narrower domain.

5.2 Specialized Research Firms

We refer to specialized research firms as growth-stage startups focused on developing or commercializing new technologies and profit-oriented third-party research institutes. Growth-stage startups are emerging companies that concentrate on developing a single technology or a narrow set of technologies, typically operating with limited financial resources but demonstrating high potential for innovation and specialized expertise. Notable examples include DeepMind (before its acquisition by Google) and Anthropic. These startups are highly relevant to current trends in the tech industry, where they play a pivotal role in driving innovation within dynamic and resource-constrained environments (Gompers and Lerner [2001]). Additionally, we include third-party research institutes, which are independent organizations dedicated to advancing specific technological fields such as quantum computing. These institutes often collaborate with multiple stakeholders, including universities, government agencies, and private companies, offering stability through more reliable funding and deep specialization ideal for focused talent allocation. Unlike academic and university-based research centers, these third-party institutes are profit-oriented, ensuring direct competition with incumbents for specialized talent. This categorization aligns with Freeman [1997] exploration of the role of research institutes in innovation ecosystems. By concentrating on growth-stage startups and third-party research institutes, we deliberately exclude academic and university-based research centers as well as in-house research labs within established firms. This exclusion is justified by the distinct operational and financial incentives of these entities, which do not directly engage in competitive talent allocation with cash-rich incumbents, thereby allowing our model to focus on the most relevant specialized research firms that influence talent dynamics and innovation outcomes.

5.3 Talents

Talents in this paper refer to highly skilled professionals with advanced research training beyond the standard undergraduate level. While not exclusively limited to STEM fields, there is a significant emphasis on STEM-related disciplines. These talents are typically engaged in roles such as research and development, engineering, product management, and other critical front-line positions within firms. Most of them hold master's degrees or possess significant professional experience, equipping them with the expertise required to successfully implement projects that can generate substantial returns for their employers. Their advanced skill sets enable

them to contribute to innovative projects, drive technological advancements, and enhance the competitive capabilities of their firms. These talents possess the individual capacity to undertake complex projects that align with their firms' strategic objectives, rendering them critical assets in both large incumbent firms and specialized research entities.

5.4 Technology and Product

In the 1950s, televisions were highly sought after; in the 1990s, computers became the technology of choice; and in the 2010s, cellphones dominated consumer preferences. Each of these technologies is profitable and significantly valued, i.e. 'trendy', only during specific periods. Consequently, in this simplified model, we assume that developed technologies are nondurable and remain relevant solely within their respective timeframes.

Having outlined the real-world entities that drive our framework, in Section 11, we formalize them into a dynamic model that captures how competition for talent unfolds when there is uncertainty over which future technologies will succeed, how incumbents might underutilize certain talents to avoid self-cannibalization, and why specialized firms may still attract talent despite their higher risk.

6 Three-Period Model (One Technology)

6.1 Overview

We begin with a compact three-period benchmark (one technology) that delivers closed-form conditions and makes the sources of talent hoarding transparent. This solved baseline fixes notation and intuition for the dynamic model that follows, which re-introduces multiple technologies and richer state dynamics.

In this model, there is one type of representative continuous talent, whose expertise can be used to develop technology in one industry. In this industry, there is one representative large firm and one representative specialized firm. The large firm has one line of stable income that earns Π_0 and one line of innovative technology. The specialized firm only has one line of innovative technology.

In the large firm, the talent is able to accumulate human capital by successfully developing the technology and the project is implemented. In the specialized firm, the talent always accumulates human capital. Thus, the talent faces the trade-off between human capital accumulation and economic gain.

Both firms need to hire human capital to develop the technology, such that they can use the technology to implement corresponding projects in the production sector to earn profit. Since our interest is on the innovation sector, the profit is exogenous in this model and we will not specify production functions or the production sector's profit maximization.

The large firm faces a potential cannibalization between its two lines. When the technology is successfully developed, it might be more profitable for the large firm to only stick with one line of income for reasons

such as convex costs or substitution between the two lines. To simplify, we assume that cannibalization happens with an exogenous probability, and if it happens, the large firm can only profit from one line. The specialized firm, in contrast, faces a potential liquidity constraint.

In the talent hiring market, the large firms have two options. They can either be wage takers offering the large-firm wage, or collude as one type to raise the wage and take advantage of specialized firms' liquidity constraint. In the production market, if either the large firm or the specialized firm is the only one to successfully develop the technology, the firms can collude to earn monopoly profit Π. If both succeed, they will mimic a competitive market and earn zero profit.

There are two final goods in this model. The line of stable income produces final good 0, and the line of innovative technology produces final good 1. Assume that the good 0 market is competitive, so equilibrium output is always at the social optimal amount. For the good 1 market, the socially optimal amount is produced when both firms successfully develop the technology, and monopoly quantity is produced when only one type succeeds.

6.1.1 Assumptions

- There is a continuum of identical talents, each capable of developing the same technology. Talents allocate labor across firms.
- There are two firms: one representative large firm F and one representative specialized firm M.
  - The large firm has one stable income line that yields exogenous profit Π_0 each period, and one innovative line that depends on technology development.
  - The specialized firm has only the innovative line.
- In each period, both firms can attempt to develop the innovative technology by hiring human capital. If the large firm hires H_F and the specialized firm hires H_M, the probabilities of success are $q_F(H_F)$ and $q_M(H_M)$, respectively. These are increasing functions mapping into $[0, 1]$.
- Success events are denoted $n_{t,i} \in \{0, 1\}$ for firm $i \in \{F, M\}$, with history $n^{t,i} = \{n_{0,i}, \ldots, n_{t,i}\}$.
- Profitability of the innovative technology is uncertain. Each period, the technology yields state $s_t \in \{0, 1\}$ with probability $P(s_t)$, where $s_t = 1$ indicates profitability.
- The large firm faces potential cannibalization between its stable and innovative lines. Each period, an independent state $z_t \in \{0, 1\}$ is realized:
  - If $z_t = 1$, cannibalization occurs, and the firm can only profit from one line (whichever yields more).
  - If $z_t = 0$, both lines can be operated simultaneously.

The probability distribution is $Q(z_t)$.

- Market payoffs for the innovative line are exogenous. If only one firm develops the technology and it is profitable, that firm earns monopoly profit $\Pi > 0$. If both firms develop it, they compete and each earns zero.

- Talents are compensated via contracts with two components: a wage and an equity share θ of realized profits. For large-firm hires, the equity share is tied to the firm's total profit (stable + innovative). For specialized-firm hires, the share is tied only to the specialized firm's innovative profit.

- Human capital evolves endogenously.

  – If a talent works at the specialized firm, human capital always accumulates at rate $g_M(h)$ regardless of whether the project is implemented.

  – If a talent works at the large firm, human capital accumulates at rate $g_F(h)$ only when the innovative project is implemented; otherwise, it remains stagnant.

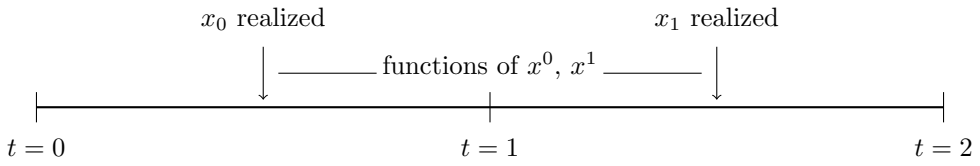
  All talents also face depreciation at rate δ_h.

- For notation, each period's realized state vector is

$$x_t = (s_t, z_t, n_{t,F}, n_{t,M}),$$

  and the history up to t is $x^t = (s^t, z^t, n^{t,F}, n^{t,M})$.

6.1.2 Time Structure



In every period, before the states are realized, the large firm and the specialized firm compete to hire a continuum of talent, offering wage and equity share schemes. The agent determines the allocation of human capital to each firm. Subsequently, firms assess whether the allocated talent successfully develops the technology and whether it becomes profitable, thereby deciding whether to implement the project. Assuming $t = 0$ is the initial period, the temporal sequence is as follows:

1. Talent Allocation Phase I ($t = 0$ to x_0 realized): Firms allocate human capital to develop the technology. Talents receive the wage for developing the technology. As $t = 0$ marks the initial period, no production has occurred, and talents are not engaged in consumption at this stage.

2. State Realization Phase I (x_0 realized): Economic states x_0 are realized, and the history x^0 is fully determined. All variables chosen after x_0 and before x_1 are functions of x^0.

3. Production Phase I (x_0 realized to $t = 1$): Firms produce goods based on allocated human capital and technological capabilities. Produced goods are slated for consumption in the next period.

4. Talent Allocation Phase II ($t = 1$ to x_1 realized): Firms allocate human capital to develop the technology. Talents receive the wage in this period's contract and equity share in the previous period's contract. Talents consume goods produced in the previous period.

6.1.3 Justification for the Model Sequence

The sequence of the model is designed to reflect the inherent uncertainty faced by talents regarding technological advancements and their implications for production and consumption. Specifically, talents are limited in their ability to foresee future technologies beyond the scope of what they currently work on. This temporal constraint decides what they can buy.

To illustrate, consider a talent receiving a salary in 2010. At that time, the talent could only purchase the goods available based on the technologies that had already been developed and brought to market, such as the iPhone 4, which was released in 2010. The talent would not have access to, nor could they consume, an iPhone model from 2016, as its underlying technology and production processes were yet to be realized. This lag between technological development and market availability captures the intertemporal dynamics of the model, where consumption in any given period is tied to the production outputs of the preceding period.

This structure captures two essential realities: First, talents cannot anticipate or consume goods based on technologies that have not yet materialized. Their consumption decisions are inherently constrained by the state of technology and production outcomes from previous periods. Second, the production process and its outcomes in each period form the foundation for consumption and economic activity in subsequent periods. This dependency creates a natural flow where talents' current consumption is shaped by past technological and production achievements. By embedding these temporal constraints into the model, we ensure that it aligns with real-world scenarios where technological advancements, production processes, and market availability evolve over time.

6.2 Talent

Given exogenous prices at each state, the firm's optimization remains unchanged, and the talent allocation problem is that the talent chooses $\{c_0(x^t), c_1(x^t)\}_{t=0}^{2} \forall x^t$, $\{h_F(x^t), h_M(x^t)\}_{t=0}^{1} \forall x^t$, and $h\left(x^1\right)$ to solved

$$\max u\left(c_0\left(x^0\right), c_1\left(x^0\right)\right) + \beta \mathbb{E}\left[u\left(c_0\left(x^1\right), c_1\left(x^1\right)\right)\right] + \beta^2 \mathbb{E}\left[u\left(c_0\left(x^2\right), c_1\left(x^2\right)\right)\right] \tag{1}$$

subject to the budget constraints,

$$
\begin{aligned}
&p_0\left(x^0\right)c_0\left(x^0\right)+p_1\left(x^0\right)c_1\left(x^0\right)+\sum_{x^1\in X^1}p_b\left(x^1\right)b(x^1)\leq\ h_F\left(x^0\right)w_F\left(x^0\right)+h_M\left(x^0\right)w_M\left(x^0\right)\\
&p_0\left(x^1\right)c_0\left(x^1\right)+p_1\left(x^1\right)c_1\left(x^1\right)+\sum_{x^2\in X^2}p_b\left(x^2\right)b(x^2)\leq\ h_F\left(x^1\right)w_F\left(x^1\right)+h_M\left(x^1\right)w_M\left(x^1\right)+b(x^1)+\\
&\qquad\qquad\qquad\qquad\qquad\qquad\qquad\qquad\qquad\qquad\frac{h_F\left(x^0\right)}{H_F\left(x^0\right)}\cdot\theta_F\Pi_F\left(x^1\right)+\frac{h_M\left(x^0\right)}{H_M\left(x^0\right)}\cdot\theta_M\Pi_M\left(x^1\right),\forall x^1\\
&p_0\left(x^2\right)c_0\left(x^2\right)+p_1\left(x^2\right)c_1\left(x^2\right)\leq\frac{h_F\left(x^1\right)}{H_F\left(x^1\right)}\cdot\theta_F\Pi_F\left(x^2\right)+\frac{h_M\left(x^1\right)}{H_M\left(x^1\right)}\cdot\theta_M\Pi_M\left(x^2\right)+b(x^2),\forall x^1,x^2
\end{aligned}
\tag{2}
$$

(Note that the difference of the period 2 budget constraint from that of period 1 is because in period 2 there is no wage income, but the dividend share that was earned in period 1 is still available)

the human capital accumulation constraints,

$$
h\left(x^1\right)=(1-\delta_h)h\left(x^0\right)+g_M\left(h_M\left(x^0\right)\right)+g_F\left(h_F\left(x^0\right)\right)\cdot\mathbb{1}(s_1=1,n_{1,F}=1)\cdot[1-\mathbb{1}\left(z_1=1,\Pi<\Pi_0\right)],\forall x^1 \tag{3}
$$

(The human capital invested in the large firm is accumulated if the large firm successfully develops type technology and implements the corresponding project. Conditional on technology is commercializable and successfully developed, within the large firm, technology corresponding project will be implemented when 1) cannibalization doesn't happen; 2) cannibalization happens but technology is more profitable than the stable income. Therefore, conditional on technology is commercializable and successfully developed by the large firm, the excluding situation in the indicator function above is when the stable line is more profitable than technology k, and cannibalization happens.)

and the human capital constraints,

$$
\begin{aligned}
&h_F\left(x^0\right)+h_M\left(x^0\right)\leq h\left(x^0\right)\\
&h_F\left(x^1\right)+h_M\left(x^1\right)\leq h\left(x^1\right),\forall x^1
\end{aligned}
\tag{4}
$$

Denote $\xi\left(x^t\right)$ the joint probability that x^t appears, for every period t, we partition the state variable $x^t:=(s_t,z_t,n_{t,F},n_{t,M})$ as $X^t=\{X^{ta},X^{tn}\}$, such that X^{ta} is the set of states that the human capital is accumulated in the large firm and X^{tn} is the set of states that the human capital is not accumulated in the large firm in period t.

6.3 Large Firm Problem

Timing within the large firm. At $t=0$ the large firm simultaneously offers state-contingent wage schedules $\{w_F(x^0),w_F(x^1)\}$ and equity shares $\{\theta_F\}$. Talents then choose employment levels $H_F(x^0)$. Nature reveals the R&D outcomes x^1; the firm earns $\Pi_F(x^1)$, distributes equity, and updates cash $C_F(x^1)$. The sequence repeats at $t=1$. Finally, in period 2 the firm liquidates and pays out the residual dividend.

The large firm will offer wage and equity shares to each type of talent before the states are realized. Once states are realized, workers will receive their corresponding share of the total profit of the firm. Given $\{w_F\left(x^0\right), w_F\left(x^1\right)\}\forall k$ and $\{H_M\left(x^0\right), H_M\left(x^1\right)\}$, the large firm chooses $\{H_F^0\left(x^0\right), H_F^1\left(x^0\right), H_F^0\left(x^1\right), H_F^1\left(x^1\right)\}$

$$\max \mathbb{E}\left[R_F\left(x^1\right)\right] - w_F\left(x^0\right) H_F\left(x^0\right) + \frac{1}{1+r} \cdot \mathbb{E}\left[R_F\left(x^2\right) - w_F\left(x^1\right) H_F\left(x^1\right)\right] \tag{5}$$

subject to for $t = 1, 2$, where Π_0 represents the stable or "legacy" line of business that the large firm already operates before any new R & D takes place, and Π represents the monopoly (or collusive) profit that can be earned if one and only one firm succeeds in the new technology and then restricts output.

$$\begin{aligned} \Pi_F\left(x^t\right) &= \begin{cases} \max\{\Pi_0, \Pi\} & \text{if } s_t = 1, z_t = 1, n_{t,F} = 1, n_{t,M} = 0 \\ \Pi_0 + \Pi & \text{if } s_t = 1, z_t = 0, n_{t,F} = 1, n_{t,M} = 0 \\ \Pi_0 & \text{otherwise} \end{cases} \\ R_F\left(x^t\right) &= \left(1 - \theta_F\right) \Pi_F\left(x^t\right). \end{aligned} \tag{6}$$

where $\mathbb{E}\left[\Pi_F\left(x^t\right)\right]$ has the closed-form:

$$\begin{aligned} \mathbb{E}\left[\Pi_F\left(x^t\right)\right] =& P\left(s_t = 1\right) Q\left(z_t = 1\right) q_F\left(H_F\left(x^{t-1}\right)\right)\left(1 - q_M\left(H_M\left(x^{t-1}\right)\right)\right) \max\{\Pi_0, \Pi\} + \\ & P\left(s_t = 1\right)\left(1 - Q\left(z_t = 1\right)\right) q_F\left(H_F\left(x^{t-1}\right)\right)\left(1 - q_M\left(H_M\left(x^{t-1}\right)\right)\right)\{\Pi_0 + \Pi\} + \\ & \left(1 - P\left(s_t = 1\right) q_F\left(H_F\left(x^{t-1}\right)\right)\left(1 - q_M\left(H_M\left(x^{t-1}\right)\right)\right)\right)\Pi_0 \end{aligned}$$

liquidity constraint with Lagrangian multipliers $\mu_F(x^0)$ and $\mu_F(x^1)$,

$$\begin{aligned} w_F\left(x^0\right) H_F\left(x^0\right) &\leq C_F(x^0) \\ w_F\left(x^1\right) H_F\left(x^1\right) &\leq C_F(x^1) \end{aligned} \tag{7}$$

human capital constraint with Lagrangian multipliers $\nu_F(x^0)$ and $\nu_F(x^1)$ $\forall k$,

$$\begin{aligned} H_F(x^0) + H_M\left(x^0\right) &\leq H(x^0) \\ H_F(x^1) + H_M\left(x^1\right) &\leq H(x^1) \end{aligned} \tag{8}$$

and the accumulation of cash (C_M and C_F are the respective cash of the firm) with Lagrangian multipliers $\gamma_F(x^1)$ and $\gamma_F(x^2)$,

$$\begin{aligned} C_F(x^1) &= C_F(x^0) + R_F(x^1) \\ C_F(x^2) &= C_F(x^1) + R_F(x^2) \end{aligned} \tag{9}$$

Specifically, in period t, $w_F\left(x^{t-1}\right)$ is the wage offered by the large firm F to the talent, $H_M\left(x^{t-1}\right)$ is the human capital hired by specialized firm M, $H_F\left(x^{t-1}\right)$ is the type human capital hired by F, $\Pi_F\left(x^t\right)$ is the profit of final good production of the large firm after the states are realized, and $R_F\left(x^t\right)$ is the after-equity

profit of the large firm after the states are realized.

6.4 Specialized Firm Problem

For the specialized firm M, given $\left\{w_M\left(x^{t-1}\right), H_F\left(x^{t-1}\right)\right\}_{t=1}^{2}$, $\left\{H_M\left(x^{t-1}\right)\right\}_{t=1}^{2}$, solves

$$\max \mathbb{E}\left[R_M\left(x^1\right)\right] - w_M\left(x^0\right) H_M\left(x^0\right) + \frac{1}{1+r} \cdot \mathbb{E}\left[R_M\left(x^2\right) - w_M\left(x^1\right) H_M\left(x^1\right)\right] \tag{10}$$

subject to $\forall \omega = k$, $\forall t, x^t$,

$$\begin{aligned} &\Pi_M\left(x^t\right) = \Pi \cdot \mathbb{1}\left(s_t = 1, n_{t,M} = 1\right) \cdot \max\{\mathbb{1}\left(n_{t,F} = 0\right), \mathbb{1}\left(n_{t,F} = 1, z_t = 1, \Pi < \Pi_0\right)\}, \\ &R_M\left(x^t\right) = \left(1 - \theta_M\right) \Pi_M\left(x^t\right) \end{aligned} \tag{11}$$

liquidity constraint with Lagrangian multipliers $\mu_M(x^0)$ and $\mu_M(x^1)$,

$$\begin{aligned} w_M\left(x^0\right) H_M\left(x^0\right) &\leq C_M(x^0) \\ w_M\left(x^1\right) H_M\left(x^1\right) &\leq C_M(x^1) \end{aligned} \tag{12}$$

human capital constraint with Lagrangian multipliers $\nu_M(x^0)$ and $\nu_M(x^1)$ $\forall k$,

$$\begin{aligned} H_F(x^0) + H_M\left(x^0\right) &\leq H(x^0) \\ H_F(x^1) + H_M\left(x^1\right) &\leq H(x^1) \end{aligned} \tag{13}$$

and cash accumulation with Lagrangian multipliers $\gamma_M(x^1)$ and $\gamma_M(x^2)$,

$$\begin{aligned} C_M(x^1) &= C_M(x^0) + R_M(x^1) \\ C_M(x^2) &= C_M(x^1) + R_M(x^2) \end{aligned} \tag{14}$$

where assume $\Pi < \Pi_0$, the specialized firm has a closed-form profit function

$$\Pi_M(x^t) = P\left(s_t = 1\right) q_M\left(H_M\left(x^{t-1}\right)\right)\left(1 - q_F\left(H_F\left(x^{t-1}\right)\right) + q_F\left(H_F\left(x^{t-1}\right)\right) Q\left(z_t = 1\right)\right) \Pi \tag{15}$$

and when $\Pi > \Pi_0$,

$$\Pi_M(x^t) = P\left(s_t = 1\right) q_M\left(H_M\left(x^{t-1}\right)\right)\left(1 - q_F\left(H_F\left(x^{t-1}\right)\right)\right) \Pi \tag{16}$$

6.5 Social Planner Problem

The social planner allocates human capital in three key ways that depart from the competitive equilibrium.

First, the planner is unconstrained by the strategic concerns that shape firm behavior in competitive

equilibrium, such as cannibalization of products within firms and profit erosion of the original product line due to the development of the new products. In private settings, cannibalization happens as firms withhold investment in a successful prototype of an innovative product if the new technology threatens existing revenue streams or if the expected gains are diminished by intensified competition and convex production costs. Moreover, profit erosion occurs when a firm successfully innovates, the competitive environment may erode profits to zero, weakening ex-ante incentives to invest in R&D. By contrast, the social planner evaluates each innovation solely based on its contribution to aggregate consumption and welfare. Since utility is increasing in consumption, any new technology product that expands the feasible consumption set is adopted without hesitation, regardless of whether it undermines existing product line or fails to yield monopoly profits. Because the economy is trying to unlock one new technology, the planner cares only that it emerges somewhere, which firm invents it, or whether several do so independently, is irrelevant. Once any firm develops a viable prototype, the planner diffuses the know-how economy-wide and mandates production at the competitive, welfare-maximizing scale. This guarantees the full productivity gain of the breakthrough and strips away the firm-level strategic distortions (cannibalization fears, monopoly-rent preservation, financing frictions) that otherwise slow or shrink its rollout. In short, the planner's allocation fully internalizes the social value of the lone innovation, unconstrained by private revenue considerations.

Second, the planner ensures that any successfully developed technology is deployed at the socially optimal scale in final-good production. In contrast, under the competitive equilibrium without a social planner, when a single firm type achieves technological success, those firms strategically restrict output to sustain monopoly rents, resulting in inefficient underproduction. The planner, by internalizing the full welfare implications of production, mandates that any productive technology be operated at the competitive level of output. Consequently, as long as at the firm successfully develops an innovative technology, the planner guarantees full utilization of the technology in the final-good sector, thereby eliminating monopoly distortions as a constraint on aggregate output.

Third, the planner's allocation never results in corner solutions driven by liquidity constraints. In the competitive equilibrium, firms may be unable to pursue innovation projects solely due to financing frictions, even when those projects exhibit positive expected returns. This results in an inefficient under-use of valuable technological opportunities. By contrast, the social planner is not subject to such constraints. The planner's objective is to allocate human capital across firms so as to maximize expected social welfare, assigning resources to all projects with nonnegative expected social value. With only one prospective technology, the planner's objective is to maximize the probability that the breakthrough occurs somewhere. Accordingly, the planner never diverts talent away from any project that has a non-negative social return merely to shift the odds toward a different firm; doing so would strictly lower the economy-wide chance of success. Liquidity constraints therefore never bar a productive project from receiving human capital. Instead, the planner assigns researchers wherever their expected contribution to aggregate welfare is positive, fully internalizing society's utility rather than individual firms' fortunes.

We assume each talent's utility has equal weight in the social welfare function.

$$\max \sum_{t=0}^{2} \sum_{x^t \in X^t} \beta^t \xi(x^t) u\left(c_0\left(x^t\right), c_1\left(x^t\right)\right) \tag{17}$$

subject to the good market clearing

$$\begin{aligned} & c_\omega\left(x^t\right)=y_\omega\left(x^t\right), \forall \omega, t, x^t \\ & y_0\left(x^t\right)=y_0^{comp}, \forall t, x^t \\ & y_1\left(x^t\right)=y_1^{comp} \cdot \mathbb{1}\left(s_t=1\right)\left(1-\mathbb{1}\left(n_{t,F}=0, n_{t,M}=0\right)\right), \forall t, x^t \end{aligned} \tag{18}$$

When a commercializable technology product is successfully developed and implemented by a firm, this implies that talents (i.e., the consumers) derive utility from consuming it in our model. In contrast, a social planner would implement all available technologies without the concern of cannibalization that private firms face. Furthermore, the social planner must account for the process of accumulation of human capital.

$$H\left(x^t\right)=(1-\delta_h) H\left(x^{t-1}\right)+g_M\left(H_M\left(x^{t-1}\right)\right)+g_F\left(H_F\left(x^{t-1}\right)\right) \cdot \mathbb{1}(s_t=1, n_{t,F}=1), \forall k, t, x^t. \tag{19}$$

and the human capital budget constraint

$$H_F\left(x^{t-1}\right)+H_M\left(x^{t-1}\right) \leq H\left(x^{t-1}\right), \forall k, t, x^t. \tag{20}$$

7 Competitive Equilibrium

7.1 First Order Conditions

7.1.1 Talent

The Lagrangian of this problem is

$$\begin{aligned}
\mathcal{L} =& u\left(c_0\left(x^0\right), c_1\left(x^0\right)\right) + \beta\mathbb{E}\left[u\left(c_0\left(x^1\right), c_1\left(x^1\right)\right)\right] + \beta^2\mathbb{E}\left[u\left(c_0\left(x^2\right), c_1\left(x^2\right)\right)\right] + \\
& \lambda_1(x^0)\xi(x^0)\Big(h_F\left(x^0\right)w_F\left(x^0\right) + h_M\left(x^0\right)w_M\left(x^0\right) - p_0\left(x^0\right)c_0\left(x^0\right) - p_1\left(x^0\right)c_1\left(x^0\right) - \sum_{x^1\in X^1} p_b\left(x^1\right)b(x^1)\Big) + \\
& \sum_{x^1\in X^1}\lambda_1(x^1)\xi(x^1)\Bigg(h_F\left(x^1\right)w_F\left(x^1\right) + h_M\left(x^1\right)w_M\left(x^1\right) + b(x^1) + \frac{h_F\left(x^0\right)}{H_F\left(x^0\right)}\cdot\theta_F\Pi_F\left(x^1\right) \\
& \qquad \frac{h_M\left(x^0\right)}{H_M\left(x^0\right)}\cdot\theta_M\Pi_M\left(x^1\right) - p_0\left(x^1\right)c_0\left(x^1\right) - p_1\left(x^1\right)c_1\left(x^1\right) - \sum_{x^2\in X^2} p_b\left(x^2\right)b(x^2)\Bigg) + \\
& \sum_{x^2\in X^2}\lambda_1(x^2)\xi(x^2)\left(\frac{h_F\left(x^1\right)}{H_F\left(x^1\right)}\cdot\theta_F\Pi_F\left(x^2\right) + \frac{h_M\left(x^1\right)}{H_M\left(x^1\right)}\cdot\theta_M\Pi_M\left(x^2\right) + b(x^2) - p_0\left(x^2\right)c_0\left(x^2\right) - p_1\left(x^2\right)c_1\left(x^2\right)\right) + \\
& \sum_{x^1\in X^1}\lambda_2(x^1)\xi(x^1)\Big((1-\delta_h)h\left(x^0\right) + g_M\left(h_M\left(x^0\right)\right) - h\left(x^1\right)\Big) + \sum_{x^1\in X^{1a}}\lambda_2(x^1)\xi(x^1)g_F\left(h_F\left(x^0\right)\right) + \\
& \lambda_3(x^0)\left(h\left(x^0\right) - h_F\left(x^0\right) - h_M\left(x^0\right)\right) + \sum_{x^1\in X^1}\lambda_3(x^1)\xi\left(x^1\right)\left(h\left(x^1\right) - h_F\left(x^1\right) - h_M\left(x^1\right)\right)
\end{aligned}$$

The first order conditions are

$$[c_0(x^t)] : \beta^t\xi\left(x^t\right)u_1\left(c_0\left(x^t\right), c_1\left(x^t\right)\right) - \xi\left(x^t\right)\lambda_1\left(x^t\right)p_0\left(x^t\right) = 0 \tag{21}$$

$$[c_1(x^t)] : \beta^t\xi\left(x^t\right)u_2\left(c_0\left(x^t\right), c_1\left(x^t\right)\right) - \xi\left(x^t\right)\lambda_1\left(x^t\right)p_1\left(x^t\right) = 0 \tag{22}$$

In addition,

$$[b(x^1)] : -\lambda_1(x^0)p_b(x^1) + \lambda_1(x^1)\xi(x^1) = 0 \tag{23}$$

$$[b(x^2)] : -\lambda_1(x^1)\xi(x^1)p_b(x^2) + \lambda_1(x^2)\xi(x^2) = 0 \tag{24}$$

Recall that the state variables for simplicity is written as this tuple $x_t = (s_t, z_t, n_{t,F}, n_{t,M}) \in X_t$, where s_t flags technical success ; z_t is the binary cannibalization indicator.

$$\xi\left(x^t|x^{t-1}\right) = P(s_t)Q(z_t)q_F\left(H_F\left(x^{t-1}\right)\right)q_M\left(H_M\left(x^{t-1}\right)\right)$$

The transition probability $\xi(x^t|x^{t-1})$ captures the likelihood of moving from state x^{t-1} to x^t, and is modeled as the product of four independent components: the probability of R&D success $P(s_t)$, the cannibalization probability $Q(z_t)$, and the probabilities that the technology is successfully developed in the large and the

specialized firm, respectively, $q_F(H_F(x^{t-1}))$ and $q_M(H_M(x^{t-1}))$. These probabilities are taken as exogenous by the representative talent but depend endogenously on firm-level human capital in equilibrium.

We have $\xi(x^0) = 1$ and for $t = 1, 2$. Thus, they are functions of firm's decisions, which are exogenous in the talent's optimization problem. Thus,

$$[h_F\left(x^0\right)] : \lambda_1(x^0)\, w_F(x^0) \;+\; \sum_{x^1 \in X^1} \lambda_1(x^1)\, \xi(x^1)\, \frac{\theta_F\, \Pi_F(x^1)}{H_F(x^0)} \;+\; \sum_{x^1 \in X^{1a}} \lambda_2(x^1)\, \xi(x^1)\, g'_F\big(h_F(x^0)\big) \;-\; \lambda_3(x^0) \;=\; 0 \tag{25}$$

When $\Pi < \Pi_0$ (the line of innovative technology is cannibalized, meaning the new product displaces the firm's existing stable-income product rather than generating new demand), the human capital invested in the large firm is accumulated with the following probability in period 1:

$$\mathcal{P}_1 = \sum_{x^1 \in X^{1a0}} \xi(x^1) = P\left(s_t = 1\right) q_F\left(H_F\left(x^0\right)\right)\Big(1 - Q\left(z_1 = 1\right)\Big)$$

When $\Pi > \Pi_0$ (the line of stable income is cannibalized, meaning the firm's new innovative product overtakes or displaces its existing stable-income line), the human capital invested in the large firm is accumulated with the probability in period 1

$$\mathcal{P}_1 = \sum_{x^1 \in X^{1a}} \xi(x^1) = P\left(s_1 = 1\right) q_F\left(H_F\left(x^0\right)\right)$$

where the large firm's R&D is successfully implemented so that the talent's specialized skill actually leads to next-period human capital accumulation. In addition,

$$[h_F\left(x^1\right)] : \lambda_1(x^1)\, \xi(x^1)\, w_F(x^1) \;+\; \sum_{x^2 \in X^2} \lambda_1(x^2)\, \xi(x^2|x^1)\xi(x^1)\, \frac{\theta_F\, \Pi_F(x^2)}{H_F(x^1)} \;-\; \lambda_3(x^1)\, \xi(x^1) \;=\; 0 \tag{26}$$

For the specialized firm, there is no cannibalization within the firm. Thus,

$$[h_M\left(x^0\right)] : \lambda_1(x^0)\, w_M\big(x^0\big) + \sum_{x^1 \in X^1} \lambda_1(x^1)\, \xi(x^1)\, \frac{\theta_M\, \Pi_M\big(x^1\big)}{H_M(x^0)} + \sum_{x^1 \in X^1} \lambda_2(x^1)\, \xi(x^1)\, g'_M\big(h_M\big(x^0\big)\big) - \lambda_3(x^0) \;=\; 0 \tag{27}$$

and

$$[h_M\left(x^1\right)] : \lambda_1(x^1)\, \xi(x^1)\, w_M\big(x^1\big) \;+\; \sum_{x^2 \in X^2} \lambda_1(x^2)\, \xi(x^2|x^1)\xi(x^1)\, \frac{\theta_M\, \Pi_M\big(x^2\big)}{H_M(x^1)} \;-\; \lambda_3(x^1)\, \xi(x^1) \;=\; 0 \tag{28}$$

Finally,

$$[h\left(x^1\right)] : -\lambda_2\left(x^1\right) \xi\left(x^1\right) + \lambda_3\left(x^1\right) \xi\left(x^1\right) = 0 \tag{29}$$

7.1.2 Large Firm

The Lagrangian is given by

$$\begin{aligned}\mathcal{L}_F =&\mathbb{E}\left[R_F\left(x^1\right)\right] - w_F\left(x^0\right) H_F\left(x^0\right) + \frac{1}{1+r}\cdot\left(\mathbb{E}\left[R_F\left(x^2\right)\right] - \sum_{x^1\in X^1}\xi(x^1) w_F\left(x^1\right) H_F\left(x^1\right)\right) + \\ &\sum_{t=0}^{1}\sum_{x^t\in X^t}\xi(x^t)\mu_F(x^t)\Big(C_F(x^t) - w_F\left(x^t\right) H_F\left(x^t\right)\Big) + \\ &\sum_{t=0}^{1}\sum_{x^t\in X^t}\xi(x^t)\nu_F(x^t)\Big(H(x^t) - H_F(x^t) - H_M\left(x^t\right)\Big) + \sum_{t=1}^{2}\sum_{x^t\in X^t}\xi(x^t)\gamma_F(x^t)\Big(C_F(x^{t-1}) + R_F(x^t) - C_F(x^t)\Big)\end{aligned}$$

The first order condition with respect to $H_F\left(x^{t-1}\right)$ for $t = 1, 2$ is

$$\begin{aligned}&\xi(x^{t-1})\left(\left(\frac{1}{1+r}\right)^{t-1} + \mu_F(x^{t-1})\right) w_F\left(x^{t-1}\right) + \xi(x^{t-1})\nu_F(x^{t-1}) = \left(\left(\frac{1}{1+r}\right)^{t-1} + \gamma_F(x^t)\right)(1-\theta_F)\, q_F'\left(H_F\left(x^{t-1}\right)\right) \\ &\cdot P\left(s_t = 1\right)\left(1 - q_M\left(H_M\left(x^{t-1}\right)\right)\right)\Big\{Q\left(z_t = 1\right)\max\{\Pi_0, \Pi\} + \left(1 - Q\left(z_t = 1\right)\right)\{\Pi_0 + \Pi\} - \Pi_0\Big\}\cdot\xi(x^{t-1})\end{aligned} \tag{30}$$

In addition, to characterize the Kuhn-Tucker conditions:

$$\begin{aligned}&[C_F(x^1)]: \xi(x^1)\mu_F(x^1) - \xi(x^1)\gamma_F(x^1) + \sum_{x^2\in X^2}\xi(x^2|x^1)\xi(x^1)\gamma_F(x^2) = 0 \\ &[C_F(x^2)]: \xi(x^2)\gamma_F(x^2) = 0\end{aligned}$$

7.1.3 Specialized Firm

The Lagrangian is given by

$$\begin{aligned}\mathcal{L}_M =&\mathbb{E}\left[R_M\left(x^1\right)\right] - w_M\left(x^0\right) H_M\left(x^0\right) + \frac{1}{1+r}\cdot\left(\mathbb{E}\left[R_M\left(x^2\right)\right] - \sum_{x^1\in X^1}\xi(x^1) w_M\left(x^1\right) H_M\left(x^1\right)\right) + \\ &\sum_{t=0}^{1}\sum_{x^t\in X^t}\xi(x^t)\mu_M(x^t)\Big(C_M(x^t) - w_M\left(x^t\right) H_M\left(x^t\right)\Big) + \\ &\sum_{t=0}^{1}\sum_{x^t\in X^t}\xi(x^t)\nu_M(x^t)\Big(H(x^t) - H_F(x^t) - H_M\left(x^t\right)\Big) + \sum_{t=1}^{2}\sum_{x^t\in X^t}\xi(x^t)\gamma_M(x^t)\Big(C_M(x^{t-1}) + R_M(x^t) - C_M(x^t)\Big)\end{aligned}$$

When $\Pi < \Pi_0$, the first order condition with respect to $H_M\left(x^{t-1}\right)$ is

$$\begin{aligned}&(1-\theta_M)\, P(s_t = 1)\, q_M'\left(H_M\left(x^{t-1}\right)\right)\cdot\left[1 - q_F\left(H_F\left(x^{t-1}\right)\right) + q_F\left(H_F\left(x^{t-1}\right)\right) Q(z_t = 1)\right]\cdot\xi(x^{t-1})\cdot\left(\left(\frac{1}{1+r}\right)^{t-1} + \gamma_M(x^t)\right)\Pi = \\ &\qquad\xi(x^{t-1})\cdot\left(\left(\left(\frac{1}{1+r}\right)^{t-1} + \mu_M\left(x^{t-1}\right)\right) w_M\left(x^{t-1}\right) + \nu_M\left(x^{t-1}\right)\right)\end{aligned} \tag{31}$$

When $\Pi > \Pi_0$, the first order condition with respect to $H_M\left(x^{t-1}\right)$ is

$$\begin{aligned}(1-\theta_M)\,P(s_t=1)\,q'_M\left(H_M\left(x^{t-1}\right)\right)\cdot\left[1-q_F\left(H_F\left(x^{t-1}\right)\right)\right]\cdot\xi(x^{t-1})\cdot\left(\left(\frac{1}{1+r}\right)^{t-1}+\gamma_M(x^t)\right)\Pi = \\ \xi(x^{t-1})\cdot\left(\left(\left(\frac{1}{1+r}\right)^{t-1}+\mu_M\left(x^{t-1}\right)\right)w_M\left(x^{t-1}\right)+\nu_M\left(x^{t-1}\right)\right)\end{aligned} \tag{32}$$

Interpretations: The left–hand side collects the marginal wage cost and the shadow cost (ν_F) of diverting one more unit of human capital to the firm, while the right–hand side is the discounted marginal increase in expected profits due to the higher project–success probability $q'_F(H_F)$.

7.1.4 Euler Equations

First, we can easily use (21) and (22) to derive intratemporal condition for type k talent:

$$\frac{u_1\left(c_0\left(x^t\right),c_1\left(x^t\right)\right)}{u_2\left(c_0\left(x^t\right),c_1\left(x^t\right)\right)}=\frac{p_0\left(x^t\right)}{p_1\left(x^t\right)},\qquad t\in\{0,1,2\} \tag{33}$$

and using (23) and (24), the intertemporal conditions are

$$\frac{\lambda_1\left(x^0\right)}{\lambda_1\left(x^1\right)}=\frac{\xi(x^1)}{p_b(x^1)}=\frac{u_1\left(c_0\left(x^0\right),c_1\left(x^0\right)\right)}{\beta u_1\left(c_0\left(x^1\right),c_1\left(x^1\right)\right)}\cdot\frac{p_0\left(x^1\right)}{p_0\left(x^0\right)}=\frac{u_2\left(c_0\left(x^0\right),c_1\left(x^0\right)\right)}{\beta u_2\left(c_0\left(x^1\right),c_1\left(x^1\right)\right)}\cdot\frac{p_1\left(x^1\right)}{p_1\left(x^0\right)} \tag{34}$$

$$\frac{\lambda_1\left(x^1\right)}{\lambda_1\left(x^2\right)}=\frac{\xi(x^2|x^1)}{p_b(x^2)}=\frac{u_1\left(c_0\left(x^1\right),c_1\left(x^1\right)\right)}{\beta u_1\left(c_0\left(x^2\right),c_1\left(x^2\right)\right)}\cdot\frac{p_0\left(x^2\right)}{p_0\left(x^1\right)}=\frac{u_2\left(c_0\left(x^1\right),c_1\left(x^1\right)\right)}{\beta u_2\left(c_0\left(x^2\right),c_1\left(x^2\right)\right)}\cdot\frac{p_1\left(x^2\right)}{p_1\left(x^1\right)} \tag{35}$$

Define

$$\phi\left(x^0,x^1\right)\equiv\frac{\lambda_1\left(x^1\right)}{\lambda_1\left(x^0\right)}\text{ and }\psi\left(x^1,x^2\right)\equiv\frac{\lambda_1\left(x^2\right)}{\lambda_1\left(x^1\right)}$$

By equating (25) and (27), we can derive the marginal condition for period-0 human-capital allocation between firms, $\forall x^0,x^1$,

$$\begin{aligned}\lambda_1(x^0)\,w_F(x^0)\;+\;\sum_{x^1\in X^1}\lambda_1(x^1)\,\xi(x^1)\,\frac{\theta_F\,\Pi_F(x^1)}{H_F(x^0)}\;+\;\sum_{x^1\in X^{1a}}\lambda_2(x^1)\,\xi(x^1)\,g'_F\big(h_F(x^0)\big)= \\ \lambda_1(x^0)\,w_M\big(x^0\big)\;+\;\sum_{x^1\in X^1}\lambda_1(x^1)\,\xi(x^1)\,\frac{\theta_M\,\Pi_M\big(x^1\big)}{H_M(x^0)}\;+\;\sum_{x^1\in X^1}\lambda_2(x^1)\,\xi(x^1)\,g'_M\big(h_M\big(x^0\big)\big)\end{aligned} \tag{36}$$

From the FOC (29), we also know that $\lambda_2\left(x^1\right)=\lambda_3\left(x^1\right)$ such that (26) and (28) can be rewritten as

$$\lambda_2(x^1)=\lambda_1(x^1)\,w_F(x^1)\;+\;\sum_{x^2\in X^2}\lambda_1(x^2)\,\xi\left(x^2|x^1\right)\,\frac{\theta_F\,\Pi_F(x^2)}{H_F(x^1)} \tag{37}$$

, which is essentially the shadow value of human capital at $t = 1$, and the shadow value inside the specialized firm:

$$\lambda_2(x^1) = \lambda_1(x^1)\, w_M\big(x^1\big) \;+\; \sum_{x^2 \in X^2} \lambda_1(x^2)\, \xi\left(x^2|x^1\right)\, \frac{\theta_M\, \Pi_M\big(x^2\big)}{H_M(x^1)} \tag{38}$$

Equating (37) and (38) generates the first trade-off between period 1 and period 2 (LHS and RHS of the equation is the marginal return of investing more human capital (wage and expected equity would equal)), which is Euler trade-off within period 1 of the large firm vs. specialized firm:

$$w_F(x^1) \;+\; \sum_{x^2 \in X^2} \psi\left(x^1, x^2\right)\, \xi\left(x^2|x^1\right)\, \frac{\theta_F\, \Pi_F(x^2)}{H_F(x^1)} = w_M\big(x^1\big) \;+\; \sum_{x^2 \in X^2} \psi\left(x^1, x^2\right)\, \xi\left(x^2|x^1\right)\, \frac{\theta_M\, \Pi_M\big(x^2\big)}{H_M(x^1)} \tag{39}$$

This equation simply covers the marginal pecuniary return from sending the next unit of human-capital time to the large incumbent firm F with the return from sending it to the specialized firm M once period 2 is terminal and no further learning can occur.

Recall that $\psi\left(x^1, x^2\right)$ is the intertemporal discount factor, the ratio of marginal utilities, adjusted by the exogenous goods-price path. Because period 2 is the terminal stage of the model, no additional human-capital accumulation takes place there. Hence, the marginal-accumulation terms $g'_F(\cdot)$ and $g'_M(\cdot)$ vanish, and 39 reduces to a comparison of purely pecuniary returns, the current wage plus the discounted expected equity payoff across the two types of firms. With this interpretation in hand, we now substitute (37) and (38) back into (36) to derive the Euler trade-off between period 0 and period 1.

$$\begin{aligned}
&\frac{u_1\left(c_0\left(x^0\right), c_1\left(x^0\right)\right)}{p_0(x^0)} \cdot w_F(x^0) \;+\; \sum_{x^1 \in X^1} \frac{\beta u_1\left(c_0\left(x^1\right), c_1\left(x^1\right)\right)}{p_0(x^1)} \cdot \xi(x^1) \cdot \frac{\theta_F\, \Pi_F(x^1)}{H_F(x^0)} + \\
&\sum_{x^1 \in X^{1a}} \left(\frac{\beta u_1\left(c_0\left(x^1\right), c_1\left(x^1\right)\right)}{p_0\left(x^1\right)} w_F(x^1) \;+\; \sum_{x^2 \in X^2} \frac{\beta^2 u_1\left(c_0\left(x^2\right), c_1\left(x^2\right)\right)}{p_0\left(x^2\right)} \xi\left(x^2|x^1\right)\, \frac{\theta_F\, \Pi_F(x^2)}{H_F(x^1)} \right) \xi(x^1)\, g'_F\big(h_F(x^0)\big) = \\
&\frac{u_1\left(c_0\left(x^0\right), c_1\left(x^0\right)\right)}{p_0\left(x^0\right)} \cdot w_M\big(x^0\big) \;+\; \sum_{x^1 \in X^1} \frac{\beta u_1\left(c_0\left(x^1\right), c_1\left(x^1\right)\right)}{p_0\left(x^1\right)} \cdot \xi(x^1) \cdot \frac{\theta_M\, \Pi_M\big(x^1\big)}{H_M(x^0)} + \\
&\sum_{x^1 \in X^1} \left(\frac{\beta u_1\left(c_0\left(x^1\right), c_1\left(x^1\right)\right)}{p_0\left(x^1\right)} w_M\big(x^1\big) \;+\; \sum_{x^2 \in X^2} \frac{\beta^2 u_1\left(c_0\left(x^2\right), c_1\left(x^2\right)\right)}{p_0\left(x^2\right)} \xi\left(x^2|x^1\right)\, \frac{\theta_M\, \Pi_M\big(x^2\big)}{H_M(x^1)} \right) \xi(x^1)\, g'_M\big(h_M\big(x^0\big)\big)
\end{aligned} \tag{40}$$

Equation (40) forces the representative worker to be exactly indifferent (considering both immediate pecuniary return, including cash and near-term equity compensation, and learning-induced payoff) at the margin between sending one extra unit of her period-0 effort (or "raw human capital") to the incumbent firm F versus the specialist entrant M.

7.2 Period 1

7.2.1 Easiest Attempt (with some additional assumptions imposed)

Assume that for all t, $\nu_F(x^{t-1}) = \nu_M(x^{t-1}) = 0$ (not restricted by human capital endowment) and $\mu_M(x^t) = \mu_F(x^t) = 0$ (not restricted by liquidity constraint). Also, assume $\Pi > \Pi_0$. Then, we have

$$w_F(x^t) = (1-\theta_F)\, P\left(s_t = 1\right) q_F'\left(H_F\left(x^{t-1}\right)\right)\left[1 - q_M\left(H_M\left(x^{t-1}\right)\right)\right]\left\{\Pi - Q(z_t = 1)\Pi_0\right\} \tag{41}$$

and

$$w_M(x^t) = (1-\theta_M)\, P(s_t = 1)\, q_M'\left(H_M\left(x^{t-1}\right)\right)\left[1 - q_F\left(H_F\left(x^{t-1}\right)\right)\right]\Pi \tag{42}$$

Assume pricing normalization $\psi(x^1, x^2) = 1 \iff \frac{\xi(x^2|x^1)}{p_b(x^2)} = \frac{u_1(x^1)}{\beta u_1(x^2)} \cdot \frac{p_0(x^2)}{p_0(x^1)} = 1$.

Plugging in $h_F(x^t) = H_F(x^t)$ and $h_M(x^t) = H_M(x^t)\ \forall t$ in (39) yields

$$\begin{aligned}
&(1-\theta_F)\, P\left(s_2 = 1\right) q_F'\left(H_F\left(x^1\right)\right)\left[1 - q_M\left(H_M\left(x^1\right)\right)\right]\left\{\Pi - Q(z_2 = 1)\Pi_0\right\} + \\
&\qquad \frac{\theta_F}{H_F(x^1)}\Big\{P\left(s_2 = 1\right) Q\left(z_2 = 1\right) q_F\left(H_F\left(x^1\right)\right)\left(1 - q_M\left(H_M\left(x^1\right)\right)\right)\max\{\Pi_0, \Pi\} + \\
&\qquad\qquad P\left(s_2 = 1\right)\left(1 - Q\left(z_2 = 1\right)\right) q_F\left(H_F\left(x^1\right)\right)\left(1 - q_M\left(H_M\left(x^1\right)\right)\right)\{\Pi_0 + \Pi\} + \\
&\qquad\qquad \left(1 - P\left(s_2 = 1\right) q_F\left(H_F\left(x^1\right)\right)\left(1 - q_M\left(H_M\left(x^1\right)\right)\right)\right)\Pi_0\Big\} = \\
&(1-\theta_M)\, P(s_2 = 1)\, q_M'\left(H_M\left(x^1\right)\right)\left[1 - q_F\left(H_F\left(x^1\right)\right)\right]\Pi + \\
&\qquad \frac{\theta_M}{H_M(x^1)}\Big\{P\left(s_2 = 1\right) q_M\left(H_M\left(x^1\right)\right)\left(1 - q_F\left(H_F\left(x^1\right)\right)\right)\Pi\Big\}
\end{aligned} \tag{43}$$

By taking the maximum, this can be reduced to

$$\begin{aligned}
&(1-\theta_F)\, P\left(s_2 = 1\right) q_F'\left(H_F\left(x^1\right)\right)\left[1 - q_M\left(H_M\left(x^1\right)\right)\right]\left\{\Pi - Q(z_2 = 1)\Pi_0\right\} + \\
&\frac{\theta_F}{H_F(x^1)}\Big\{\left(1 - P\left(s_2 = 1\right) Q(z_2 = 1) q_F\left(H_F\left(x^1\right)\right)\left(1 - q_M\left(H_M\left(x^1\right)\right)\right)\right)\Pi_0 + P\left(s_2 = 1\right) q_F\left(H_F\left(x^1\right)\right)\left(1 - q_M\left(H_M\left(x^1\right)\right)\right)\Pi\Big\} \\
&= (1-\theta_M)\, P(s_2 = 1)\, q_M'\left(H_M\left(x^1\right)\right)\left[1 - q_F\left(H_F\left(x^1\right)\right)\right]\Pi + \frac{\theta_M}{H_M(x^1)}\Big\{P\left(s_2 = 1\right) q_M\left(H_M\left(x^1\right)\right)\left(1 - q_F\left(H_F\left(x^1\right)\right)\right)\Pi\Big\}
\end{aligned} \tag{44}$$

7.3 Period 0

Similarly, we further assume $\psi(x^1, x^2) = 1$, $\forall x^1, x^2$, which essentially means

$$\frac{\xi(x^2|x^1)}{p_b(x^2)} = \frac{u_1\left(c_0\left(x^1\right), c_1\left(x^1\right)\right)}{\beta u_1\left(c_0\left(x^2\right), c_1\left(x^2\right)\right)} \cdot \frac{p_0\left(x^2\right)}{p_0\left(x^1\right)} = \frac{u_2\left(c_0\left(x^1\right), c_1\left(x^1\right)\right)}{\beta u_2\left(c_0\left(x^2\right), c_1\left(x^2\right)\right)} \cdot \frac{p_1\left(x^2\right)}{p_1\left(x^1\right)} = 1 \tag{45}$$

Further assume $\phi(x^0, x^1) = 1$, $\forall x^0, x^1$.

$$\frac{\xi(x^1)}{p_b(x^1)} = \frac{u_1\left(c_0\left(x^0\right), c_1\left(x^0\right)\right)}{\beta u_1\left(c_0\left(x^1\right), c_1\left(x^1\right)\right)} \cdot \frac{p_0\left(x^1\right)}{p_0\left(x^0\right)} = \frac{u_2\left(c_0\left(x^0\right), c_1\left(x^0\right)\right)}{\beta u_2\left(c_0\left(x^1\right), c_1\left(x^1\right)\right)} \cdot \frac{p_1\left(x^1\right)}{p_1\left(x^0\right)} = 1 \tag{46}$$

We can rewrite (40) as

$$\begin{aligned}
&\frac{u_1\left(c_0\left(x^0\right), c_1\left(x^0\right)\right)}{p_0(x^0)} \cdot \left(w_F(x^0) \; + \sum_{x^1 \in X^1} \xi(x^1) \cdot \frac{\theta_F \, \Pi_F(x^1)}{H_F(x^0)} \right) + \\
&\sum_{x^1 \in X^{1a}} \left(\frac{\beta u_1\left(c_0\left(x^1\right), c_1\left(x^1\right)\right)}{p_0\left(x^1\right)} w_F(x^1) \; + \sum_{x^2 \in X^2} \frac{\beta^2 u_1\left(c_0\left(x^2\right), c_1\left(x^2\right)\right)}{p_0\left(x^2\right)} \xi\left(x^2 | x^1\right) \; \frac{\theta_F \, \Pi_F(x^2)}{H_F(x^1)} \right) \xi(x^1) \, g_F'\big(h_F(x^0)\big) = \\
&\frac{u_1\left(c_0\left(x^0\right), c_1\left(x^0\right)\right)}{p_0\left(x^0\right)} \cdot \, w_M\big(x^0\big) \; + \sum_{x^1 \in X^1} \frac{\beta u_1\left(c_0\left(x^1\right), c_1\left(x^1\right)\right)}{p_0\left(x^1\right)} \cdot \xi(x^1) \cdot \, \frac{\theta_M \, \Pi_M\big(x^1\big)}{H_M(x^0)} + \\
&\sum_{x^1 \in X^1} \left(\frac{\beta u_1\left(c_0\left(x^1\right), c_1\left(x^1\right)\right)}{p_0\left(x^1\right)} w_M\big(x^1\big) \; + \sum_{x^2 \in X^2} \frac{\beta^2 u_1\left(c_0\left(x^2\right), c_1\left(x^2\right)\right)}{p_0\left(x^2\right)} \xi\left(x^2 | x^1\right) \; \frac{\theta_M \, \Pi_M\big(x^2\big)}{H_M\big(x^1\big)} \right) \xi(x^1) \, g_M'\big(h_M\big(x^0\big)\big)
\end{aligned} \tag{47}$$

8 Social Planner Equilibrium

8.1 Period 1

Let X^{tas} be the set that has human capital accumulated in the large firm in the context of social planner (the history of the world up to calendar date), that is, technology is commercializable and developed successfully in the large firm (i.e. When the human capital is accumulated in the large firm, the corresponding final product is necessarily developed there). The Lagrangian of this problem is

$$\begin{aligned}
\mathcal{L}_s = &\sum_{t=0}^{2} \sum_{x^t \in X^t} \beta^t \xi(x^t) u\left(c_0\left(x^t\right), c_1\left(x^t\right)\right) + \sum_{t=0}^{2} \sum_{\omega=0}^{1} \sum_{x^t \in X^t} \mu_{s,\omega}(x^t) \xi(x^t) \left(y_\omega(x^t) - c_\omega(x^t)\right) + \\
&\sum_{x^1 \in X^1} \lambda_s(x^1) \xi(x^1) \Big((1-\delta_h) H\left(x^0\right) + g_M\left(H_M\left(x^0\right)\right) - H(x^1) \Big) + \sum_{x^1 \in X^{1as}} \lambda_s(x^1) \xi(x^1) g_F\left(H_F\left(x^0\right)\right) + \\
&\sum_{t=0}^{1} \sum_{x^t \in X^t} \nu_s(x^t) \xi(x^t) \left(H\left(x^t\right) - H_F\left(x^t\right) - H_M\left(x^t\right)\right)
\end{aligned}$$

The first order conditions are

$$[c_0(x^t)] : \beta^t \xi(x^t) u_1\left(c_0\left(x^t\right), c_1\left(x^t\right)\right) - \mu_{s,0}(x^t) \xi(x^t) = 0 \tag{48}$$

$$[c_1(x^t)] : \beta^t \xi(x^t) u_2\left(c_0\left(x^t\right), c_1\left(x^t\right)\right) - \mu_{s,1}(x^t) \xi(x^t) = 0 \tag{49}$$

Using (48) and (49), the intratemporal condition is, $\forall t, x^t$,

$$\frac{u_1\left(c_0\left(x^t\right), c_1\left(x^t\right)\right)}{u_2\left(c_0\left(x^t\right), c_1\left(x^t\right)\right)} = \frac{\mu_{s,0}(x^t)}{\mu_{s,1}(x^t)} \tag{50}$$

Notice that $y_w(x^t)$ is a binary result, where consumers have nothing to consume or consumers consume y_ω^{comp} because utility is monotone increasing. Since there is no cannibalization in the social planner problem, the line of stable income will always produce at the social optimal level $y_0(x^t)$. Also, for $\omega = 1$, $y_1(x^t) = y_1^{comp}$ happens with the probability

$$\mathcal{P}_{t,socialeq} = P(s_t = 1)\left(1 - \left(1 - q_F\left(H_F\left(x^{t-1}\right)\right)\right)\left(1 - q_M\left(H_M\left(x^{t-1}\right)\right)\right)\right)$$

Also, recall that

$$\xi\left(x^t | x^{t-1}\right) = P(s_{t,0})Q(z_t)q_F\left(H_F\left(x^{t-1}\right)\right)q_M\left(H_M\left(x^{t-1}\right)\right)$$

where $Q(z_t = 0) = 1$ in the social planner problem. Since the utility is monotone increasing in both consumptions and the probability of success is monotone increasing in human capital, all the constraints should be binding, and thus, terms $\left[\frac{\partial \xi(x^t)}{\partial H} \cdot (\text{constraints})\right]$ will be omitted. (Note that $H_F(x^1)$ and $H_M(x^1)$ only affect the objective only through success probabilities.) Thus

$$[H_F(x^1)] : \beta^2 \sum_{x^2 \in X^2} \frac{\partial \xi(x^2|x^1)}{\partial H_F(x^1)} \cdot u\left(c_0\left(x^2\right), c_1\left(x^2\right)\right) - \nu_s(x^1)\xi(x^1) = 0$$

which is equivalent to

$$[H_F(x^1)] : \beta^2\left(\frac{\partial \mathcal{P}_{2,socialeq}}{\partial H_F(x^1)} \cdot u\left(y_0^{comp}, 0\right) + \frac{\partial\left(1 - \mathcal{P}_{2,socialeq}\right)}{\partial H_F(x^1)} \cdot u\left(y_0^{comp}, y_1^{comp}\right)\right) = \nu_s(x^1)\xi(x^1) \tag{51}$$

By symmetry, we can also easily obtain

$$[H_M(x^1)] : \beta^2\left(\frac{\partial \mathcal{P}_{2,socialeq}}{\partial H_M(x^1)} \cdot u\left(y_0^{comp}, 0\right) + \frac{\partial\left(1 - \mathcal{P}_{2,socialeq}\right)}{\partial H_M(x^1)} \cdot u\left(y_0^{comp}, y_1^{comp}\right)\right) = \nu_s(x^1)\xi(x^1) \tag{52}$$

This implies that in period 1, the social planner would choose $\{H_F(x^1), H_M(x^1)\}$ such that

$$\frac{\partial \mathcal{P}_{2,socialeq}}{\partial H_F(x^1)} \cdot u\left(y_0^{comp}, 0\right) + \frac{\partial\left(1 - \mathcal{P}_{2,socialeq}\right)}{\partial H_F(x^1)} \cdot u\left(y_0^{comp}, y_1^{comp}\right) = \frac{\partial \mathcal{P}_{2,socialeq}}{\partial H_M(x^1)} \cdot u\left(y_0^{comp}, 0\right) + \frac{\partial\left(1 - \mathcal{P}_{2,socialeq}\right)}{\partial H_M(x^1)} \cdot u\left(y_0^{comp}, y_1^{comp}\right) \tag{53}$$

which can be reduced to

$$q_F'\left(H_F(x^1)\right)\left(1 - q_M\left(H_M(x^1)\right)\right) = q_M'\left(H_M(x^1)\right)\left(1 - q_F\left(H_F(x^1)\right)\right) \tag{54}$$

The economic meaning here, in period 1, is to allocate an extra unit of human capital to the large firm until the expected incremental success gain from doing so equals that of sending it to the medium firm.

Rearrange

$$\frac{q_F'\left(H_F\right)}{1-q_F\left(H_F\right)}=\frac{q_M'\left(H_M\right)}{1-q_M\left(H_M\right)} \quad \Longrightarrow \quad \frac{d}{dH_F}\left[-\ln\left(1-q_F\left(H_F\right)\right)\right]=\frac{d}{dH_F}\left[-\ln\left(1-q_M\left(H-H_F\right)\right)\right].$$

Hence

$$-\ln\left(1-q_F\left(H_F\right)\right)=-\ln\left(1-q_M\left(H-H_F\right)\right)\Longrightarrow 1-q_F\left(H_F\right)=1-q_M\left(H-H_F\right),$$

so that

$$q_F\left(H_F\left(x^1\right)\right)=q_M\left(H\left(x^1\right)-H_F\left(x^1\right)\right).$$

Plugging in the human capital clearing condition generates the closed form solution for human capital conditional on the total endowment of human capital.

8.2 Period 0

The first order condition with respect to $H(x^1)$ is

$$[H(x^1)]:\lambda_s(x^1)\xi(x^1)=\nu_s(x^1)\xi(x^1) \tag{55}$$

such that $\lambda_s(x^t)\xi(x^1)$ are given by the LHS of (51) and (52). Define

$$\begin{aligned}\lambda_s(x^1)\xi(x^1)&\equiv h\left(H_F(x^0),H_M(x^0),H_F(x^1),H_M(x^1)\right)\\&=\beta^2\left(\frac{\partial\mathcal{P}_{2,socialeq}}{\partial H_F(x^1)}\cdot u\left(y_0^{comp},0\right)+\frac{\partial\left(1-\mathcal{P}_{2,socialeq}\right)}{\partial H_F(x^1)}\cdot u\left(y_0^{comp},y_1^{comp}\right)\right)\\&=\beta^2\left(\frac{\partial\mathcal{P}_{2,socialeq}}{\partial H_M(x^1)}\cdot u\left(y_0^{comp},0\right)+\frac{\partial\left(1-\mathcal{P}_{2,socialeq}\right)}{\partial H_M(x^1)}\cdot u\left(y_0^{comp},y_1^{comp}\right)\right)\end{aligned} \tag{56}$$

Recall that, for every state $x^1\in X^{1as}$, the human-capital stock built up in period 0 is fully preserved; therefore the talent enters each of these states with the same total human-capital endowment. That implies the talent should allocate the same amount of human capital in the large firm and the specialized firm in each state, following the closed-form solution. The same conclusion applies to every state $x^1\in X^1\backslash X^{1ns}$.

Define H^a as the first-period human capital when period-0 investment is accumulated in the large firm and H^n when it is not. In equilibrium, for each state k, the talent allocates amounts H_i^a and H_i^n across $i\in\{F,M\}$ such that $H_F^a+H_M^a=H^a$, $H_F^n+H_M^n=H^n$, and (54) are satisfied. Specifically, we have

$$H^a=(1-\delta_h)H(x^0)+g_M(H_M(x^0))+g_F(H_F(x^0))$$

and

$$H^n=(1-\delta_h)H(x^0)+g_M(H_M(x^0))$$

The first order condition with respect to $H_F(x^0)$ is

$$[H_F(x^0)] : \beta \sum_{x^1 \in X^1} \frac{\partial \xi(x^1)}{\partial H_F(x^0)} \cdot u\left(c_0\left(x^1\right), c_1\left(x^1\right)\right) - \sum_{x^1 \in X^{1as}} \lambda_s(x^1)\xi(x^1) g'_F\left(H_F(x^0)\right) - \nu_s(x^0) = 0 \quad (57)$$

Since there are 4 binary states, there are 16 realizations, and among them human capital of type k is accumulated in exactly $16/4 = 4$ of them – the ones with $s_1 = 1, n_{1,F} = 1$. For all $x^1 \in X^{1as}$,

$$\lambda_s(x^1)\xi(x^1) = h\left(H_F(x^0), H_M(x^0), H_F^a, H_M^a\right)$$

Thus, $[H_F(x^0)]$ is equivalent to

$$4h\left(H_F(x^0), H_M(x^0), H_F^a, H_M^a\right) g'_F(H_F(x^0)) + \nu_s(x^0) = \beta\left(\frac{\partial \mathcal{P}_{1,socialeq}}{\partial H_F(x^1)} \cdot u\left(y_0^{comp}, 0\right) + \frac{\partial\left(1 - \mathcal{P}_{1,socialeq}\right)}{\partial H_F(x^1)} \cdot u\left(y_0^{comp}, y_1^{comp}\right)\right) \quad (58)$$

By symmetry, the first order condition with respect to $H_M(x^0)$ is

$$[H_M(x^0)] : \beta \sum_{x^1 \in X^1} \frac{\partial \xi(x^1)}{\partial H_M(x^0)} \cdot u\left(c_0\left(x^1\right), c_1\left(x^1\right)\right) - \sum_{x^1 \in X^1} \lambda_s(x^1)\xi(x^1) g'_M\left(H_M(x^0)\right) - \nu_s(x^0) = 0 \quad (59)$$

which is equivalent to

$$4h\left(H_F(x^0), H_M(x^0), H_F^a, H_M^a\right) g'_M(H_M(x^0)) + 12h\left(H_F(x^0), H_M(x^0), H_F^n, H_M^n\right) g'_M(H_M(x^0)) + \nu_s(x^0) = \beta\left(\frac{\partial \mathcal{P}_{1,socialeq}}{\partial H_M(x^1)} \cdot u\left(y_0^{comp}, 0\right) + \frac{\partial\left(1 - \mathcal{P}_{1,socialeq}\right)}{\partial H_M(x^1)} \cdot u\left(y_0^{comp}, y_1^{comp}\right)\right) \quad (60)$$

The LHS captures the marginal resource cost of allocating one more unit of period-0 human capital to the small/specialized firm M. The cost $g'_M(H_M(x^0))$ is incurred in all future states and weighted by the corresponding shadow values $h(\cdot)$: 4 states with accumulation ($s_1 = 1, n_{1,F} = 1$) contribute $4h_a$, and 12 other states without accumulation contribute $12h_n$. The term $\nu_s(x^0)$ reflects the shadow value of the aggregate human-capital constraint in period 0. The RHS is the discounted expected marginal utility gain that one extra unit of $H_M(x^0)$ delivers in period 1, working only through how it shifts the success probability $\mathcal{P}_{1,socialeq}$. The first derivative multiplies the utility vector $(y_0^{comp}, 0)$, the "bad-outcome" consumption bundle, whereas the second derivative multiplies (y_0^{comp}, y_1^{comp}), the "good-outcome" bundle.

The economic meaning here is to invest in firm M up to the point where the discounted, state-contingent utility gain from nudging the period-1 success probability is exactly offset by the present-period resource cost of creating that extra unit of human capital.

This leads to the allocation rules in the period 0, where simply the LHS is the difference in marginal

resource cost and RHS is the difference in marginal utility benefit.

$$4h\left(H_F(x^0), H_M(x^0), H_F^a, H_M^a\right)\left(g'_M(H_M(x^0)) - g'_F(H_F(x^0))\right) + 12h\left(H_F(x^0), H_M(x^0), H_F^n, H_M^n\right) g'_M(H_M(x^0)) =$$
$$\beta\left(\left(\frac{\partial \mathcal{P}_{1,socialeq}}{\partial H_M(x^1)} - \frac{\partial \mathcal{P}_{1,socialeq}}{\partial H_F(x^1)}\right)\cdot u\left(y_0^{comp}, 0\right) + \left(\frac{\partial\left(1-\mathcal{P}_{1,socialeq}\right)}{\partial H_M(x^1)} - \frac{\partial\left(1-\mathcal{P}_{1,socialeq}\right)}{\partial H_F(x^1)}\right)\cdot u\left(y_0^{comp}, y_1^{comp}\right)\right) \tag{61}$$

If increasing H_M raises the success probability more than increasing H_F does (RHS positive), the planner will re-allocate talent toward M until its marginal resource cost premium on the LHS catches up. If $g'_M > g'_F$ everywhere, the specialized research firm M must deliver correspondingly larger probability gains to justify any allocation there. So (58) and (60) pin down the absolute optimal scale of investment in the large firm F and specialized research firm M, respectively; while (61) delivers the relative allocation rule between the specialized research firm M and the large firm F.

9 Analytical Solution

We assume the probability of successfully developing the technology is linear with human capital, which means each extra unit of R&D human-capital raises the project's chance of succeeding by a constant amount, i.e., assume

$$q_F(h) = \varphi_F\, h, \qquad q_M(h) = \varphi_M\, h, \qquad q'_F(h) = \varphi_F, \qquad q'_M(h) = \varphi_M.$$

valid on the domain $0 \le h \le 1/\varphi_k$ so that every probability stays in $[0,1]$. Also, assume

$$g_F(h) = \alpha_F h, \qquad g_M(h) = \alpha_M h,$$

9.1 Competitive Equilibrium

9.1.1 Period 1

Insert q_F, q_M (and their derivatives) into the single first-order condition

$$(1-\theta_F)\,P(s_2=1)\,\varphi_F\,\Big[1-\varphi_M\,H_M(x^1)\Big]\,\Big[\Pi - Q(z_2=1)\,\Pi_0\Big] +$$
$$\frac{\theta_F}{H_F(x^1)}\Big\{\Big[1-P(s_2=1)\,Q(z_2=1)\,\varphi_F H_F(x^1)\big[1-\varphi_M H_M(x^1)\big]\Big]\Pi_0 + P(s_2=1)\,\varphi_F H_F(x^1)\big[1-\varphi_M H_M(x^1)\big]\Pi\Big\}$$
$$= (1-\theta_M)P(s_2=1)\,\varphi_M\,\big[1-\varphi_F H_F(x^1)\big]\Pi + \frac{\theta_M}{H_M(x^1)}\Big\{P(s_2=1)\,\varphi_M H_M(x^1)\big[1-\varphi_F H_F(x^1)\big]\Pi\Big\}.$$

Substitute $H_M(x^1) = H(x^1) - H_F(x^1)$. Define for brevity $H \equiv H(x^1)$ (a constant) and $h \equiv H_F(x^1)$. Write $S \equiv 1 - \varphi_M\big[H-h\big] = 1 - \varphi_M H + \varphi_M h$. The FOC becomes

$$h(1-\theta_F)P\varphi_F\,S\big[\Pi - Q(z_2=1)\Pi_0\big] + \theta_F\Big\{\big[1-PQ(z_2=1)\varphi_F hS\big]\Pi_0 + P\varphi_F hS\Pi\Big\} = (1-\theta_M)hP\varphi_M\big[1-\varphi_F h\big]\Pi.$$

Multiply out and collect powers of h:

$$A_2\,h^2 + B_1\,h + C_0 = 0,$$

with

$$A_2 = -\,P\,Q(z_2 = 1)\,\Pi_0\,\varphi_F\,\varphi_M,$$

$$B_1 = P\,\varphi_F\big(1 - \varphi_M H\big)\big[\Pi - Q(z_2 = 1)\,\Pi_0\big] - (1 - \theta_M)P\,\varphi_M\,\Pi,$$

$$C_0 = \theta_F\,\Pi_0.$$

Then, the allocation rules are

$$H_F(x^1) = \frac{-\,B_1 + \sqrt{B_1^2 - 4A_2C_0}}{2A_2},$$

$$H_M(x^1) = H(x^1) - H_F(x^1).$$

Use the + root so that $H_F(x^1) \geq 0$. Feasibility further requires $0 \leq \varphi_F H_F(x^1) \leq 1$ and $0 \leq \varphi_M H_M(x^1) \leq 1$.

9.2 Social Planner Equilibrium

9.2.1 Period 1

With linear probability function, (54) becomes

$$\varphi_F\big(1 - \varphi_M H_M(x^1)\big) = \varphi_M\big(1 - \varphi_F H_F(x^1)\big).$$

Using $H_F(x^1) + H_M(x^1) = H(x^1)$ and solving for $H_F(x^1)$ yields the unique interior allocation

$$H_F(x^1) = \frac{H(x^1)}{2} - \frac{\varphi_F - \varphi_M}{2\varphi_F\varphi_M}, \qquad H_M(x^1) = \frac{H(x^1)}{2} + \frac{\varphi_F - \varphi_M}{2\varphi_F\varphi_M}.$$

where symmetric arrival rates ($\varphi_F = \varphi_M$) give the intuitive 50–50 split $H_F = H_M = H/2$.

9.2.2 Period 0

With linear probability function, the multiplier that appears in

$$\lambda_s(x^1)\xi(x^1) = \beta^2 P_s\,\Delta u\,\underbrace{\Big[\varphi_F - \varphi_F\varphi_M H_M(x^1)\Big]}_{\partial_{H_F}\mathcal{P}_{2,\text{social}}}$$

collapses to an affine function of $H_M(x^1)$; the exponential terms in the original draft disappear entirely. Denote $\Delta u \equiv u(y_0^{\text{comp}}, 0) - u(y_0^{\text{comp}}, y_1^{\text{comp}}) > 0$. Then,

$$h^a = \beta^2 P_s \Delta u\,\Big[\varphi_F - \varphi_F\varphi_M H_M^a\Big], \qquad h^n = \beta^2 P_s \Delta u\,\Big[\varphi_F - \varphi_F\varphi_M H_M^n\Big],$$

where H_M^a and H_M^n are the period-1 M-firm stocks in the accumulating and non-accumulating states, computed with the split above and the two different totals

$$H^a = (1-\delta_h)H^0 + \alpha_F H_F^0 + \alpha_M H_M^0, \qquad H^n = (1-\delta_h)H^0 + \alpha_M H_M^0.$$

Keep linear training technologies $g_F(h) = \alpha_F h$, $g_M(h) = \alpha_M h$ and write $H_M^0 = H^0 - s$. With the algebra spelled out in the margin notes, the scalar condition is

$$4h^a\big(\alpha_M - \alpha_F\big) \;+\; 12h^n\alpha_M \;=\; \beta P_s \Delta u\Big[(\varphi_M - \varphi_F) + \varphi_F\varphi_M\big(H^0 - 2s\big)\Big].$$

Because h^a and h^n are now linear in the choice variables, (LH-FOC) is a polynomial equation rather than a transcendental one.

If training productivities are the same ($\alpha_F = \alpha_M \equiv \alpha$), the first term on the left of (LH-FOC) vanishes and the condition is linear in s. Solving gives

$$H_F^{0*} = \frac{6\beta\alpha^2 H^0\varphi_F\varphi_M - 6\beta\alpha\delta_h H^0\varphi_F\varphi_M + 6\beta\alpha H^0\varphi_F\varphi_M - 6\beta\alpha(\varphi_F+\varphi_M) - \varphi_F + \varphi_M + H^0\varphi_F\varphi_M}{2\varphi_F\varphi_M\big(3\beta\alpha^2+1\big)}.$$

The denominator $2\varphi_F\varphi_M(3\beta\alpha^2+1)$ is strictly positive, so the solution is unique whenever $0 < \varphi_k H_i^0 \le 1$.

10 Comparative Statics

10.1 Period 1 (No Human Capital Accumulation)

With the linear success technologies

$$q_F(h) = \varphi_F h, \qquad q_M(h) = \varphi_M h,$$

the single first-order condition in period 1 collapses to the quadratic

$$A_2 h^2 + B_1 h + C_0 = 0, \qquad h \equiv H_F(x^1), \quad H_M(x^1) = H - h,$$

where

$$\begin{aligned} A_2 &= -\,P\,Q\,\Pi_0\,\varphi_F\varphi_M, \\ B_1 &= P\Big[\,\varphi_F\big(1-\varphi_M H\big)\underbrace{\big(\Pi - Q\Pi_0\big)}_{\Delta\Pi} \;-\; (1-\theta_M)\,\varphi_M\Pi\Big], \\ C_0 &= \theta_F\,\Pi_0. \end{aligned}$$

All parameters are positive (profits, probabilities, productivities) and $\theta_F, \theta_M \in (0,1)$.

Divide through by $-A_2 > 0$:

$$h^2 - \beta\, h - \gamma = 0, \qquad \beta \equiv \frac{B_1}{-A_2},\ \gamma \equiv \frac{C_0}{-A_2},$$

such that

$$\beta = \frac{\varphi_F\big(1 - \varphi_M H\big)\,\Delta\Pi - (1-\theta_M)\varphi_M \Pi}{Q\Pi_0\,\varphi_F\varphi_M},$$

$$\gamma = \frac{\theta_F}{P\,Q\,\varphi_F\varphi_M}.$$

Take the economically admissible (non-negative) root:

$$H_F^{\mathrm{CE}} = \frac{\beta + \sqrt{\beta^2 + 4\gamma}}{2}, \qquad H_M^{\mathrm{CE}} = H - H_F^{\mathrm{CE}}.$$

To compare to the social planner allocation rule, we need to turn the exact closed form into the second-order approximation. First, we factor β out of the radical

$$\sqrt{\beta^2 + 4\gamma} = \beta\sqrt{1 + \frac{4\gamma}{\beta^2}} = \beta\,\sqrt{1+x}, \qquad x \equiv \frac{4\gamma}{\beta^2}.$$

Since the series of $\sqrt{1+x}$ can be expanded as

$$\sqrt{1+x} = 1 + \frac{x}{2} - \frac{x^2}{8} + O(x^3), \qquad |x| \ll 1.$$

we have

$$\sqrt{\beta^2 + 4\gamma} = \beta\Big[\,1 + \frac{2\gamma}{\beta^2} - \frac{2\gamma^2}{\beta^4} + O(\gamma^3)\Big].$$

Therefore,

$$\begin{aligned} H_F^{\mathrm{CE}} &= \frac{1}{2}\Big[\beta + \beta\Big(1 + \frac{2\gamma}{\beta^2} - \frac{2\gamma^2}{\beta^4} + \ldots\Big)\Big] \\ &= \frac{1}{2}\Big[2\beta + \frac{2\gamma}{\beta} - \frac{2\gamma^2}{\beta^3} + \ldots\Big] \\ &= \beta + \frac{\gamma}{\beta} - \frac{\gamma^2}{\beta^3} + O(\gamma^3). \end{aligned}$$

This is a second-order Taylor expansion around $\theta_F = 0,\ \theta_M = 1$ but keeps cannibalization Q arbitrary. Substituting $\beta = \beta_0 - \delta\beta$ with

$$\beta_0 = \frac{(1 - \varphi_M H)\,\Delta\Pi}{Q\Pi_0\varphi_M}, \qquad \delta\beta = \frac{(1-\theta_M)\Pi}{Q\Pi_0\varphi_F},$$

and $\gamma = \theta_F/(PQ\varphi_F\varphi_M)$ gives

$$H_F^{\mathrm{CE}} = \underbrace{\beta_0}_{\text{baseline cannibalization / mark-up}} - \underbrace{\frac{(1-\theta_M)\,\Pi}{Q\Pi_0\varphi_F}}_{\text{liquidity-constraint wedge}} + \underbrace{\frac{\theta_F}{P\,Q\,\varphi_F\varphi_M\,\beta_0}}_{\text{fixed-wage wedge}} + O\big(\theta_F^2, (1-\theta_M)^2\big).$$

Subtract (SP) from (T2):

$$H_F^{\mathrm{CE}} - H_F^{\mathrm{SP}} = \underbrace{\Big[\beta_0 - \frac{H}{2} + \frac{\varphi_F - \varphi_M}{2\varphi_F\varphi_M}\Big]}_{\text{pure market-power / cannibalization term}} - \frac{(1-\theta_M)\Pi}{Q\Pi_0\varphi_F} + \frac{\theta_F}{P\,Q\,\varphi_F\varphi_M\,\beta_0} + O\big(\theta_F^2, (1-\theta_M)^2\big).$$

Since we expand around the friction-free point $\theta_F \to 0$ and $\theta_M \to 1$, both the liquidity wedge and the fixed-wage wedge shrink linearly to zero. What is left is the pure market-power / cannibalization term

$$H_F^{\mathrm{CE}} - H_F^{\mathrm{SP}} \;\longrightarrow\; \Delta_{\mathrm{MP}} \;\equiv\; \beta_0 - \frac{H}{2} + \frac{\varphi_F - \varphi_M}{2\varphi_F\varphi_M},$$

with

$$\beta_0 = \frac{(1-\varphi_M H)\,\Delta\Pi}{Q\,\Pi_0\,\varphi_M}, \qquad \Delta\Pi \equiv \Pi - Q\Pi_0.$$

Insert (3) into (2) and rearrange the difference between the competitive equilibrium human capital allocation rule and the social planner human capital allocation rule:

$$\Delta_{\mathrm{MP}} = \Big[\frac{(1-\varphi_M H)\,\Pi}{Q\Pi_0\,\varphi_M}\Big] - \Big[(1-\varphi_M H) + \frac{H}{2}\Big] + \frac{\varphi_F - \varphi_M}{2\varphi_F\varphi_M}.$$

10.1.1 Interpretation.

The decomposition can be read term by term. The monopoly–mark-up component, $\big[(1-\varphi_M H)\Pi\big]/(Q\Pi_0\varphi_M)$, captures the incremental rent the incumbent extracts from its innovative line except when cannibalization (with probability Q) pushes payoff back to the safe profit Π_0. The multiplier $(1-\varphi_M H)$ measures how much "slack" remains in the specialist's success probability that the incumbent can still purchase by poaching talent. Ceteris paribus, this term is positive and therefore draws talent toward the incumbent. Set against this is the foregone specialist rent, $-(1-\varphi_M H)$. Removing a researcher from the specialist reduces that project's success probability by exactly the available slack, creating a social loss. This term is always negative and pushes talent back toward the specialist. A further benchmark correction, $-H/2$, simply reflects that the planner starts from an even split of talent before adjusting for technology gaps. Finally, technological asymmetry, $(\varphi_F - \varphi_M)/(2\varphi_F\varphi_M)$, tilts both the planner and the market toward whichever side is more productive: if $\varphi_F > \varphi_M$ the term is positive and favors the incumbent; if the specialist is more productive, it is negative.

Economic scenarios (contracting wedges negligible). Two polar constellations pin down the sign of Δ_{MP}. When cannibalization risk is low and the monopoly mark-up is high, and the specialist still has residual success slack ($\varphi_M H < 1$), we obtain $\Delta_{\mathrm{MP}} > 0$. The competitive equilibrium then over-allocates researchers to the large firm—an instance of "talent hoarding" that reduces experimentation diversity. By contrast, when cannibalization risk is high, or the specialist is near-saturated or technologically superior ($\varphi_M > \varphi_F$), we have $\Delta_{\mathrm{MP}} < 0$. The incumbent voluntarily scales back R&D to protect the safe line, so the competitive equilibrium under-allocates talent to the large firm even though a planner would prefer more incumbent innovation effort. When θ_F and $1 - \theta_M$ are genuinely small, the misallocation essentially collapses to the single product-market parameter β_0 embedded in Δ_{MP}. Nonetheless, even modest contracting frictions can flip the sign, so policies that ease specialist financing ($\theta_M \uparrow$) or strengthen incentive pay inside incumbents ($\theta_F \downarrow$) remain powerful tools for correcting the allocation of scarce research talent.

Why the equity wedges θ_F and θ_M still matter. In the model, θ_F (incumbent) and θ_M (specialist) denote the equity shares granted to hired researchers. Raising a researcher's equity improves their upside but reduces the firm's retained profit. For the specialist, the term $-(1-\theta_M)\varphi_M \Pi$ in β shows that a larger equity grant shrinks retained cash flow and weakens the specialist's ability to bid for talent. Algebraically $\partial\beta/\partial\theta_M > 0$, so a richer specialist package increases β and shifts researchers toward the incumbent. Cutting the specialist's equity stake ($\theta_M \downarrow$) has the opposite, cash-flow–enhancing effect and pulls talent back. For the incumbent, the coefficient $\gamma = \theta_F/(P, Q, \varphi_F\varphi_M)$ enters $H_F^{\mathrm{CE}} = \frac{1}{2}\left[\beta + \sqrt{\beta^2 + 4\gamma}\right]$ positively. A higher θ_F therefore raises H_F^{CE}: the incumbent can credibly substitute equity for cash wages and ends up hiring more researchers. Even when $|\theta_F|$ and $|1-\theta_M|$ are numerically small, their effects on β and γ are first-order relative to the product-market term Δ_{MP}. Hence modest tweaks to equity desig, such as VC-style carve-outs for specialists or option-pool caps for incumbents, can overturn the sign of the deviation and move the allocation toward the planner's benchmark.

Take-away. With contracting frictions muted, misallocation is governed by the single parameter β_0, which summarizes the trade-off between the incumbent's monopoly rent and cannibalization risk, net of the specialist's remaining room for success. Equity design is not a sideshow: θ_F and θ_M enter linearly through γ and the second term of β, so small policy or contractual changes can reverse the direction of talent flows. Policy should target the margin that generates the gap. Competition policy that lowers $\Pi - \Pi_0$ or raises Q reduces β_0 when incumbents over-hoard talent. Innovation finance that lets specialists surrender less equity ($\theta_M \downarrow$) counteracts hoarding. Incentive-design tools (e.g., caps on option pools or milestone-based vesting) can limit the incumbent's equity offer ($\theta_F \downarrow$) when society needs less incumbent R&D, or expand it when more is desirable. Thus, the framework isolates whether product-market power or equity contracting drives the wedge between competitive and first-best talent allocations, and it maps that diagnosis into the least-distortive intervention.

11 Dynamic Model of Talent Hiring Competition

11.1 From Benchmark to Dynamic Model

The three-period, single-technology benchmark provides closed-form intuition for how talent hoarding arises from the trade-offs between human capital accumulation, liquidity constraints, and potential cannibalization within the large firm. To better capture the richness of firm behavior under uncertainty, we extend the framework to an infinite-horizon model with two technologies.

The infinite horizon eliminates end-of-game effects and allows talent allocation and human capital accumulation to unfold over repeated cycles, mirroring real-world labor markets and R&D strategies. Introducing a second technology also brings in additional dynamics: the large firm may face cross-technology cannibalization risks, while the specialized firms confront persistent financing frictions. This richer environment highlights how repeated opportunities for innovation shape long-run patterns of talent allocation and strategic blocking by incumbents.

The disadvantage of this extension is tractability. Closed-form solutions are no longer available, and the model must be analyzed through recursive structure and simulation. In the sections that follow, we present simulation results that illustrate how the infinite-horizon, two-technology setting alters equilibrium wages, talent flows, and long-run innovation outcomes compared to the benchmark case.

11.2 Large Firm Problem

The large firm will offer wage and equity shares to each type of talent before the states are realized. Once states are realized, workers will receive the wage and their corresponding share of the total profit of the firm. Assume that the large firm is not restricted by the liquidity constraint and human capital constraint. Then, the large firm maximizes the profit in each period. Given $\{w_F^k\left(x^{t-1}\right), H_{M_k}\left(x^{t-1}\right)\}_{t=0}^{\infty} \forall k$, the large firm chooses $\{H_F^0\left(x^{t-1}\right), H_F^1\left(x^{t-1}\right)\}_{t=0}^{\infty}$ to solve

$$\max \sum_{t=0}^{\infty} \left(\frac{1}{1+r}\right)^t \mathbb{E}\left[R_F\left(x^t\right) - \sum_{k\in\{0,1\}} w_F^k\left(x^{t-1}\right) H_F^k\left(x^{t-1}\right)\right]$$

subject to

$$\Pi_F\left(x^t\right)=\begin{cases}\max\left\{\Pi_0,\Pi_1\right\} & \text{if } s_{t,0}=1,s_{t,1}=1,z_t=1,n_{t,0,F}=1,n_{t,1,F}=1,n_{t,0,M}=0,n_{t,1,M}=0\\ & \textbf{i.e. Both type-0 and type-1 succeed, large firm implements the bigger } \Pi, \\ & \textbf{both specialized firms fail}\\ \Pi_0+\Pi_1 & \text{if } s_{t,0}=1,s_{t,1}=1,z_t=0,n_{t,0,F}=1,n_{t,1,F}=1,n_{t,0,M}=0,n_{t,1,M}=0\\ & \textbf{i.e. Both succeed, } z_t=0 \textbf{ so the firm implements } \Pi_0+\Pi_1\textbf{, both specialized}\\ & \textbf{firms fail}\\ \Pi_0 & \text{if } s_{t,0}=1,n_{t,0,F}=1,n_{t,0,M}=0,\neg\left(n_{t,1,F}=1,s_{t,1}=1,n_{t,1,M}=0\right)\\ & \textbf{i.e. only type-0 project makes positive profit, type-0 specialized firm fails}\\ \Pi_1 & \text{if } s_{t,1}=1,n_{t,1,F}=1,n_{t,1,M}=0,\neg\left(n_{t,0,F}=0,s_{t,0}=1,n_{t,0,M}=0\right)\\ & \textbf{i.e. only type-1 project makes positive profit, type-1 specialized firm fails}\\ 0 & \text{otherwise,}\\ & \textbf{i.e. No projects make profits}\end{cases}$$

$$R_F\left(x^t\right)=\left(1-\theta_F^0-\theta_F^1\right)\Pi_F\left(x^t\right).$$

where $\mathbb{E}\left[\Pi_F\left(x^t\right)\right]$ has the closed-form:

$$\begin{aligned}&P\left(s_{t,0}=1\right)P\left(s_{t,1}=1\right)Q\left(z_t=1\right)q_F^0\left(H_F^0\left(x^{t-1}\right)\right)q_F^1\left(H_F^1\left(x^{t-1}\right)\right)\left(1-q_{M_0}\left(H_{M_0}\left(x^{t-1}\right)\right)\right)\left(1-q_{M_1}\left(H_{M_1}\left(x^{t-1}\right)\right)\right)\max\{\Pi_0,\Pi_1\}+\\&P\left(s_{t,0}=1\right)P\left(s_{t,1}=1\right)\left(1-Q\left(z_t=1\right)\right)q_F^0\left(H_F^0\left(x^{t-1}\right)\right)q_F^1\left(H_F^1\left(x^{t-1}\right)\right)\left(1-q_{M_0}\left(H_{M_0}\left(x^{t-1}\right)\right)\right)\left(1-q_{M_1}\left(H_{M_1}\left(x^{t-1}\right)\right)\right)\{\Pi_0+\Pi_1\}+\\&P\left(s_{t,0}=1\right)q_F^0\left(H_F^0\left(x^{t-1}\right)\right)\left(1-q_{M_0}\left(H_{M_0}\left(x^{t-1}\right)\right)\right)\left(1-q_F^1\left(H_F^1\left(x^{t-1}\right)\right)\right)P\left(s_{t,1}=1\right)\left(1-q_{M_1}\left(H_{M_1}\left(x^{t-1}\right)\right)\right)\Pi_0+\\&P\left(s_{t,1}=1\right)q_F^1\left(H_F^1\left(x^{t-1}\right)\right)\left(1-q_{M_1}\left(H_{M_1}\left(x^{t-1}\right)\right)\right)\left(1-q_F^0\left(H_F^0\left(x^{t-1}\right)\right)\right)P\left(s_{t,0}=1\right)\left(1-q_{M_0}\left(H_{M_0}\left(x^{t-1}\right)\right)\right)\Pi_1\end{aligned}$$

Specifically, in period t, $w_F^k\left(x^{t-1}\right)$ is the wage offered by the large firm F to the type k talent, $H_{M_k}\left(x^{t-1}\right)$ is the type k human capital hired by specialized firm M_k, $H_F^k\left(x^{t-1}\right)$ is the type k human capital hired by F, $\Pi_F\left(x^t\right)$ is the profit of final good production of the large firm after the states are realized, and $R_F\left(x^t\right)$ is the after-equity profit of the large firm after the states are realized. As specified in Section 5.2.2, in period t, variables determined before the state x^t is realized are functions of all the previous states x^{t-1} (e.g. human capital hired, wage, etc.).

Since we assume all states are identically and independently distributed, the allocation of human capital in each period is independent of the others. As a result, we can reduce this present-value future profit maximization problem into a single-period profit maximization problem. In the period t, given $\{w_F^k\left(x^{t-1}\right),H_{M_k}\left(x^{t-1}\right)\}\forall k$, the large firm chooses $\{H_F^0\left(x^{t-1}\right),H_F^1\left(x^{t-1}\right)\}$ to solve

$$\max\mathbb{E}\left[R_F\left(x^t\right)\right]-\sum_{k\in\{0,1\}}w_F^k\left(x^{t-1}\right)H_F^k\left(x^{t-1}\right)$$

subject to the same constraints.

11.3 Specialized Firm Problem

Assume both specialized firms are not restricted by the liquidity constraint and human capital constraint. Using the same logic as for the large firm, we can also reduce the specialized firm problem into a single-period maximization problem. For each M_k firm, given $\{w_{M_k}\left(x^{t-1}\right), H_F^k\left(x^{t-1}\right)\}$, $\{H_{M_k}\left(x^{t-1}\right)\}$, solves

$$\max \mathbb{E}\left[R_{M_k}\left(x^t\right)\right] - w_{M_k}\left(x^{t-1}\right) H_{M_k}\left(x^{t-1}\right)$$

subject to

$$\Pi_{M_k}\left(x^t\right) = \Pi_\omega \cdot \mathbb{1}\left(s_{t,k}=1, n_{t,k,M}=1\right) \cdot \max\{\mathbb{1}\left(n_{t,k,F}=0\right), \mathbb{1}\left(s_{t,-k}=1, n_{t,-k,F}=1, n_{t,k,F}=1, z_t=1, \Pi_k < \Pi_{-k}\right)\},$$
$$R_{M_k}\left(x^t\right) = \left(1-\theta_{M_k}\right)\Pi_{M_k}\left(x^t\right)$$

Without loss of generality, we assume $\Pi_0 < \Pi_1$ because we do not distinguish between two types of technology, thereby ensuring that type-1 projects are never cannibalized within the large firm. Note that here $\Pi_{M_k}\left(x^t\right)$ is zero unless the specialized firm both (i) has actually developed type k (i.e. $n_{k,M}=1$) and (ii) is not overridden by the large firm in the event of competition or cannibalization, and thus $R_{M_k}\left(x^t\right)$ is the after-equity revenue.

Generally, the expected profit of the specialized firm M_k is they only earn anything if: (1) their technology is profitable and significantly valued (2) the specialized firm actually succeeds in developing it $q_{M_k}(H_{M_k})$ (3) They are not blocked or overshadowed by the large firm.

$$\mathbb{E}\left[\Pi_{M_k}\left(x^t\right)\right] = \underbrace{P(s_{t,k}=1)}_{\text{tech is successfully developed}} \cdot \underbrace{q_{M_k}\left(H_{M_k}\left(x^{t-1}\right)\right)}_{\text{specialist's success}} \cdot \left[1 - \Pr(\text{blocked by big firm})\right] \cdot \Pi_k$$

The type-0 specialized research firm's technology will be overshadowed if: (1) The large firm also invests in Technology 0, so a direct overlap in Technology 0 leads to zero duopoly profits, (2) The large firm invests in Technology 1 as well, and if technology-1 is successful in a cannibalization state ($z_t=1$), it overshadows technology-0, and (3) $\Pi_1 > \Pi_0$. The expected after-equity profit for the specialized firm M_0 is given by

$$\mathbb{E}\left[\Pi_{M_0}\left(x^t\right)\right] = P(s_{t,0}=1)\, q_{M_0}\left(H_{M_0}\left(x^{t-1}\right)\right) \cdot \left[1 - q_F^0\left(H_F^0\left(x^{t-1}\right)\right) - P(s_{t,1}=1)\, q_F^1\left(H_F^1\left(x^{t-1}\right)\right) Q(z_t=1)\right] \cdot \Pi_0$$

Likewise, for the type 1 specialized research firm, the specialized 1 can be overshadowed if the large firm invests in the same Technology 1 and both succeed (duopoly). Since we are assuming $\Pi_1 > \Pi_0$ with our loss of generality then 0 never overshadows 1 in a cannibalization scenario, the main overshadow for a type-1 specialized firm might be only that the big firm invests in 1 as well, causing zero duopoly profits if both

succeed. Thus, specialized firm M_1's after-equity profit is

$$\mathbb{E}\left[\Pi_{M_1}\left(x^t\right)\right] = P(s_{t,1}=1)\, q_{M_1}\left(H_{M_1}\left(x^{t-1}\right)\right) \cdot \left[1 - q_F^1\left(H_F^1\left(x^{t-1}\right)\right)\right] \cdot \Pi_1$$

11.4 Talent's Optimization Problem

Given $\{w_F^k\left(x^{t-1}\right), w_{M_k}\left(x^{t-1}\right), \Pi_F^k\left(x^{t-1}\right), \Pi_{M_k}\left(x^{t-1}\right), H_F^k\left(x^{t-1}\right), H_{M_k}\left(x^{t-1}\right)\}$ and exogenously determined Bertrand-pricing solution prices $\{p_\omega\left(x^{t-1}\right)\}$ for $\omega \in \{0,1\}$, type k talent chooses $\{c_0^k\left(x^{t-1}\right),\ c_1^k\left(x^{t-1}\right),\ h_F^k\left(x^{t-1}\right),\ h_{M_k}\left(x^{t-1}\right),\ h^k\left(x^t\right)\}$ to solve

$$\max \sum_{t=0}^{\infty} \beta^t \mathbb{E}\left[u^k\left(c_0^k\left(x^{t-1}\right), c_1^k\left(x^{t-1}\right)\right)\right]$$

subject to

$$\begin{aligned}
p_0\left(x^{t-1}\right) c_0^k\left(x^{t-1}\right) + p_1\left(x^{t-1}\right) c_1^k\left(x^{t-1}\right) &\leq h_F^k\left(x^{t-1}\right) w_F^k\left(x^{t-1}\right) + \frac{h_F^k\left(x^{t-2}\right)}{H_F^k\left(x^{t-2}\right)} \cdot \theta_F^k \Pi_F\left(x^{t-1}\right) + \\
&\qquad h_{M_k}\left(x^{t-1}\right) w_{M_k}\left(x^{t-1}\right) + \frac{h_{M_k}\left(x^{t-2}\right)}{H_{M_k}\left(x^{t-2}\right)} \cdot \theta_{M_k} \Pi_{M_k}\left(x^{t-1}\right), \\
h^k\left(x^t\right) &= (1-\delta_h) h^k\left(x^{t-1}\right) + g_{M_k}\left(h_{M_k}\left(x^{t-1}\right)\right) + g_F^k\left(h_F^k\left(x^{t-1}\right)\right) \cdot \mathbb{1}(s_{t,k}=1, n_{t,k,F}=1) \cdot \\
&\qquad \left(1 - \mathbb{1}\left(z_t=1, s_{t,-k}=1, n_{t,-k,F}=1, \Pi_k < \Pi_{-k}\right)\right) \\
h_F^k\left(x^{t-1}\right) + h_{M_k}\left(x^{t-1}\right) &\leq h^k\left(x^{t-1}\right)
\end{aligned}$$

We distinguish between the human capital supplied by the talent h and that demanded by the firm H. In this framework, talents solely determine the quantity of human capital to supply.

12 Equilibrium Analysis

12.1 Large Firm

The first order condition with respect to $H_F^0\left(x^{t-1}\right)$ is

$$\begin{aligned}
&\left(1 - \theta_F^0 - \theta_F^1\right) q_F^{0\prime}\left(H_F^0\left(x^{t-1}\right)\right) \cdot \\
&\Big\{ P\left(s_{t,0}=1\right) P\left(s_{t,1}=1\right) Q\left(z_t=1\right) q_F^1\left(H_F^1\left(x^{t-1}\right)\right) \left(1 - q_{M_0}\left(H_{M_0}\left(x^{t-1}\right)\right)\right) \left(1 - q_{M_1}\left(H_{M_1}\left(x^{t-1}\right)\right)\right) \Pi_1 \\
&+ P\left(s_{t,0}=1\right) P\left(s_{t,1}=1\right) \left(1 - Q\left(z_t=1\right)\right) q_F^1\left(H_F^1\left(x^{t-1}\right)\right) \left(1 - q_{M_0}\left(H_{M_0}\left(x^{t-1}\right)\right)\right) \left(1 - q_{M_1}\left(H_{M_1}\left(x^{t-1}\right)\right)\right) \left\{\Pi_0 + \Pi_1\right\} \\
&+ P\left(s_{t,0}=1\right) \left(1 - q_{M_0}\left(H_{M_0}\left(x^{t-1}\right)\right)\right) \left(1 - q_F^1\left(H_F^1\left(x^{t-1}\right)\right)\right) P\left(s_{t,1}=1\right) \left(1 - q_{M_1}\left(H_{M_1}\left(x^{t-1}\right)\right)\right) \Pi_0 \\
&- P\left(s_{t,1}=1\right) q_F^1\left(H_F^1\left(x^{t-1}\right)\right) \left(1 - q_{M_1}\left(H_{M_1}\left(x^{t-1}\right)\right)\right) P\left(s_{t,0}=1\right) \left(1 - q_{M_0}\left(H_{M_0}\left(x^{t-1}\right)\right)\right) \Pi_1 \Big\} = w_F^0\left(x^{t-1}\right)
\end{aligned}$$

The last line represents a scenario where the success of Technology 1 kills off the profit from 0. Specifically,

if both technologies 0 and 1 are successfully developed, the marginal effect of increasing H_F^0 may reduce the probability of Π_1 being the sole realized profit. In addition, the first order condition with respect to $H_F^1\left(x^{t-1}\right)$ is

$$
\begin{aligned}
&\left(1-\theta_F^0-\theta_F^1\right) q_F^{1\prime}\left(H_F^1\left(x^{t-1}\right)\right)\cdot \\
&\Big\{P\left(s_{t,0}=1\right)P\left(s_{t,1}=1\right)Q\left(z_t=1\right)q_F^0\left(H_F^0\left(x^{t-1}\right)\right)\left(1-q_{M_0}\left(H_{M_0}\left(x^{t-1}\right)\right)\right)\left(1-q_{M_1}\left(H_{M_1}\left(x^{t-1}\right)\right)\right)\Pi_1 \\
&+P\left(s_{t,0}=1\right)P\left(s_{t,1}=1\right)\left(1-Q\left(z_t=1\right)\right)q_F^0\left(H_F^0\left(x^{t-1}\right)\right)\left(1-q_{M_0}\left(H_{M_0}\left(x^{t-1}\right)\right)\right)\left(1-q_{M_1}\left(H_{M_1}\left(x^{t-1}\right)\right)\right)\left\{\Pi_0+\Pi_1\right\} \\
&-P\left(s_{t,0}=1\right)q_F^0\left(H_F^0\left(x^{t-1}\right)\right)\left(1-q_{M_0}\left(H_{M_0}\left(x^{t-1}\right)\right)\right)P\left(s_{t,1}=1\right)\left(1-q_{M_1}\left(H_{M_1}\left(x^{t-1}\right)\right)\right)\Pi_0+ \\
&+P\left(s_{t,1}=1\right)\left(1-q_{M_1}\left(H_{M_1}\left(x^{t-1}\right)\right)\right)\left(1-q_F^0\left(H_F^0\left(x^{t-1}\right)\right)P\left(s_{t,0}=1\right)\left(1-q_{M_0}\left(H_{M_0}\left(x^{t-1}\right)\right)\right)\Pi_1\Big\}=w_F^1\left(x^{t-1}\right)
\end{aligned}
$$

12.2 Specialized Firm

The first order condition with respect to $H_{M_0}\left(x^{t-1}\right)$ is

$$
\left(1-\theta_{M_0}\right)P(s_{t,0}=1)\,q_{M_0}'\left(H_{M_0}\left(x^{t-1}\right)\right)\cdot\left[1-q_F^0\left(H_F^0\left(x^{t-1}\right)\right)-P(s_{t,1}=1)\,q_F^1\left(H_F^1\left(x^{t-1}\right)\right)\,Q(z_t=1)\right]\cdot\Pi_0=w_{M_0}\left(x^{t-1}\right)
$$

and the first order condition with respect to
$H_{M_1}\left(x^{t-1}\right)$ is

$$
\left(1-\theta_{M_1}\right)P(s_{t,1}=1)\,q_{M_1}'\left(H_{M_1}\left(x^{t-1}\right)\right)\cdot\left[1-q_F^1\left(H_F^1\left(x^{t-1}\right)\right)\right]\cdot\Pi_1=w_{M_1}\left(x^{t-1}\right)
$$

12.3 Talent

Denote $\xi\left(x^t\right)$ the joint probability that x^t appears. Since each state is independently and identically distributed across periods, and all states are independent of one another in every period, this joint probability can be expressed as the product of the probabilities of each state within the period. Also, denote $X_F^{k,t}$ the set such that the type k human capital invested in the large firm accumulates. The Lagrangian of this problem is

$$
\begin{aligned}
\mathcal{L}_a^k=&\sum_{t=0}^{\infty}\sum_{x^{t-1}\in X^{t-1}}\beta^t\xi\left(x^{t-1}\right)u^k\left(c_0^k\left(x^{t-1}\right),c_1^k\left(x^{t-1}\right)\right)+\sum_{t=0}^{\infty}\sum_{x^{t-1}\in X^{t-1}}\xi\left(x^{t-1}\right)\lambda_1^k\left(x^{t-1}\right)\Bigg(h_F^k\left(x^{t-1}\right)w_F^k\left(x^{t-1}\right)+ \\
&\frac{h_F^k\left(x^{t-2}\right)}{H_F^k\left(x^{t-2}\right)}\cdot\theta_F^k\Pi_F\left(x^{t-1}\right)+h_{M_k}\left(x^{t-1}\right)w_{M_k}\left(x^{t-1}\right)+\frac{h_{M_k}\left(x^{t-2}\right)}{H_{M_k}\left(x^{t-2}\right)}\cdot\theta_{M_k}\Pi_{M_k}\left(x^{t-1}\right)-p_0\left(x^{t-1}\right)c_0^k\left(x^{t-1}\right)- \\
&p_1\left(x^{t-1}\right)c_1^k\left(x^{t-1}\right)\Bigg)+\sum_{t=0}^{\infty}\sum_{x^{t-1}\in X^{t-1}}\xi\left(x^{t-1}\right)\lambda_2^k\left(x^t\right)\Bigg((1-\delta_h)h^k\left(x^{t-1}\right)+g_{M_k}\left(h_{M_k}\left(x^{t-1}\right)\right)-h^k\left(x^t\right)+ \\
&\sum_{x^t\in X_F^t}\xi\left(x_t|x^{t-1}\right)g_F^k\left(h_F^k\left(x^{t-1}\right)\right)\Bigg)+\sum_{t=0}^{\infty}\sum_{x^{t-1}\in X^{t-1}}\xi\left(x^{t-1}\right)\lambda_3^k\left(x^{t-1}\right)\left(h^k\left(x^{t-1}\right)-h_F^k\left(x^{t-1}\right)-h_{M_k}\left(x^{t-1}\right)\right)
\end{aligned}
$$

The first order condition with respect to $c_0^k\left(x^{t-1}\right)$ is

$$\frac{\partial \mathcal{L}_a^k}{\partial c_0^k\left(x^{t-1}\right)} = \beta^t \xi\left(x^{t-1}\right) u_1^k\left(c_0^k\left(x^{t-1}\right), c_1^k\left(x^{t-1}\right)\right) - \xi\left(x^{t-1}\right) \lambda_1^k\left(x^{t-1}\right) p_0\left(x^{t-1}\right) = 0$$

with respect to $c_1^k\left(x^{t-1}\right)$ is

$$\frac{\partial \mathcal{L}_a^k}{\partial c_1^k\left(x^{t-1}\right)} = \beta^t \xi\left(x^{t-1}\right) u_2^k\left(c_0^k\left(x^{t-1}\right), c_1^k\left(x^{t-1}\right)\right) - \xi\left(x^{t-1}\right) \lambda_1^k\left(x^{t-1}\right) p_1\left(x^{t-1}\right) = 0$$

and with respect to $h_F^k\left(x^{t-1}\right)$ is

$$\begin{aligned}\frac{\partial \mathcal{L}_a^k}{\partial h_F^k\left(x^{t-1}\right)} =& \xi\left(x^{t-1}\right) \lambda_1^k\left(x^{t-1}\right) w_F^k\left(x^{t-1}\right) + \xi\left(x^t\right) \lambda_1^k\left(x^t\right) \cdot \frac{1}{H_F^k\left(x^{t-1}\right)} \cdot \theta_F^k \Pi_F\left(x^t\right) + \xi\left(x^{t-1}\right) \lambda_2^k\left(x^t\right) \\ & \Big[P\left(s_{t,0}=1\right) q_F^0\left(H_F^0\left(x^{t-1}\right)\right)\left(1 - Q\left(z_t=1\right) P\left(s_{t,1}=1\right) q_F^1\left(H_F^1\left(x^{t-1}\right)\right)\right)\Big] g_F^{k\prime}\left(h_F^k\left(x^{t-1}\right)\right) - \\ & \xi\left(x^{t-1}\right) \lambda_3\left(x^{t-1}\right) = 0\end{aligned}$$

Note that $\left(1 - Q\left(z_t=1\right) P\left(s_{t,1}=1\right) q_F^1\left(H_F^1\left(x^{t-1}\right)\right)\right)$ is the probability that we are not overshadowed by the other technology, and $P\left(s_{t,0}=1\right) q_F^0\left(H_F^0\left(x^{t-1}\right)\right)\left(1 - Q\left(z_t=1\right) P\left(s_{t,1}=1\right) q_F^1\left(H_F^1\left(x^{t-1}\right)\right)\right)$ is the probability that the big firm's type-k R&D is successfully implemented, so that the talent's specialized skill actually leads to next-period capital. In addition, the first order condition with respect to $h_{M_k}\left(x^{t-1}\right)$ is

$$\begin{aligned}\frac{\partial \mathcal{L}_a^k}{\partial h_{M_k}\left(x^{t-1}\right)} =& \xi\left(x^{t-1}\right) \lambda_1^k\left(x^{t-1}\right) w_{M_k}\left(x^{t-1}\right) + \xi\left(x^t\right) \lambda_1^k\left(x^t\right) \cdot \frac{1}{H_{M_k}\left(x^{t-1}\right)} \cdot \theta_{M_k} \Pi_{M_k}\left(x^t\right) + \\ & \xi\left(x^{t-1}\right) \lambda_2^k\left(x^t\right) g_{M_k}'\left(h_{M_k}\left(x^{t-1}\right)\right) - \xi\left(x^{t-1}\right) \lambda_3\left(x^{t-1}\right) = 0\end{aligned}$$

and with respect to $h^k\left(x^t\right)$ is

$$\frac{\partial \mathcal{L}_a^k}{\partial h^k\left(x^t\right)} = \xi\left(x^{t-1}\right) \lambda_2^k\left(x^t\right) - (1-\delta_h) \xi\left(x^t\right) \lambda_2^k\left(x^{t+1}\right) + \xi\left(x^t\right) \lambda_3\left(x^t\right) = 0$$

Essentially, $\lambda_3\left(x^t\right)$ reflects the tradeoff between devoting one's human capital to the large firm versus the specialized firm. This leads to the intratemporal condition that the marginal rate of substitution between goods 0 and 1 must equal their relative price,

$$\frac{u_1^k\left(c_0^k\left(x^{t-1}\right), c_1^k\left(x^{t-1}\right)\right)}{u_2^k\left(c_0^k\left(x^{t-1}\right), c_1^k\left(x^{t-1}\right)\right)} = \frac{p_0\left(x^{t-1}\right)}{p_1\left(x^{t-1}\right)}$$

By subtracting the first-order condition (FOC) with respect to $h_F^k\left(x^{t-1}\right)$ from the FOC with respect to $h_{M_k}\left(x^{t-1}\right)$, we can isolate $\lambda_2^k(x^t)$ by plugging in $\lambda_1^k\left(x^{t-1}\right)$ and $\lambda_1^k\left(x^t\right)$:

$$\lambda_2^k\left(x^t\right)=\frac{\lambda_1^k\left(x^{t-1}\right)\left(w_F^k\left(x^{t-1}\right)-w_{M_k}\left(x^{t-1}\right)\right)+\xi\left(x_t|x^{t-1}\right)\lambda_1^k\left(x^t\right)\left(\frac{\theta_F^k\Pi_F\left(x^{t-1}\right)}{H_F^k\left(x^{t-1}\right)}-\frac{\theta_{M_k}\Pi_{M_k}\left(x^{t-1}\right)}{H_{M_k}\left(x^{t-1}\right)}\right)}{g'_{M_k}\left(h_{M_k}\left(x^{t-1}\right)\right)-P\left(s_{t,0}=1\right)q_F^0\left(H_F^0\left(x^{t-1}\right)\right)\left(1-Q\left(z_t=1\right)P\left(s_{t,1}=1\right)q_F^1\left(H_F^1\left(x^{t-1}\right)\right)\right)g_F^{k\prime}\left(h_F^k\left(x^{t-1}\right)\right)}$$

Plugging in the FOC with respect to $h^k\left(x^{t-1}\right)$ yields

$$\lambda_3^k\left(x^t\right)=-\frac{\xi\left(x_{t-1}\mid x^t\right)\left(\lambda_1^k\left(x^{t-1}\right)\left(w_F^k\left(x^{t-1}\right)-w_{M_k}\left(x^{t-1}\right)\right)+\xi\left(x_t\mid x^{t-1}\right)\lambda_1^k\left(x^t\right)\left(\frac{\theta_F^k\Pi_F\left(x^{t-1}\right)}{H_F^k\left(x^{t-1}\right)}-\frac{\theta_{M_k}\Pi_{M_k}\left(x^{t-1}\right)}{H_{M_k}\left(x^{t-1}\right)}\right)\right)}{g'_{M_k}\left(h_{M_k}\left(x^{t-1}\right)\right)-P\left(s_{t,0}=1\right)q_F^0\left(H_F^0\left(x^{t-1}\right)\right)\left(1-Q\left(z_t=1\right)P\left(s_{t,1}=1\right)q_F^1\left(H_F^1\left(x^{t-1}\right)\right)\right)g_F^{k\prime}\left(h_F^k\left(x^{t-1}\right)\right)}$$
$$+\left(1-\delta_h\right)\cdot\frac{\lambda_1^k\left(x^t\right)\left(w_F^k\left(x^t\right)-w_{M_k}\left(x^t\right)\right)+\xi\left(x_{t+1}\mid x^t\right)\lambda_1^k\left(x^{t+1}\right)\left(\frac{\theta_F^k\Pi_F\left(x^t\right)}{H_F^k\left(x^t\right)}-\frac{\theta_{M_k}\Pi_{M_k}\left(x^t\right)}{H_{M_k}\left(x^t\right)}\right)}{g'_{M_k}\left(h_{M_k}\left(x^t\right)\right)-P\left(s_{t,0}=1\right)q_F^0\left(H_F^0\left(x^t\right)\right)\left(1-Q\left(z_t=1\right)P\left(s_{t,1}=1\right)q_F^1\left(H_F^1\left(x^t\right)\right)\right)g_F^{k\prime}\left(h_F^k\left(x^t\right)\right)}$$

Essentially, $\lambda_2^k(x^t)$ measures how valuable it is (in present-value utility terms) to add one extra unit of future skill next period, net of depreciation, because the numerator captures the immediate gain (wages + profit shares) from pushing a marginal unit of skill into the large firm rather than the specialized firm, and the denominator captures the difference in how that extra skill would accumulate future human capital if placed in the specialized firm versus the large firm.

In addition, $\lambda_3^k(x^t)$ is basically an opportunity-cost multiplier that arises from the fact that there is only one unit of skill to distribute across $\{F, M\}$. A large positive $\lambda_3^k(x^t)$ indicates a substantial shadow cost of placing skill in one sector vs. the other. The first fraction represents the short-term incentive to reallocate skills between large and specialized firms in the current period. This is adjusted by the conditional probabilities $\xi(\cdot)$ and scaled by the differences in marginal accumulation. The negative sign results from how λ_3^k enters with the pposite sign in each FOC. The second big fraction captures how next period's skill $\left(h^k(x^t)\right)$ in turn influences the same trade-off again, discounted by $(1-\delta_h)$.

Having obtained all the explicit forms of the Lagrangian multipliers, we proceed to derive the Euler equations that characterize the equilibrium conditions of the model by plugging firms' FOCs and three Lagrangian multipliers into the FOCs with respect to $h_F^k\left(x^{t-1}\right)$ and $h_{M_k}\left(x^{t-1}\right)$.

12.4 Steady State Competitive Equilibrium Analysis

In the steady state, the current value of each variable equals its expected value in the next period. For instance, the type 0 human capital employed by the large firm satisfies $\bar{h}_F^0 = h_F^0\left(x^{t-1}\right) = \mathbb{E}\left[h_F^0\left(x^t\right)\right]$. Consequently, the Lagrangian multiplier $\bar{\lambda}_1^k$ cancels out in the Euler equations. By setting $h_{M_k} = H_{M_k}$ and $h_F^k = H_F^k$ for all k, we obtain two equations with four unknowns at the steady-state equilibrium: $\bar{H}_F^0$, $\bar{H}_F^1$, $\bar{H}_{M_0}$, and $\bar{H}_{M_1}$.

Incorporating the two market-clearing conditions

$$\bar{H}_F^0 + \bar{H}_{M_0} = \bar{H}^0 \text{ and } \bar{H}_F^1 + \bar{H}_{M_1} = \bar{H}^1,$$

we can determine the steady-state competitive equilibrium allocation of human capital, provided the explicit functional form of human capital accumulation is specified.

13 Negative Externalities and Social Optimum

In equilibrium, the incumbent's privately optimal strategy is often to hoard talent, preempting rivals and preserving flexibility under uncertainty, even though this creates a distortion. The result is a systematic misallocation of researchers away from specialized firms, where they would be more fully utilized, and into underemployed roles inside the incumbent. We isolate this inefficiency by comparing the competitive equilibrium to a constrained social planner's allocation that maximizes aggregate innovation while still recognizing monopoly rents. The divergence highlights a welfare loss attributable specifically to talent hoarding, distinct from the conventional deadweight loss of monopoly in the product market.

The core source of misallocation is the difference in incentives and constraints between incumbents and specialized firms. Specialized firms can typically deploy talent more effectively by dedicating resources to a single R&D line and fostering stronger skill accumulation. Yet talented researchers, especially early, career PhDs and research masters, are drawn to large incumbents because these employers offer employment stability and the ability to hedge against technological uncertainty. From the worker's perspective, joining the incumbent provides a "certainty premium", even if it means occupying a less productive or ill-defined role.

Liquidity and financing constraints at specialized firms exacerbate researchers' preference for large incumbents. When smaller entrants lack the financial resources to match the wage offers of large firms, incumbents exploit this disparity by overhiring. This strategic hoarding effectively reinforces the incumbent's dominant market position with continued technology edge and unmatched position in the product market. Such preemptive hiring not only stifles rival R&D efforts but also sequesters human capital that could otherwise generate greater social returns within specialized laboratories.

While our model simplifies the landscape by considering a single large incumbent, the core dynamics remain applicable in more complex real-world scenarios with multiple cash-rich incumbents. In practice, multiple large firms may likely engage in similar hoarding strategies, collectively inflating wages and siphoning talent away from specialized entrants. Despite the increased competition among incumbents, the fundamental mechanism of superior resource capacity enabling strategic overhiring continues to drive the misallocation of specialized human capital. This simplification allows us to clearly illustrate the strategic interactions and resultant inefficiencies without the added complexity of multiple large firms.

13.1 Social Planner Problem

As a benchmark, we consider a social planner who allocates talent with the sole objective of maximizing total welfare. For this planner to effectively optimize allocations, we assume that they possess comprehensive visibility into each firm's technological projects, success probabilities, and potential payoffs. This information might be accessible through regulatory filings, R&D disclosures, advisory boards with industry expertise, tax records, grants, or public–private partnerships. Although real-world governments rarely have perfect information, they often maintain sufficient partial visibility through industry associations and officials with prior business experience. They may not know exactly what projects each firm has, but can largely group the type of technology as well as the stage of the firms. This assumption illustrates an ideal planner with full information that allocates talent by precisely aligning private incentives with social returns, thereby preventing misallocation.

The social planner's objective is to determine the optimal allocation of resources to maximize social welfare. In the social planner's problem, we assume that once a technology is developed, regardless of the firm responsible, the social planner would enforce the project to be implemented and produce at the socially optimal level. Specifically, the social planner chooses the following variables $\left\{c_0^k\left(x^{t-1}\right),\ c_1^k\left(x^{t-1}\right),\ y_\omega\left(x^t\right),\right.$ $\left.H_F^k\left(x^{t-1}\right),\ H_{M_k}\left(x^{t-1}\right),\ H^k\left(x^{t-1}\right)\right\}$ to solve

$$\max \sum_{t=0}^{\infty} \sum_{k=0}^{1} \beta^t u^k \left(c_0^k\left(x^{t-1}\right), c_1^k\left(x^{t-1}\right)\right)$$

subject to

$$\begin{aligned}
&c_\omega^0\left(x^{t-1}\right) + c_\omega^1\left(x^{t-1}\right) = y_\omega\left(x^{t-1}\right), \forall \omega \\
&y_\omega\left(x^t\right) = y_\omega^{comp} \cdot \mathbb{1}\left(s_{t,k}=1\right)\left(1 - \mathbb{1}\left(n_{t,k,F}=0, n_{t,k,M}=0\right)\right) \\
&H^k\left(x^t\right) = (1-\delta_h) H^k\left(x^{t-1}\right) + g_{M_k}\left(H_{M_k}\left(x^{t-1}\right)\right) + g_F^k\left(H_F^k\left(x^{t-1}\right)\right) \cdot \mathbb{1}(s_{t,k}=1, n_{t,k,F}=1), \forall k. \\
&H_F^k\left(x^{t-1}\right) + H_{M_k}\left(x^{t-1}\right) \leq H^k\left(x^{t-1}\right)
\end{aligned}$$

Denote X_ω^t the set of states that the socially optimal level (equivalent to Bertrand pricing duopoly amount) y_ω^{comp} is produced. Denote $X_{F,h}^t$ the set of states that the technology is profitable and significantly valued and successfully developed by the large firm. The Lagrangian of this problem is

$$\mathcal{L}_s = \sum_{k=0}^{1}\left(\sum_{t=0}^{\infty}\sum_{x^{t-1}\in X^{t-1}}\beta^t\xi\left(x^{t-1}\right)u^k\left(c_0^k\left(x^{t-1}\right),c_1^k\left(x^{t-1}\right)\right)+\sum_{t=0}^{\infty}\sum_{x^t\in X_\omega^t}\mu_1^k\left(x^{t-1}\right)\xi\left(x^{t-1}\right)\Big(y_\omega\left(x^{t-1}\right)-c_0^k\left(x^{t-1}\right)-\right.$$
$$\left.c_1^k\left(x^{t-1}\right)\Big)+\sum_{t=0}^{\infty}\sum_{x^t\in X_\omega^t}\mu_2^k\left(x^t\right)\xi\left(x^{t-1}\right)\left(\left(\sum_{x^t\in X_\omega^t}\xi\left(x_t|x^{t-1}\right)y_\omega^{comp}\right)-y_\omega\left(x^t\right)\right)+\sum_{t=0}^{\infty}\sum_{x^{t-1}\in X^{t-1}}\mu_3^k\left(x^t\right)\xi\left(x^{t-1}\right)$$
$$\left((1-\delta_h)H^k\left(x^{t-1}\right)+g_{M_k}\left(H_{M_k}\left(x^{t-1}\right)\right)-H^k\left(x^t\right)+\sum_{x^t\in X_{F,h}^t}\xi\left(x_t|x^{t-1}\right)g_F^k\left(H_F^k\left(x^{t-1}\right)\right)\right)+$$
$$\left.\sum_{t=0}^{\infty}\sum_{x^{t-1}\in X^{t-1}}\mu_4^k\left(x^{t-1}\right)\xi\left(x^{t-1}\right)\left(H^k\left(x^{t-1}\right)-H_F^k\left(x^{t-1}\right)-H_{M_k}\left(x^{t-1}\right)\right)\right)$$

The first order condition wrt $c_0^k\left(x^{t-1}\right)$,

$$\frac{\partial\mathcal{L}_s}{\partial c_0^k\left(x^{t-1}\right)}=\beta^t\xi\left(x^{t-1}\right)u_1^k\left(c_0^k\left(x^{t-1}\right),c_1^k\left(x^{t-1}\right)\right)-\mu_1^k\left(x^{t-1}\right)\xi\left(x^{t-1}\right)=0$$

wrt $c_1^k\left(x^{t-1}\right)$,

$$\frac{\partial\mathcal{L}_s}{\partial c_1^k\left(x^{t-1}\right)}=\beta^t\xi\left(x^{t-1}\right)u_2^k\left(c_0^k\left(x^{t-1}\right),c_1^k\left(x^{t-1}\right)\right)-\mu_1^k\left(x^{t-1}\right)\xi\left(x^{t-1}\right)=0$$

wrt $y_\omega\left(x^t\right)$,

$$\frac{\partial\mathcal{L}_s}{\partial y_\omega\left(x^t\right)}=\mu_1^k\left(x^t\right)\xi\left(x^t\right)-\mu_2^k\left(x^t\right)\xi\left(x^{t-1}\right)=0$$

wrt $H_F^k\left(x^{t-1}\right)$,

Notice that $y_\omega\left(x^{t-1}\right)=y_\omega^{comp}$ appears with the probability $P\left(s_{t,k}=1\right)\Big(1-\left(1-q_F^k\left(H_F^k\left(x^{t-1}\right)\right)\right)\left(1-q_{M_k}\left(H_{M_k}\left(x^{t-1}\right)\right)\right)\Big)$ and the human capital accumulates with the probability $P\left(s_{t,k}=1\right)q_F^k\left(H_F^k\left(x^{t-1}\right)\right)$

$$\frac{\partial\mathcal{L}_s}{\partial H_F^k\left(x^{t-1}\right)}=\mu_2^k\left(x^{t-1}\right)\xi\left(x^{t-1}\right)P\left(s_{t,k}=1\right)q_F^{k\prime}\left(H_F^k\left(x^{t-1}\right)\right)\left(1-q_{M_k}\left(H_{M_k}\left(x^{t-1}\right)\right)\right)y_\omega^{comp}+$$
$$\mu_3^k\left(x^t\right)\xi\left(x^{t-1}\right)P\left(s_{t,k}=1\right)\left(q_F^k\left(H_F^k\left(x^{t-1}\right)\right)g_F^{k\prime}\left(H_F^k\left(x^{t-1}\right)\right)+q_F^{k\prime}\left(H_F^k\left(x^{t-1}\right)\right)g_F^k\left(H_F^k\left(x^{t-1}\right)\right)\right)-$$
$$\mu_4^k\left(x^{t-1}\right)\xi\left(x^{t-1}\right)=0$$

wrt $H_{M_k}\left(x^{t-1}\right)$,

$$\frac{\partial\mathcal{L}_s}{\partial H_{M_k}\left(x^{t-1}\right)}=\mu_2^k\left(x^{t-1}\right)\xi\left(x^{t-1}\right)P\left(s_{t,k}=1\right)\left(1-q_F^k\left(H_F^k\left(x^{t-1}\right)\right)\right)q_{M_k}'\left(H_{M_k}\left(x^{t-1}\right)\right)y_\omega^{comp}+$$
$$\mu_3^k\left(x^t\right)\xi\left(x^{t-1}\right)g_{M_k}'\left(H_{M_k}\left(x^{t-1}\right)\right)-\mu_4^k\left(x^{t-1}\right)\xi\left(x^{t-1}\right)=0$$

wrt $H^k\left(x^t\right)$

$$\frac{\partial \mathcal{L}_s}{\partial H^k\left(x^t\right)} = \left(1-\delta_h\right)\mu_3^k\left(x^{t+1}\right)\xi\left(x^t\right) - \mu_3^k\left(x^t\right)\xi\left(x^{t-1}\right) + \mu_4^k\left(x^t\right)\xi\left(x^t\right) = 0$$

such that

$$\mu_1^k\left(x^{t-1}\right) = \beta u_1^k\left(c_0^k\left(x^{t-1}\right), c_1^k\left(x^{t-1}\right)\right)$$

and

$$\mu_2^k\left(x^t\right) = \frac{\beta u_2^k\left(c_0^k\left(x^t\right), c_1^k\left(x^t\right)\right)\xi\left(x^t\right)}{\xi\left(x^{t-1}\right)}$$

and

$$\mu_3^k\left(x^t\right) = \frac{\mu_2^k\left(x^{t-1}\right)P\left(s_{t,k}=1\right)\left[q_F^{k\prime}\left(H_F^k\right)\left(1-q_{M_k}\left(H_{M_k}\right)\right) - q'_{M_k}\left(H_{M_k}\right)\left(1-q_F^k\left(H_F^k\right)\right)\right]y_\omega^{duo}}{P\left(s_{t,k}=1\right)q_F^k\left(H_F^k\right)g_F^{k\prime}\left(H_F^k\right) - g'_{M_k}\left(H_{M_k}\right)}$$

and

$$\mu_4^k\left(x^t\right) = \frac{\mu_3^k\left(x^t\right)\xi\left(x^{t-1}\right) - \left(1-\delta_h\right)\mu_3^k\left(x^{t+1}\right)\xi\left(x^t\right)}{\xi\left(x^t\right)}$$

13.2 Misallocation

In a standard market clearing scenario, large firms tend to attract a disproportionate share of specialized talent. This outcome arises even in cases where specialized research and development (R&D) might achieve technological breakthroughs more efficiently than large incumbents. This skewed allocation arises because incumbents offer superior compensation, enhanced risk-sharing, and more secure career prospects. A fundamental reason the risk-sharing channel arises in our model is the realistic assumption that complete Arrow securities do not exist in actual financial markets. [11]

Consequently, researchers are inclined to join large firms, resulting in underinvestment in specialized R&D within smaller firms. These advantages incentivize researchers to prefer employment with large firms, leading to underinvestment in specialized R&D within smaller firms. Consequently, a gap emerges between private and social outcomes, and that reflects a partial misallocation of human capital.

Euler equations embody that the marginal benefit of investing in the future equals the marginal cost of forgoing current resources. This balance determines the allocation of human capital across firms and technologies. In a competitive equilibrium, individuals and firms navigate the private trade-off between earning wages (or capturing equity returns) and investing in specialized human capital. Conversely, in a social planner's setting, the objective is to balance immediate production with building human capital to

[11] For more illustrations and analysis, see B.

maximize the probability of developing new technologies. By comparing the Euler equations derived from both scenarios, where private talents prioritize private returns and the planner considers broader social benefits, we can identify discrepancies that indicate the misallocation of human capital.

13.2.1 Shadow Values and Resource Allocation

Note that μ_1^k and μ_2^k both correspond to λ_1^k; μ_3^k corresponds to λ_2^k; and μ_4^k corresponds to λ_3^k. For notational simplicity, we focus on λ. In this framework,λ_1^k represents the shadow value of current resources, including consumption and wages. whenever λ_1^k multiplies w_F^k, w_{M_k}, $\theta_F^k \Pi_F$, or $\theta_{M_k} \Pi_{M_k}$, it signifies that each additional dollar earned today must be balanced against the immediate consumption value of that same dollar, ensuring the contemporaneous budget constraint holds.

Meanwhile, λ_2^k denotes the shadow value of future human capital. It captures how much an additional unit of skill, accumulated in period t and available in $t+1$, contributes to future payoffs, net of depreciation. In other words, λ_2^k embodies the idea that the planner or talent values building human capital in proportion to the higher profits or wages it yields in subsequent periods.

Lastly, λ_3^k enforces the constraint that talent has only one unit of type-k skill in each period, which must be allocated either to the large firm or to the specialized firm. This Lagrange multiplier often appears with a negative sign in the first-order conditions for h_F^k and h_{M_k} because increasing skill in one sector necessarily reduces it in the other. Consequently, a large positive λ_3^k indicates that there is a substantial opportunity cost of continuing to allocate skill in one firm rather than the alternative, reflecting a strong incentive to reallocate skill across firms.

13.2.2 Risk-Sharing and Cannibalization Channels

Two primary channels visible from the first-order conditions (FOCs) shape how skills are allocated between the large firm and specialized firms. The first channel risk-sharing arises because, in specialized firms, equity payoffs depend solely on the success of a single technology. If that technology fails, the equity becomes worthless, yielding zero returns. In contrast, large firms manage multiple technologies, so even if one project fails, workers can still share in the profits from other successful projects. Mathematically, this distinction appears in the FOCs for the specialized firm that only the success probability $q_{M_k}(H_{M_k})$ multiplies $\theta_{M_k} \Pi_{M_k}$, where q_{M_k} is the success probability dependent on human capital H_{M_k}, θ_{M_k} represents the weight of profits, and Π_{M_k} denotes the profit from technology k. Meanwhile, in the large-firm FOCs, additional terms capture the possibility that, when one technology fails, another might succeed, thus still yielding a partial payoff to labor and mitigating the downside risk for workers. This difference in payoff structures underpins the risk-sharing advantage of large, multi-technology firms over specialized ventures. Furthermore, theoretically connected to the 'paying to not leave' perspective in Anton and Yao [1994] in the IP setting, this channel can be further interpreted as that large incumbents effectively pay their talented employees, even those whose technologies might not ultimately be commercialized, in order to keep them from exiting and potentially

turning the firm's monopoly position into a duopoly. This setup deters expropriation and preserves the monopolist profit (by preventing new entrants) rather than slipping into a duopolist profit scenario.

Second, there is a cannibalization channel in the large firm. Here, the success of one technology can negate or reduce the incremental profit of another, as reflected in negative terms that appear whenever both technologies succeed simultaneously. For instance, in the FOC with respect to $H_F^0\left(x^{t-1}\right)$, a term like

$$-P\left(s_{t,1}=1\right) q_F^1(\cdots)\Pi_1$$

indicates that if Technology 1 is developed successfully, it may cannibalize the profits from Technology 0, reducing the marginal gain to investing additional skill in Technology 0. An important subtlety in this framework is that cannibalization can reduce both the immediate payoff via profit dilution and the incentive to invest in future human capital. Consequently, it is not straightforward to predict whether the large firm will over-invest or under-invest in skilled workers relative to a scenario without overshadowing.

When the probability of success of the large firm is high for each R&D line and cannibalization is minimal, the firm is especially inclined to hire skilled labor. Under these conditions, every project has a strong chance of success, and the firm can take advantage of multiple successful technologies rather than being forced to choose among them. This configuration is also pragmatic from an ex ante standpoint: if the firm already knows that certain technologies are unlikely to succeed or are highly cannibalized, investing heavily in them would be suboptimal. In contrast, where high success probabilities and weak overlap prevail, scaling up R&D across multiple lines becomes a clear strategy to secure substantial total returns, thereby justifying a more aggressive hiring approach. Previous literature shows that when previously standalone targets are absorbed through diversifying mergers, their post-acquisition R&D output drops both in quantity and novelty, showing that when previously independent targets are absorbed through diversifying mergers, their post-acquisition R&D output drops both in quantity and novelty Seru [2014]. This empirical pattern is consistent with the prediction of our model that overlapping technological lines within a large firm end up cannibalizing one another, lowering the marginal return to additional skilled labor.

13.3 Cash Constraint within One Period

When smaller rivals face stringent liquidity constraints and the potential monopoly payoffs for incumbents are substantial, large firms may engage in total hoarding of specialized talent. By monopolizing the employment of all available talents in a relevant field, the incumbent effectively prevents smaller competitors from succeeding in critical technological areas. This strategic talent stockpiling behavior allows the incumbent to maintain near-monopoly profits, but it comes at the expense of substantial innovation opportunities missed. These corner solutions represent the most extreme form of inefficiency that hinders innovation, where specialized talents are concentrated under monopolistic control.

Suppose that while each large firm individually lacks significant market power in hiring, the collective

action of all large firms effectively creates a duopsony in the labor market. In this framework, no single company has the ability to unilaterally set wages. However, the coordinated actions of these firms collectively shape labor market conditions. Profit in this setting can be expressed as a weighted sum of profits across all possible outcomes: (1) if $z = 1$ and both 0,1 succeed, the firm picks whichever yields a bigger payoff, (2) if $z = 0$ and both succeed, the firm does both $\Pi_0 + \Pi_1$, (3) if only Technology 0 is successful, and (4) if only Technology 1 is successful.

$$\begin{aligned}\mathbb{E}\left[\Pi_F\right] =& P\left(s_0 = 1\right) P\left(s_1 = 1\right) Q\left(z = 1\right) q_F^0\left(H_F^0\right) q_F^1\left(H_F^1\right) \left(1 - q_{M_0}\left(H_{M_0}\right)\right) \left(1 - q_{M_1}\left(H_{M_1}\right)\right) \Pi_1 + \\ & P\left(s_0 = 1\right) P\left(s_1 = 1\right) \left(1 - Q\left(z = 1\right)\right) q_F^0\left(H_F^0\right) q_F^1\left(H_F^1\right) \left(1 - q_{M_0}\left(H_{M_0}\right)\right) \left(1 - q_{M_1}\left(H_{M_1}\right)\right) \left\{\Pi_0 + \Pi_1\right\} + \\ & P\left(s_0 = 1\right) q_F^0\left(H_F^0\right) \left(1 - q_{M_0}\left(H_{M_0}\right)\right) \left(1 - q_F^1\left(H_F^1\right)\right) P\left(s_1 = 1\right) \left(1 - q_{M_1}\left(H_{M_1}\right)\right) \Pi_0 + \\ & P\left(s_1 = 1\right) q_F^1\left(H_F^1\right) \left(1 - q_{M_1}\left(H_{M_1}\right)\right) \left(1 - q_F^0\left(H_F^0\right)\right) P\left(s_0 = 1\right) \left(1 - q_{M_0}\left(H_{M_0}\right)\right) \Pi_1\end{aligned}$$

where we can clearly see that if the large firm hires all the type 0 talent,

$$\begin{aligned}\mathbb{E}\left[\Pi_F^*\right] =& P\left(s_0 = 1\right) P\left(s_1 = 1\right) Q\left(z = 1\right) q_F^0\left(H^0\right) q_F^1\left(H_F^1\right) \left(1 - q_{M_1}\left(H_{M_1}\right)\right) \Pi_1 + \\ & P\left(s_0 = 1\right) P\left(s_1 = 1\right) \left(1 - Q\left(z = 1\right)\right) q_F^0\left(H^0\right) q_F^1\left(H_F^1\right) \left(1 - q_{M_1}\left(H_{M_1}\right)\right) \left\{\Pi_0 + \Pi_1\right\} + \\ & P\left(s_0 = 1\right) q_F^0\left(H^0\right) \left(1 - q_F^1\left(H_F^1\right)\right) P\left(s_1 = 1\right) \left(1 - q_{M_1}\left(H_{M_1}\right)\right) \Pi_0 + \\ & P\left(s_1 = 1\right) q_F^1\left(H_F^1\right) \left(1 - q_{M_1}\left(H_{M_1}\right)\right) \left(1 - q_F^0\left(H_F^0\right) P\left(s_0 = 1\right) \left(1 - q_{M_0}\left(H_{M_0}\right)\right) \Pi_1\end{aligned}$$

Given that $q_F^0\left(\cdot\right)$ is monotone increasing and $q_F^0(H^0) > q_F^0(H_F^0)[1 - q_{M_0}(H_{M_0})]$, the hoarding strategy of the large firm significantly reduces the specialized research firm's probability of success.

$$\begin{aligned}\mathbb{E}\left[\Pi_F^*\right] - \mathbb{E}\left[\Pi_F\right] =& \Big(q_F^0\left(H^0\right) - q_F^0\left(H_F^0\right)\left(1 - q_{M_0}\left(H_{M_0}\right)\right)\Big)\Big(P\left(s_0 = 1\right) P\left(s_1 = 1\right) Q\left(z = 1\right) q_F^1\left(H_F^1\right) \left(1 - q_{M_1}\left(H_{M_1}\right)\right) \Pi_1 \\ & P\left(s_0 = 1\right) P\left(s_1 = 1\right) \left(1 - Q\left(z = 1\right)\right) q_F^1\left(H_F^1\right) \left(1 - q_{M_1}\left(H_{M_1}\right)\right) \left\{\Pi_0 + \Pi_1\right\} + \\ & P\left(s_0 = 1\right) \left(1 - q_F^1\left(H_F^1\right)\right) P\left(s_1 = 1\right) \left(1 - q_{M_1}\left(H_{M_1}\right)\right) \Pi_0\Big) > 0\end{aligned}$$

Consequently, the large firm has a clear incentive to employ the entire type-0 workforce, effectively blocking M_0 and increasing its expected profit when type-0 technology proves valuable. This result naturally leads to a corner solution under the specified boundary conditions, where hoarding ensures higher profits for the large firm.

Now, consider the scenario where specialized firms face a liquidity constraint, C_{M_k}. Under these conditions, the specialized firm cannot maximize its profit and instead seeks to hire as much human capital as its liquidity allows. To analyze this dynamic, we derive the relationship between w_{M_k} and w_F^k that the talent will ensure talents are indifferent between working for the large firm or the specialized firm. Given

this relationship, the specialized firm's hiring capacity is determined as C_{M_k}/w_{M_k}.

For simplicity, we directly plug in $h = H$. Consider the scenario that the other market is still at equilibrium. Recall that now the firm's FOCs don't hold. Since two Euler equations are the functions of four human capital allocations and two wages. Hold two type $-k$ human capitals unchanged (bc they're at equilibrium), and knowing $H_{M_k} = C_{M_k}/w_{M_k}$, by plugging w_F^k, we can solve for w_{M_k} and H_F^k. Now, we can write $w_{M_k}(w_F^k)$, $H_{M_k}(w_F^k)$, and $H_F^k(w_F^k)$ as a function of w_F^k. Therefore, the large firm can choose w_F^k such that

$$\begin{aligned} w_F^{k\prime} = \arg\max_{w_F^k} \mathbb{E}\left[\Pi_F(w_F^k)\right] - w_F^k H_F^k(w_F^k) \\ \text{s.t. } w_F^k H_F^k(w_F^k) - w_F^{k*} H_F^{k*} \leq \mathbb{E}[\Pi_F^*] - \mathbb{E}[\Pi_F(w_F^k)] \end{aligned}$$

and if there exists $w_F^{k\prime}$ such that

$$P\left(s_{t,0}=1\right) q_{M_0}\left(H_{M_0}\left(w_F^{k\prime}\right)\right) \cdot \left[1 - q_F^0\left(H_F^0\left(w_F^{k\prime}\right)\right) - P\left(s_{t,1}=1\right) q_F^1\left(H_F^1\left(w_F^{k\prime}\right)\right) Q\left(z_t=1\right)\right] \cdot \Pi_0 \leq 0$$

it ensures that either the specialized firm chooses not to invest in Technology 0 or there's no incremental payoff from 0 as the terms inside the bracket are 0. And if, the large firm chooses to hoard up all the talents.

13.3.1 When is Hoarding Not a Corner Solution? Extension to Infinitely Repeated Cash Constraints

In certain parameter regions, the large firm finds it optimal to hire only a partial share of type-k talent. This partial hiring strategy arises when marginal hiring costs, such as steeply rising wages or diminishing success probability gains from additional talent, outweigh the benefits of fully hoarding talent. For instance, if wages rise steeply with H_F^k, or if the large firm's marginal success probability gains are limited by R&D congestion, then the cost of fully hoarding all talent may exceed the expected benefit of guaranteeing monopoly. In these cases, the equilibrium outcome is characterized by an interior solution or a continuum of equilibria.

Nonetheless, when the potential payoff from monopoly status is large and the cost of hiring extra research talent is relatively small (e.g., highly cash-flush tech or finance incumbents), a corner solution becomes not only possible but also highly plausible. By clearing the entire talent market on its own, the large firm precludes competitors from acquiring the specialized knowledge needed to challenge its dominance, particularly when emerging technologies gain prominence.

To extend the analysis, we incorporate a liquidity constraint faced by the specialized firm and reformulate the problem using a dynamic programming framework, as detailed in Appendix A. In this setup, the firm's cash position is introduced as a state variable, evolving intertemporally based on revenues, costs, and liquidity constraints. The dynamic program captures the firm's optimal decisions regarding production and human capital allocation, accounting for the interaction between current and future constraints. This framework offers two key contributions: first, it provides a computational foundation for solving equilibrium outcomes in

settings with dynamic liquidity constraints, enabling numerical solutions to otherwise intractable problems; second, it generalizes the analysis by incorporating the dynamics of cash as a state variable, creating a flexible structure that future research can extend to explore richer financial and economic environments. While we do not solve the dynamic program explicitly, as it lies beyond the scope of this paper, its inclusion offers a robust foundation for studying the interplay between liquidity constraints and human capital allocation in competitive markets.

14 Simulation

This paper also presents a simple example to compare the steady state of the competitive equilibrium with that of the social planner's steady state. In this example, we examine two scenarios characterized by low cannibalization probability $Q(z = 1) = 0.1$ and high cannibalization probability $Q(z = 1) = 0.7$. Human capital accumulation is modeled using concave functions, capturing diminishing returns as investment in human capital increases. The accumulation functions for the large firms and specialized firms are defined as

$$g_F^k = \left(H_F^k\right)^{\alpha_F} \text{ and } g_{M_k} = \left(H_{M_k}\right)^{\alpha_M}$$

where $\alpha^F = 0.4$ and $\alpha^M = 0.8$. The probability of a project's success is modeled using logistic functions, which provide a bounded and smooth transition from low to high probability as human capital investment increases:

$$q_F^k = \frac{H_F^k}{1 + H_F^k} \text{ and } q_{M_k} = \frac{H_{M_k}}{1 + H_{M_k}}$$

The heatmaps Figure 1 and Figure 2 generated from our model vividly illustrate the contrasting steady-state outcomes under the social planner's cooperative investment strategy versus the competitive equilibrium framework across the two cannibalization scenarios. Specifically, the x-axis denotes the probability that Technology 0 becomes profitable, while the y-axis represents the probability that Technology 1 becomes profitable. Each heatmap cell corresponds to a unique combination of probabilities that Technology 0 and 1 are successfully developed, illustrating how human capital is distributed to the large firm under these probabilities.

Regardless of the cannibalization scenario, the social planner consistently achieves a uniform distribution of human capital allocation across all combinations of probability parameters. This uniformity indicates that the social planner optimally balances investments in both technologies, ensuring equitable and efficient resource distribution irrespective of their individual success probabilities. Under all combinations of probabilities, the social planner attains a substantially higher level of overall human capital compared to the competitive equilibrium, highlighting the superior effectiveness of coordinated investment strategies in maximizing collective human capital accumulation.

In the low cannibalization probability scenario, the competitive equilibrium exhibits distinct allocation

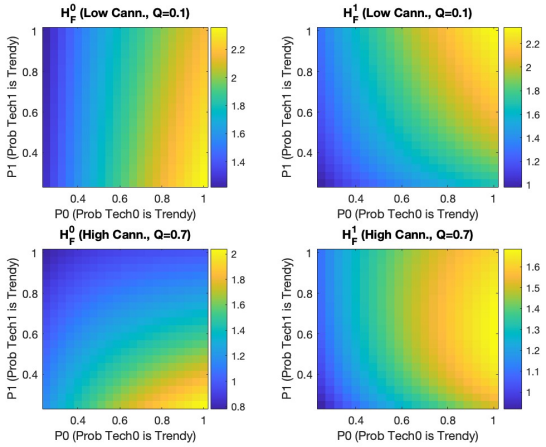


Figure 1: Low Cannibalization

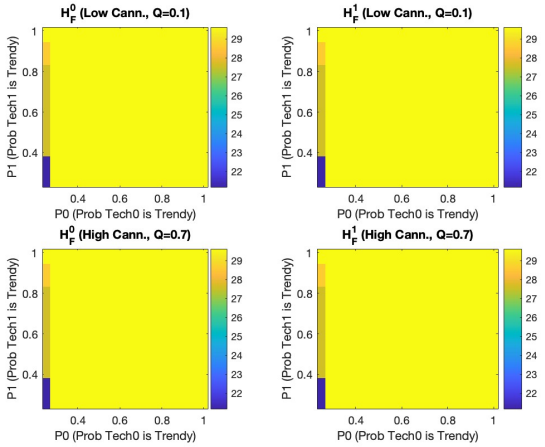


Figure 2: High Cannibalization

patterns. Specifically, the allocation to Technology 0 increases with the probability of Technology 0 being profitable but decreases as the probability of Technology 1 being profitable rises. This inverse relationship arises because Technology 0 is susceptible to cannibalization when both technologies are developed. In contrast, the allocation to Technology 1 increases with both probabilities, reflecting strategic adjustments by firms that consider the interplay between the success probabilities of both technologies.

In addition, under a high cannibalization probability scenario, the competitive equilibrium allocation patterns become significantly more pronounced. Cannibalization effects intensify, leading firms to preferentially allocate human capital to Technology 1. Specifically, even when the probability of Technology 0 being profitable approaches unity, if the probability of Technology 1 being profitable is similarly high, firms exhibit a reluctance to invest in Technology 0. This reluctance stems from the heightened risk of cannibalization when both technologies are concurrently developed. Consequently, human capital allocation to Technology 0 diminishes despite its strong profitability prospects, while investment in Technology 1 increases across all combinations of success probabilities. This pronounced cannibalization pressure results in a marked preference for Technology 1, as firms strategically optimize their investments to maximize returns while minimizing the adverse effects of overlapping technological advancements. The competitive equilibrium under high cannibalization thus demonstrates a shift towards concentrated investment in Technology 1, highlighting the inefficiencies that arise from uncoordinated, short-term decision-making in highly competitive environments.

15 Future Research Directions

15.1 Beyond Corner Solutions: Liquidity Constraints and Infinite Horizons

As discussed in Section 13.3.1, our analysis indicates that over-hiring equilibria are more likely to occur at corner solutions when incumbents possess abundant cash reserves. However, introducing liquidity constraints

and considering infinite-horizon settings can lead to partial or interior allocations of talent, potentially resulting in cyclical or more nuanced hoarding patterns. Future research could extend our dynamic programming framework to explore how liquidity constraints and long-term considerations influence the equilibrium distribution of human capital across firms over time, especially in response to macroeconomic shocks or variations in financing conditions. The comparative statics can be modeled by plugging in real-world parameters such as startup funding availability, discount factors, and R&D success elasticities to analyze when firms opt for complete or partial hoarding strategies.

15.2 Modeling Worker Heterogeneity and Risk Appetites

Introducing heterogeneity in risk preferences, career motivations, and opportunity costs among workers (research talent) could provide more nuanced equilibrium outcomes. In practice, some highly specialized researchers gravitate toward stable, high-paying positions at cash-rich incumbents, while others prefer the more uncertain but potentially rewarding environments of startups or small research labs. Incorporating such heterogeneity could reveal more detailed equilibrium dynamics. For instance, if risk-averse talents disproportionately prefer large incumbents, then the observed hoarding may become more extreme, whereas a critical mass of risk-loving researchers might choose smaller, specialized firms if those firms can match some baseline wage or equity upside. Such a framework would generate empirically testable predictions or stylized facts about how macro shocks or policy changes affecting the risk environment (for example, new labor-mobility legislation or altered patent regimes) might shift the distribution of advanced talent between incumbents and startups.

15.3 University–Academia Management and Funding Mechanisms

The broader institutional setting in which advanced talent is trained and funded has significant implications for both university and policy design. Concerns arise when large numbers of publicly funded PhD degree holders end up in relatively idle roles at big incumbents. Future studies could analyze how different PhD funding models, ranging from traditional fellowships to more targeted grants, affect the direction of graduates' career choices and whether universities should impose certain commitments or conditions to ensure that publicly funded human capital is productively deployed. Building on Yue [2024], one might also investigate more nuanced frameworks of university–industry partnerships that can spur breakthroughs without excessively diverting scientists' agendas to commercial priorities. Similarly, the approach in Myers [2020] could be used to compare the outcomes of graduates who move to industry labs with those who pursue research in academia or specialized institutes. By elucidating how certain institutional designs, fellowship requirements, or cooperative models mitigate misallocation, we could inform better policies for graduate-level training and public funding of science.

15.4 Equity Compensation, Moral Hazard, and Capital Allocation

Finally, our model highlights equity compensation as a central tool that helps incumbent firms attract and retain researchers, particularly when the firms can better absorb uncertainty across multiple R&D lines. A deeper investigation into the design of equity (and other incentive pay) could reveal how to align private and social outcomes more effectively. Key questions include how firms should structure restricted stock, options, or profit-sharing to prevent underutilization of top talent, and whether the moral hazard inherent in intangible research-intensive projects can be mitigated by certain contractual forms. For example, future studies could embed moral-hazard constraints in a dynamic equilibrium, examining how incumbents' ability to cheaply issue equity versus smaller rivals' struggles to do so exaggerate hoarding. Connecting back to Fazzari et al. [1988], researchers might explore whether constraints on external finance or expansions in equity markets lead to increased over-hiring and how policymakers or institutional investors can design more effective governance or compensation guidelines to mitigate socially harmful blocking while fostering genuine innovation and transformational entrepreneurial projects (Schoar [2010]).

16 Limitations and Extensions

While our model abstracts talent as being strictly 'type-k', that is, each research talent is assumed to be optimally suited only for developing technology k. We acknowledge that in reality advanced researchers typically possess a broader range of transferable skills. These skills (e.g., advanced problem-solving, quantitative analysis, and interdisciplinary thinking) allow them to contribute to projects even if those projects do not perfectly match their nominal specialization. They may also meaningfully create new research directions by collaborating with other researchers possessing different expertise.

We intentionally impose the restriction that type-k talent works exclusively on type-k technology to keep the analysis tractable and to isolate the core mechanisms driving talent hoarding and misallocation. Our primary objective is to demonstrate how strategic behavior by large incumbents, driven by financial strength, risk sharing, and competitive blocking, can lead to over-hiring and underutilization of highly specialized labor. It is plausible that future research can extend our our framework by allowing for partial cross-technology productivity or by endogenizing the evolution of general versus specialized skills. Incorporating a richer model of multi-dimensional human capital would indeed capture additional nuances in the highly educated talents' productivity, but would also complicate the analysis without qualitatively altering our key insights regarding talent misallocation. Our simplifying assumption is simply a useful first step to highlight the strategic talent stockpiling behavior observed in practice.

One further mechanism that could amplify talent hoarding that we do not explicitly model here is a prestige or branding effect. In some industries such as the tech sector, large incumbents may aggressively hire high-skilled research talents to signal their status to attract clients and investors and recruit star candidates). The simple presence of big names can raise the incumbent's reputation and help secure future talent or

partnerships. Our baseline framework focuses on the misallocation that arises from blocking and real-options incentives. A prestige-driven hiring spree would likely reinforce the over-hiring result since it gives incumbents an additional reason to accumulate surplus PhDs and thereby contributes to the same labor-market distortions. This might be an interesting direction for future empirical research, especially for those curious about disentangling which fraction of surplus hires are driven by brand benefits versus blocking or cannibalization concerns.

17 Conclusion

We develop a dynamic applied theory framework in which a deep-pocket incumbent competes with specialized labs for frontier researchers whose effort shifts discovery probabilities. The model delivers a simple logic for incumbent over-hiring and under-deployment through four forces: real-options value from parallel R&D bets under uncertainty; risk-sharing via broad equity that attracts risk-averse or liquidity-constrained talent; cash-based outbidding when specialists face financing frictions; and strategic blocking amplified by in-house cannibalization concerns. The resulting wedge between private and social returns arises upstream, at the research and early-development stages, rather than from product-market pricing power alone.

These incentives can misallocate scarce, high-skill human capital away from higher-fit specialized uses, dampen experimentation and diffusion, and redirect technology trajectories before market entry. The wedge is stronger when uncertainty and cannibalization risk are high and when specialist financing is tight, as our planner comparison clarifies. The framework suggests targeted remedies: easing specialist financing or strengthening non-dilutive support can counter cash-driven outbidding; competition policy that raises the expected cost of blocking (or the likelihood of cannibalization) tempers hoarding motives; and compensation design that limits blanket equity for idle roles or ties equity to externally verifiable milestones can reduce under-deployment while preserving incentives to innovate.

Several extensions are natural. Allowing richer skill portfolios and cross-technology productivity, embedding explicit moral-hazard and cash-constraint dynamics (as outlined in our DP appendix), and testing the model's predictions in microdata—e.g., how shocks to incumbent liquidity, option-granting capacity, or expected cannibalization alter hiring and redeployment—would sharpen both identification and policy design.

Importantly, the problem is unlikely to resolve itself without intervention because incumbents retain strong private motivations to block or preempt rival R&D, especially if they have abundant resources and face minimal constraints. Beyond labor regulations, the findings raise questions about how university and public funding structures might inadvertently amplify misallocation, for example by training advanced researchers whose skills are never fully deployed for innovations. Future work can build on our framework by introducing richer heterogeneity in worker preferences, liquidity constraints, and organizational structures, as well as testing for these mechanisms in large-scale microdata. Ultimately, a deeper understanding of talent hoarding

will help economists, policymakers, and university administrators improve labor-market efficiency and the innovation ecosystem, which hopefully also guides firm strategy on R&D portfolio breadth, equity and internal-labor-market design, and whether to build, partner, acquire, or spin out.

Appendix

A Dynamic Programming Approach with Cash Constraint

As mentioned in Section 13.3.1, the following is how to set up the problem in the dynamic programming approach. This would allow future researchers to carry this out computationally, and this approach also has cash as a state variable, if further generality is needed beyond the paper's main results.

A.1 Cash Constraint across Periods

A.1.1 Large Firm Problem

Given the initial conditions $\{w_F^k, H_{M_k}\}\forall k$, $\{H_F^0, H_F^1, C'_F\}$, solves

$$V_F\left(C_F, x_{-1}\right) = \max \mathbb{E}\left[R'_F - \sum_{k\in\{0,1\}} w_F^k H_F^k + \frac{1}{1+r}\cdot V_F\left(C'_F, x\right)\right]$$

subject to

$$\Pi_F\left(x^t\right) = \begin{cases} \max\left\{\Pi_0, \Pi_1\right\} & \text{if } s_0=1, s_1=1, z=1, n_{0,F}=1, n_{1,F}=1, n_{0,M}=0, n_{1,M}=0 \\ & \textbf{i.e. Both type-0 and type-1 succeed, large firm implements the bigger } \Pi, \\ & \textbf{both specialized firms fail} \\ \Pi_0+\Pi_1 & \text{if } s_0=1, s_1=1, z=0, n_{0,F}=1, n_{1,F}=1, n_{0,M}=0, n_{1,M}=0 \\ & \textbf{i.e. Both succeed, } z_t=0 \textbf{ so the firm implements } \Pi_0+\Pi_1\textbf{, both specialized} \\ & \textbf{firms fail} \\ \Pi_0 & \text{if } s_0=1, n_{0,F}=1, n_{0,M}=0, \neg(n_{1,F}=1, s_1=1, n_{1,M}=0) \\ & \textbf{i.e. only type-0 project makes positive profit, type-0 specialized firm fails} \\ \Pi_1 & \text{if } s_1=1, n_{1,F}=1, n_{1,M}=0, \neg(n_{0,F}=0, s_0=1, n_{0,M}=0) \\ & \textbf{i.e. only type-1 project makes positive profit, type-1 specialized firm fails} \\ 0 & \text{otherwise,} \\ & \textbf{i.e. No projects make profits} \end{cases}$$

$$R'_F = \left(1-\theta_F^0-\theta_F^1\right)\Pi'_F,$$

$$H_F^k + H_{M_k} \leq H^k,$$

$$w_F^0 H_F^0 + w_F^1 H_F^1 \leq C_F$$

$$C'_F = C_F + R'_F - w_F^0 H_F^0 - w_F^1 H_F^1.$$

where

$$\begin{aligned}\frac{\mathbb{E}\left[R'_F\right]}{1-\theta_F^0-\theta_F^1} =& P\left(s_0=1\right)P\left(s_1=1\right)Q\left(z=1\right)q_F^0\left(H_F^0\right)q_F^1\left(H_F^1\right)\left(1-q_{M_0}\left(H_{M_0}\right)\right)\left(1-q_{M_1}\left(H_{M_1}\right)\right)\max\{\Pi_0,\Pi_1\}+\\ & P\left(s_0=1\right)P\left(s_1=1\right)\left(1-Q\left(z=1\right)\right)q_F^0\left(H_F^0\right)q_F^1\left(H_F^1\right)\left(1-q_{M_0}\left(H_{M_0}\right)\right)\left(1-q_{M_1}\left(H_{M_1}\right)\right)\left\{\Pi_0+\Pi_1\right\}+\\ & P\left(s_0=1\right)q_F^0\left(H_F^0\right)\left(1-q_{M_0}\left(H_{M_0}\right)\right)\left(1-q_F^1\left(H_F^1\right)\right)P\left(s_1=1\right)\left(1-q_{M_1}\left(H_{M_1}\right)\right)\Pi_0+\\ & P\left(s_1=1\right)q_F^1\left(H_F^1\right)\left(1-q_{M_1}\left(H_{M_1}\right)\right)\left(1-q_F^0\left(H_F^0\right)P\left(s_0=1\right)\left(1-q_{M_0}\left(H_{M_0}\right)\right)\Pi_1\end{aligned}$$

A.1.2 Specialized Firm Problem

Each specialized firm M_k solves the following problem: given $\{w_{M_k}, H_F^k\}$, the firm chooses talent allocation $\{H_{M_k}\}$ to solve:

$$V_{M_k}\left(C_{M_k}, x_{-1}\right) = \max \mathbb{E}\left[R'_{M_k} - w_{M_k}H_{M_k} + \frac{1}{1+r}\cdot V_{M_k}\left(C'_{M_k}, x\right)\right]$$

subject to

$$\begin{aligned}&\Pi'_{M_k} = \Pi_\omega \cdot \mathbb{1}\left(s_k=1, n_{k,M}=1\right)\cdot\max\{\mathbb{1}\left(n_{k,F}=0\right), \mathbb{1}\left(s_{-k}=1, n_{-k,F}=1, n_{k,F}=1, z=1, \Pi_k<\Pi_{-k}\right)\},\\ &R'_{M_k} = \left(1-\theta_{M_k}\right)\Pi'_{M_k},\\ &C'_{M_k} = C_{M_k} + R'_{M_k} - w_{M_k}H_{M_k},\\ &w_{M_k}H_{M_k} \le C_{M_k},\\ &H_F^k + H_{M_k} \le H^k.\end{aligned}$$

A.1.3 Talent Problem

Given $\{w_F^k, w_{M_k}, \Pi_F^k, \Pi_{M_k}, H_{F,-1}^k, H_{M_k,-1}, h_F^{-k}, h_{M_{-k}}\}$ and $\{p_{\omega,-1}\}$ for $\omega \in \{0,1\}$, type k talent chooses $\{c_0^k$, c_1^k, h_F^k, h_{M_k}, $h^{k\prime}\}$ to solve

$$V^k\left(h_{F,-1}^k, h_{M_k,-1}, h^k, x_{-1}\right) = \max \mathbb{E}\left[u^k\left(c_0^k, c_1^k\right) + \beta V^k\left(h_F^k, h_{M_k}, h^{k\prime}, x\right)\right]$$

subject to

$$\begin{aligned}&p_0c_0^k + p_1c_1^k \le h_F^k w_F^k + \frac{h_{F,-1}^k}{H_{F,-1}^k}\cdot\theta_F^k\Pi_{F,-1} + h_{M_k}w_{M_k} + \frac{h_{M_k,-1}}{H_{M_k,-1}}\cdot\theta_{M_k}\Pi_{M_k,-1},\\ &h^{k\prime} = (1-\delta_h)h^k + g_{M_k}\left(h_{M_k}\right) + g_F^k\left(h_F^k\right)\cdot\mathbb{1}(s_k=1, n_{k,F}=1)\cdot\left(1-\mathbb{1}\left(z=1, s_{-k}=1, n_{-k,F}=1, \Pi_k<\Pi_{-k}\right)\right)\end{aligned}$$

Let $p_k := P(s_k = 1 \mid s_{k,-1})$ and $p_z := Q(z = 1 \mid z_{-1})$. Since h_F^k and h_{M_k} are not state-specific, and multiple states will lead to the same level of human capital in the next period, we use $V^k\left(h^{k\prime}\right)$ for simplicity

to expand the expectation of value function for type 0 talent is

$$(1-t)V^0\left((1-\delta_h)h^0+g_{M_0}\left(h_{M_0}\right)\right)+tV^0\left((1-\delta_h)h^0+g_{M_0}\left(h_{M_0}\right)+g_F^0\left(h_F^0\right)\right)$$

where $t=p_0q_F^0\left(h_F^0\right)\left(1-p_1q_F^1\left(h_F^1\right)\right)$ and for type 1 talent is

$$\left(1-p_1q_F^1\left(h_F^1\right)\right)V^1\left((1-\delta_h)h^1+g_{M_1}\left(h_{M_1}\right)\right)+p_1q_F^1\left(h_F^1\right)V^1\left((1-\delta_h)h^1+g_{M_1}\left(h_{M_1}\right)+g_F^1\left(h_F^1\right)\right)$$

A.1.4 Social Planner and Pareto Optimum

The social planner chooses $\{c_0^k,c_1^k,H_F^k,H_{M_k}\}_{k\in\{0,1\}}$ and $\{H^{0\prime},H^{1\prime}\}$ to solve

$$V\left(H^0,H^1,y_0,y_1,x_{-1}\right)=\max\left(\sum_{k=0}^{1}u^k\left(c_0^k,c_1^k\right)\right)+\beta\mathbb{E}\left[V\left(H^{0\prime},H^{1\prime},y_0^{\prime},y_1^{\prime},x\right)\right]$$

subject to

$$\begin{aligned}
&c_\omega^0+c_\omega^1=y_\omega,\forall\omega\\
&y_k^{\prime}=y_k^{comp}\cdot\mathbb{1}\left(s_k=1\right)\left(1-\mathbb{1}\left(n_{k,F}=0,n_{k,M}=0\right)\right)\\
&H^{k\prime}=(1-\delta_h)H^k+g_{M_k}\left(H_{M_k}\right)+g_F^k\left(H_F^k\right)\cdot\mathbb{1}(s_k=1,n_{k,F}=1),\forall k.
\end{aligned}$$

Since human capital always depreciates and human capital invested in the specialized firms always accumulates, denote $\mathcal{H}^{k\prime}=(1-\delta_h)H^k+g_{M_k}\left(H_{M_k}\right)$. Since multiple states might lead to the same values for state variables, we can reduce x for simplicity. Thus,

$$\begin{aligned}
\mathbb{E}\left[V\left(H^{0\prime},H^{1\prime},x,y_0^{\prime},y_1^{\prime}\right)\right]=\;&p_0p_1q_F^0\left(H_F^0\right)q_F^1\left(H_F^1\right)V\left(\mathcal{H}^{0\prime}+g_F^0\left(H_F^0\right),\mathcal{H}^{1\prime}+g_F^1\left(H_F^1\right),y_0^{comp},y_1^{comp}\right)+\\
&p_1q_{M_1}\left(H_{M_1}\right)p_0q_F^0\left(H_F^0\right)\left(1-q_F^1\left(H_F^1\right)\right)V\left(\mathcal{H}^{0\prime}+g_F^0\left(H_F^0\right),\mathcal{H}^{1\prime},y_0^{comp},y_1^{comp}\right)+\\
&\left(1-p_1q_{M_1}\left(H_{M_1}\right)\right)p_0q_F^0\left(H_F^0\right)\left(1-p_1q_F^1\left(H_F^1\right)\right)V\left(\mathcal{H}^{0\prime}+g_F^0\left(H_F^0\right),\mathcal{H}^{1\prime},y_0^{comp},0\right)+\\
&p_0q_{M_0}\left(H_{M_0}\right)p_1q_F^1\left(H_F^1\right)\left(1-q_F^0\left(H_F^0\right)\right)V\left(\mathcal{H}^{0\prime},\mathcal{H}^{1\prime}+g_F^1\left(H_F^1\right),y_0^{comp},y_1^{comp}\right)+\\
&\left(1-p_0q_{M_0}\left(H_{M_0}\right)\right)p_1q_F^1\left(H_F^1\right)\left(1-p_0q_F^0\left(H_F^0\right)\right)V\left(\mathcal{H}^{0\prime},\mathcal{H}^{1\prime}+g_F^1\left(H_F^1\right),0,y_1^{comp}\right)+\\
&p_0p_1q_{M_0}\left(H_{M_0}\right)q_{M_1}\left(H_{M_1}\right)\left(1-q_F^0\left(H_F^0\right)-q_F^1\left(H_F^1\right)\right)V\left(\mathcal{H}^{0\prime},\mathcal{H}^{1\prime},y_0^{comp},y_1^{comp}\right)+\\
&\left(1-p_0q_{M_0}\left(H_{M_0}\right)\right)p_1q_{M_1}\left(H_{M_1}\right)\left(1-p_0q_F^0\left(H_F^0\right)-q_F^1\left(H_F^1\right)\right)V\left(\mathcal{H}^{0\prime},\mathcal{H}^{1\prime},0,y_1^{comp}\right)+\\
&p_0q_{M_0}\left(H_{M_0}\right)\left(1-p_1q_{M_1}\left(H_{M_1}\right)\right)\left(1-q_F^0\left(H_F^0\right)-p_1q_F^1\left(H_F^1\right)\right)V\left(\mathcal{H}^{0\prime},\mathcal{H}^{1\prime},y_0^{comp},0\right)+\\
&\left(1-p_0q_{M_0}\left(H_{M_0}\right)\right)\left(1-p_1q_{M_1}\left(H_{M_1}\right)\right)\left(1-p_0q_F^0\left(H_F^0\right)-p_1q_F^1\left(H_F^1\right)\right)V\left(\mathcal{H}^{0\prime},\mathcal{H}^{1\prime},0,0\right)
\end{aligned}$$

B Market Frictions and the Absence of Arrow Securities

A fundamental reason the risk-sharing channel emerges in our model is the realistic assumption that complete Arrow securities do not exist in actual financial markets. In an idealized setting with complete markets, individuals could engage in state-contingent trades, allowing them to perfectly hedge against all possible future outcomes. For instance, an entrepreneur like Elon Musk graduating from Wharton could hypothetically purchase Arrow securities tied to the incomes of classmates who pursue careers in banking or consulting while shorting those tied to his success as the founder of Tesla. This would enable him to diversify his income risk, ensuring financial stability regardless of his entrepreneurial ventures' success or failure.

However, in reality, such Arrow securities are non-existent due to market frictions like information asymmetries, high transaction costs, and the impracticality of designing securities for highly specific states such as individual career trajectories or entrepreneurial outcomes. Consequently, individuals cannot perfectly hedge their idiosyncratic risks through state-contingent contracts. This limitation makes risk-averse or liquidity-constrained talents reliant on large, financially robust firms that can internally pool and manage risks across multiple projects and technologies. Without the ability to trade state-contingent claims, talents cannot diversify their income streams or shield themselves from entrepreneurial uncertainties. Consequently, they seek employment with large firms offering stable compensation and diversified equity, reinforcing incumbents' ability to attract and retain specialized talent. By incorporating these market frictions into our model, we ensure the risk-sharing channel operates under plausible conditions. This further enhances the validity of our theoretical predictions regarding talent misallocation.

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