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The asset specificity dilemma and emergence of general purpose technologies

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ABSTRACT

Asset specificity critically determines governance structures under incomplete contracting. While transaction cost economics prescribes hierarchical governance to protect specific investments, this view overlooks their potential to drive technological change. This paper models how asset specificity evolves and facilitates the emergence of General Purpose Technologies (GPTs). We show that governance focused on static efficiency can suppress innovation, creating a trade-off between appropriation protection and innovation. Under uncertainty, firms choosing market governance despite high asset specificity enable systemic spillovers and technological generalization. The model integrates transaction cost economics, capabilities theory, and GPT literature, reinterpreting relational contracts as governance mechanisms for dynamic efficiency.

1. Introduction

The governance of interfirm transactions has long been a central concern in organizational economics. Transaction Cost Economics (TCE), as articulated by Williamson [1975, 1985], argues that governance structures arise as responses to asset-specific investments and the associated hazards of contractual maladaptation and opportunism. According to this view, as asset specificity increases, firms are incentivized to internalize transactions to mitigate risks of ex post hold-up and underinvestment [Klein et al., 1978; Rogerson, 1992, 1996]. Building on this foundation, the incomplete contracting approach provided a more formal treatment of these issues [Grossman and Hart, 1986; Hart and Moore, 1990]. While this literature significantly advanced the theoretical rigor of governance analysis, it remains predominantly static, focusing on appropriation safeguards and incentive alignment rather than technological dynamics or capability development.

Recent theoretical and empirical research has increasingly questioned the adequacy of this static logic. Scholars within the capabilities tradition [Eisenhardt and Martin, 2000; Helfat et al., 2007; Langlois and Foss, 1999; Langlois and Robertson, 1989] contend that organizational boundaries are influenced not only by incentives but also by firms' ability to develop and reconfigure knowledge. This perspective highlights that governance choices affect not only appropriation safeguards but also the capacity of firms to explore, coordinate, and adapt. However, while this literature emphasizes dynamic aspects of organizational learning and innovation, it often remains conceptual and lacks a formal model linking these capacities to investment dynamics under governance constraints.

The emerging literature on modularity and open innovation underscores the value of loosely coupled systems that facilitate experimentation and recombination across firm boundaries [Langlois, 2002, 2003, 2006; Zheng et al., 2021]. Related empirical studies emphasize that governance structures often combine formal and relational elements, adapting to institutional and environmental contingencies [De Vita et al., 2011; Delbufalo, 2017, 2021; Geyskens et al., 2006; Henisz and Macher, 2004; Poppo and Zenger, 1998]. These perspectives suggest that governance should be understood not only as a safeguard against transaction hazards but also as a mechanism for enabling systemic learning and knowledge recombination. This broader view directly connects to research on General Purpose Technologies (GPTs), where governance and technological evolution are deeply intertwined.

The GPT literature emphasizes that transformative innovations—such as electricity, machine tools, information technologies, and chemical engineering—often arise from decentralized experimentation and subsequently diffuse across sectors [Bresnahan and Trajtenberg, 1995; Helpman, 1998; Rosenberg, 1998]. Three recurring insights are particularly relevant for understanding the relation between governance and innovation. First, GPTs typically originate in sector-specific contexts before proving generalizable. Second, their productivity impact depends critically on complementary innovations and organizational adjustments. Third, they generate systemic spillovers that reshape long-run economic trajectories [Bresnahan, 2010; David, 1990; Jovanovic and

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Rousseau, 2005; Nelson and Winter, 1982].

Rosenberg's historical analyses illustrate this mechanism vividly: GPTs often began with highly specific investments by specialist firms—such as in metalworking or chemicals—that later evolved into knowledge centers enabling widespread technological diffusion through vertical disintegration and market-based learning [Rosenberg, 1998]. More recent studies extend these insights to digital and platform technologies, showing how modularity and openness shape GPT diffusion across industries [Pulsiri and Vatananan, 2018; Shao and An, 2024; Wang et al., 2019; West et al., 2014]. Such accounts challenge the notion that high asset specificity necessarily mandates hierarchical governance. Instead, they suggest that market governance—despite appropriation risks—may provide a fertile environment for dynamic technological evolution.

Despite these insights, few formal models have endogenized asset specificity and its dynamic interaction with governance. Most models treat asset specificity as a fixed parameter and examine governance choice under the assumption of perfect foresight. However, in many real-world contexts, firms face substantial uncertainty regarding the future value of specific investments and whether such investments might trigger general-purpose spillovers. This necessitates a dynamic framework in which the evolution of asset specificity is modeled endogenously with the emergence of GPTs.

This paper addresses this gap by developing a formal model in which firms choose between market and hierarchical governance under uncertain expectations about GPT emergence. In our model, specific investments accumulate over time and may, probabilistically, reach a threshold that triggers a general-purpose innovation. Crucially, the governance structure influences both the incentives for continued investment and the likelihood of GPT emergence. While vertical integration secures appropriation, it may hinder the accumulation needed to reach the GPT threshold. Though riskier in the short term, market governance enables continued investment that may ultimately culminate in technological generalization. In line with the capabilities perspective, we treat firms' ability to explore, coordinate, and redesign interfaces as being realized through sustained investment, thereby linking abstract capability concepts to concrete investment dynamics.

This framework introduces the concept of the asset specificity dilemma, characterized by a trade-off between static efficiency, achieved through appropriation protection, and dynamic efficiency, facilitated by innovation enablement. In conditions of uncertainty, firms may prematurely integrate, thereby forfeiting the potential emergence of GPTs. Conversely, firms that persist in investing under market governance may ultimately reap benefits from cross-sectoral spillovers. Our model offers a theoretical foundation for comprehending this dilemma and elucidates why certain firms continue to sustain relationship-specific investments under market governance.

Furthermore, the model provides new insights into the phenomenon of relational contracting. Traditional interpretations, such as those by Dyer and Singh [1998], conceptualize relational contracts as repeated games that leverage trust and reputation to mitigate opportunism. However, we propose an alternative perspective: relational contracts may represent a governance strategy that prioritizes dynamic efficiency. Firms may uphold market-based relationships while making specific investments due to anticipated long-term innovation gains. Historical and contemporary examples substantiate this perspective. For instance, Rosenberg [1998] documents how the development of chemical engineering exemplified such dynamics, with specialized firms investing under market governance to become knowledge hubs for other sectors.

This paper contributes to the literature in three ways. First, it presents a formal model in which asset specificity evolves endogenously, and governance influences the dynamic trajectory of innovation. Second, it elucidates the conditions under which the asset specificity dilemma arises and when market governance may enhance innovation. Third, it offers a reinterpretation of relational contracts as governance solutions for dynamic rather than static efficiency. By integrating insights from TCE, capabilities theory, incomplete contract theory, and the GPT literature, our model provides a unified framework for understanding governance under technological uncertainty.

The remainder of the paper is organized as follows. Section 2 develops the formal model of asset specificity dynamics and analyzes governance choices under uncertainty. Section 3 discusses the theoretical, managerial, and policy implications of the model. Section 4 concludes with a summary and future research directions.

2. The model

This section introduces a formal model wherein asset specificity develops endogenously through firm investment and strategic governance decisions. The model is based on a dynamic framework in which firms invest in relationship-specific assets under either market or organizational governance. The accumulation of these assets influences both the marginal returns and the nature of governance itself.

2.1. Basic setting

We consider a representative firm that engages in long-term investment in relationship-specific assets, denoted by capital stock K_t. Time is discrete and infinite, indexed by t. In each period, the firm chooses investment I_t which contributes to the accumulation of K_t subject to depreciation $\rho \in (0,1)$ and efficiency $\alpha > 0$. The evolution of capital stock K_t follows the standard law of motion with depreciation and investment, widely used in dynamic investment models [Dixit and Pindyck, 1994] as follows:

$$K_{t+1} = (1-\rho)K_t + \alpha I_t. \tag{1}$$

The firm operates under a governance structure characterized by $\beta \in (0,1]$, representing the share of returns from specific capital that the firm can appropriate. $\beta = 1$ represents full internalization (organizational governance), while $\beta < 1$ corresponds to market governance with incomplete contracts.

The firm's revenue from specific capital is modeled as a concave quadratic function $f(K) = AK - bK^2$, $A > 0$ and $b > 0$, capturing diminishing marginal returns. This functional form reflects a widely adopted approach in dynamic investment models [Dixit and Pindyck, 1994], where such curvature allows for closed-form value function analysis. It should be noted that this is a revenue function, not a production function, and similar forms have also been used as local approximations in optimal control settings [Aoki, 1986; Kydland and Prescott, 1982]. Investment incurs a linear cost cI_t, with $c > 0$. Future payoffs are discounted by $\delta \in (0,1)$. The firm's value function is derived as follows:

$$V(K_t) = \max_{I_t} \beta f(K_t) - cI_t + \delta V(K_{t+1}). \tag{2}$$

To facilitate analytical tractability and to focus on the long-run comparative effects of governance choices, we focus on a steady-state analysis of investment in which the firm follows a constant proportional investment policy. This approach is widely used in dynamic economic modeling such as in growth theory and real options analysis where the key interest lies in characterizing long-run equilibria rather than transient adjustment paths [Acemoglu, 2009; Barro and Sala-i-Martin, 2004; Dixit and Pindyck, 1994].

Assuming steady-state investment $I = \rho/\alpha K$, the value function becomes as follows:

$$V(K) = \frac{1}{1-\delta}\left[\beta\left(AK - bK^2\right) - c\rho\,/\,\alpha K\right]. \tag{3}$$

This expression shows how the firm's long-run value under constant investment is determined by the trade-off between the partially appropriated return $\beta f(K)$ and the linear cost of maintaining capital $c\rho/\alpha K$. As K increases, the quadratic return term $-bK^2$ induces diminishing marginal returns, while the cost term scales linearly. Consequently, the optimal capital stock under market governance achieves a balance in this curvature, indicative of the firm's constrained capacity to fully realize investment benefits within a contracting framework.

Maximizing the value function with respect to K, we obtain the following:

$$V^*(\beta) \equiv \max_K V(K,\beta) = \frac{1}{1-\delta}\frac{(\beta A - c\rho/\alpha)^2}{4\beta b}, \tag{4}$$

$$K^* = \frac{\beta A - c\rho/\alpha}{2\beta b}. \tag{5}$$

The second-order condition, $-2\beta b/1-\delta < 0$, is always satisfied and ensures concavity. To make the model economically meaningful, we assume that the optimal capital stock K^* remains non-negative throughout the analysis.

Note that in the context of the steady-state analysis, the derivative of the value function with respect to β, $dV^*/d\beta$, can be expressed using the envelope theorem as the marginal return from capital evaluated at the steady-state level. Under purely static conditions, this derivative would indeed be expected to be positive, as a higher appropriation rate directly increases the firm's retained returns from investment. However, once dynamic effects such as spillovers or threshold-driven innovations are introduced in later sections, this monotonicity may no longer hold. The possibility of non-monotonic behavior reflects the central trade-off between static efficiency and dynamic efficiency that defines the asset specificity dilemma.

2.2. Governance choice

It is assumed that the firm initially operates under market governance. The decision to transition from market to organizational governance is based on a comparison of the expected lifetime values under each governance mode. If the value under organizational governance exceeds that under market governance, the firm will endogenously opt for vertical integration. This corresponds to $V^*(1) > V^*(\beta) + F$. For analytical tractability, we focus on this benchmark case without additional switching costs. This omission is reasonable in contexts where the lifetime gains from governance selection substantially exceed the switching cost.

In this case, the threshold level of β is derived as follows:

$$\overline{\beta} = \left(\frac{c\rho}{A\alpha}\right)^2. \tag{6}$$

This threshold expression shows that the minimum required appropriation rate β for market governance to be preferable increases with higher investment cost c, higher depreciation rate ρ, and lower investment efficiency α or productivity A. Intuitively, when it is costly or inefficient to maintain capital, the firm needs to capture a larger share of the returns (β) to justify operating under market governance. Conversely, if productivity A is high or investment efficiency α is strong, the firm can tolerate a lower β, making market governance viable even under partial appropriation. In other words, the threshold $\overline{\beta}$ increases with capital friction and decreases with technological productivity.

While the classical literature on governance choice emphasizes the direct role of contractual incompleteness and hold-up problems in shaping ownership decisions [Grossman and Hart, 1986; Hart and Moore, 1990; Holmström and Roberts, 1998], our model diverges in highlighting the potential of technical productivity and investment efficiency to exert a first-order influence. That is, while prior work treats technology primarily as a background factor that interacts with incentive constraints, our formulation endogenizes technology-related parameters such as productivity A and investment efficiency α as direct determinants of governance thresholds.

Subsequent work connects these insights to innovation and technological change [Bresnahan and Trajtenberg, 1995; Gans and Stern, 2003; Shao and An, 2024; Wang et al., 2019; West et al., 2014], showing that governance structures can influence not only appropriation but also the diffusion and scaling of general-purpose technologies.

Proposition 1. *The optimal governance choice is given by the following:*

(i) If $\beta > \overline{\beta}$, market governance is preferred.
(ii) If $\beta < \overline{\beta}$, organizational governance dominates.

These threshold dynamics reinforce a general intuition: firms are more likely to maintain market governance when the investment environment is productive and efficient, as they can coordinate through decentralized mechanisms without resorting to integration, while full appropriation under organizational governance becomes more attractive as diminishing returns or capital frictions intensify.

2.3. Perfect foresight of general-purpose technology (GPT)

We posit that when the stock of relationship-specific capital attains a certain threshold, the embedded knowledge and routines inherent in that capital become generalizable beyond the initial transaction. Although the physical asset remains specific to a particular use or partner, the technological know-how it embodies may find broader applications. Consequently, we propose that a new source of value is unlocked through diversification or technology licensing, thereby generating spillover effects that enhance firm value in a general-purpose manner.

We now formalize the conditions under which the emergence of GPT influences the firm's optimal governance choice. Suppose the firm's investment in relationship-specific assets surpasses a threshold K_g at which point the embedded knowledge becomes transferable beyond the initial transactional context—enabling diversification, technology licensing, or other spillover channels. We adopt a quadratic GPT spillover function dK^2 $(d > 0)$ for analytical tractability, capturing increasing returns to scale in general use.

The firm's value function under market governance with GPT activation is as follows:

$$V_{GPT}(K_t) = \max_{I_t}\left\{\beta f(K_t) + dK_t^2 - cI_t + \delta V_{GPT}(K_{t+1})\right\}, \tag{7}$$

where $K \geq K_g$. Assuming steady-state investment $I = \rho/\alpha K$, the value function becomes the following:

$$V_{GPT}(K) = \frac{1}{1-\delta}\left[(\beta A - c\rho/\alpha)K + (d - \beta b)K^2\right]. \tag{8}$$

Maximizing this expression with respect to K, we obtain the following:

$$V^*_{GPT}(\beta) = \frac{1}{1-\delta}\frac{(\beta A - c\rho/\alpha)^2}{4(\beta b - d)}, \tag{9}$$

$$K^*_{GPT} = \frac{\beta A - c\rho/\alpha}{2(\beta b - d)}. \tag{10}$$

The concavity of this value function is preserved as long as $d < \beta b$. If this condition is violated, the value function becomes convex, resulting in the absence of a finite optimum. This implies that the firm would prefer to invest indefinitely, a scenario that is economically implausible. In the subsequent analysis, we assume that this condition is met to ensure a well-defined interior solution. A comparison between (4) and (9) yields the following result.

Lemma 1. *If $d < \beta b$, the value of the firm after GPT activation is always higher than before. That is, $V^*_{GPT}(\beta) > V^*(\beta)$.*

This result implies that when the spillover effects from GPT are sufficiently moderate to maintain concavity, GPT activation unambiguously enhances firm value. Concavity ensures the existence of an interior optimum and precludes unstable explosive growth, while the addition of general-purpose value ensures that the total return surpasses the pre-GPT scenario.

Under conditions of perfect foresight regarding GPT activation, Lemma 1 implies that the firm will persist in investing to capitalize on the arrival of the GPT. Within this context, the criterion for the firm's selection between governance structures is derived by comparing $V^*_{GPT}(\beta)$ and $V^*_{GPT}(1)$.

Proposition 2. *Under perfect foresight, the optimal governance choice is characterized as follows:*

(i) If $\beta > \bar{\beta}$ and $d < \bar{d}$, then organizational governance is preferred, where $\bar{d} \equiv \frac{(\beta-\bar{\beta})b}{(1-\beta)\left((1+\beta)-2\sqrt{\bar{\beta}}\right)}$.

(ii) Otherwise, market governance is preferred.

Notably, Proposition 2 reverses the implication of Proposition 1. While Proposition 1 suggests that higher appropriation levels ($\beta > \bar{\beta}$) favor market governance by ensuring sufficient investment incentives under incomplete contracting, Proposition 2 demonstrates that under conditions of GPT emergence, organizational governance may yield higher value even when appropriation is high—provided that spillover effects are limited ($d < \bar{d}$). Conversely, when appropriation is low ($\beta < \bar{\beta}$), the potential for dynamic gains through GPT activation may justify continued investment under market governance. This reversal highlights how dynamic efficiency considerations can override static governance logic.

The threshold $\bar{d}$ characterizes the minimum GPT spillover intensity required to make market governance dynamically preferable, even when the firm cannot fully appropriate the returns (i.e., when β is low). In this expression, the numerator $(\beta - \bar{\beta})b$ captures the potential gains from internalizing GPT-driven productivity through organizational governance. A larger difference between the actual appropriation rate β and the minimum threshold $\bar{\beta}$, combined with higher internal GPT productivity b, strengthens the case for integration.

The denominator reflects how the strategic advantage of organizational governance increases with higher appropriation. A higher value of β reduces the overall denominator and thus raising the threshold. The second component, $(1+\beta) - 2\sqrt{\bar{\beta}}$, captures the gap between static and dynamic governance thresholds. A smaller gap indicates that the conditions for internalizing GPT gains through integration are more favorable. As this gap narrows, the threshold rises, making it more likely that the actual spillover d falls below it.

Importantly, this proposition reveals a structural instance of what we term the asset specificity dilemma. This dilemma refers to a fundamental trade-off between static efficiency, achieved through appropriation protection under organizational governance, and dynamic efficiency, enabled by spillover-driven innovation under market governance. Organizational governance, while efficient in static terms due to full appropriation, may limit the overall realized value of GPTs if that value depends on diffusion, recombination, or reuse beyond firm boundaries. This does not imply that integration blocks spillovers entirely, but rather that the general-purpose value of the technology is less fully captured within a closed governance structure.

By contrast, market governance—despite providing weaker short-term appropriation—allows broader diffusion and external scaling of GPTs, thereby unlocking greater long-term value when spillovers are substantial. This dynamic is embedded in our model via the β parameter, which governs the endogenous emergence of GPT. When firms invest under market governance, they forgo some immediate rents but stimulate the accumulation of exploratory capacity and GPT activation—especially when the external returns to GPT spillovers are high. When GPT emergence is foreseeable and spillovers are expected to be significant, rational firms may therefore prefer market governance, even under high asset specificity. Persisting with integration in such contexts may lead to under-realization of GPT value—exemplifying the misalignment between static efficiency and dynamic innovation that defines the asset specificity dilemma.

This interpretation aligns with the insights of Aghion and Tirole [1994], who emphasize the ownership–innovation trade-off under incomplete contracting. The threshold derived in Proposition 2 thus delineates the region in which dynamic innovation potential outweighs static ownership control, shifting the optimal governance structure toward market-based arrangements.

2.4. *Unawareness of GPT*

While the previous analysis assumes perfect foresight regarding GPT activation, firms do operate under uncertainty, lacking full knowledge of future technological breakthroughs. This section relaxes the assumption of full rationality or perfect foresight and explicitly incorporates Knightian uncertainty [Knight, 1921], acknowledging that firms cannot even assign probabilities to future GPT realization. In such cases, the firm invests based on pre-GPT expectations, without anticipating the eventual emergence of general-purpose spillovers.

Let the firm invest in relationship-specific capital under pre-GPT expectations. GPT is endogenously triggered when the firm's optimal capital accumulation under the pre-GPT regime exceeds the critical threshold K_{GPT} required for general-purpose spillovers to materialize. As Eq. (5) shows, the optimal investment level is strictly increasing in β. Hence, organizational governance ($\beta = 1$) yields a strictly higher investment level than market governance ($\beta < 1$), making it more likely that the condition $K^* > K_{GPT}$ is satisfied.

Proposition 3. *GPT is more likely to emerge under vertical integration ($\beta = 1$) than under market governance ($\beta < 1$).*

While Proposition 3 considers the case of $K^* > K_{GPT}$, what happens when $K^* < K_{GPT}$? In such instances, GPT activation does not occur, and the firm remains unaware of the missed opportunity.

A historical example from Rosenberg [1976] sheds light on this mechanism. In the case of the American machine tool industry, GPT development initially occurred within vertically integrated textile firms. However, the subsequent vertical disintegration of these firms led to the emergence of independent machine tool producers. This trajectory can be interpreted in light of Proposition 2: when the spillover potential of a technology is high, market governance enables higher GPT value realization. Hence, vertical disintegration may have been a rational response to the increasing generality and applicability of machine tools, allowing specialized suppliers to emerge and diffuse the technology more broadly.

2.5. *Probabilistic expectation of GPT*

In our examination of the two extreme scenarios—complete foresight of GPT activation and the total absence of such expectations—we now enhance our analysis by incorporating a probabilistic belief framework.

Specifically, we introduce a subjective probability $p \in (0, 1)$ that reflects the firm's belief about the likelihood of GPT activation. Suppose that a firm operates under a given governance structure characterized by a parameter β, and has achieved its optimal investment level K^*, but has not yet reached the threshold for GPT emergence (i.e., $K^* < K_{GPT}$).

In this setting, the firm's investment decision is guided by a comparison between the current realized value and the expected value if the GPT were to emerge. Specifically, we define the value gap as follows:

$$\Delta(\beta) \equiv pV^*_{GPT}(\beta) - V^*(\beta) = \frac{(\beta A - c\rho/\alpha)^2}{4(1-\delta)} \frac{d-(1-p)\beta b}{(\beta b - d)\beta b}. \tag{11}$$

We then consider the relative value gap between market-based and organization-based governance as follows:

$$\Delta \equiv \frac{\Delta(\beta)}{\Delta(1)} = \frac{(\beta A - c\rho/\alpha)^2}{(A - c\rho/\alpha)^2}\,\frac{b(b-d)}{\beta b(\beta b - d)}\,\frac{d-(1-p)\beta b}{d-(1-p)b}. \tag{12}$$

This ratio captures how the expected benefit from GPT emergence, relative to the current value, differs across governance forms. A higher ratio implies that the incentive to invest in GPT is stronger under market-based governance. Since we assume that the investment cost function is the same under both market and organizational governance, the relative incentive to invest in GPT hinges largely on the magnitude of this value gap. As evident from the right-hand side of Eq. (9), the ratio Δ diverges to infinity as β approaches zero. This implies the following result.

Proposition 4. *As β becomes small and approaches zero, the incentive to invest in GPT becomes stronger under market-based governance than under vertical integration.*

While the value ratio Δclearly converges to unity as β approaches 1, it is analytically intractable to determine whether this ratio increases or decreases in the immediate neighborhood of $\beta = 1$ without imposing specific parameter restrictions. By contrast, when β is small, the ratioΔ clearly increases and diverges to infinity. In this region, the GPT investment incentive under market governance becomes unambiguously strong.

This asymmetry could be interpreted as follows. When β is small, reflecting loosely coordinated, market-based governance, the firm's current value remains relatively low. In such cases, the gap between the current value and the potential value associated with GPT emergence becomes especially large. As a result, the incentive to invest in GPT is strong, as it promises a significant improvement over the status quo. In contrast, when β is high, corresponding to tightly coordinated, organizational governance, the firm already achieves a high level of value. The additional benefit from GPT investment is therefore more limited, which makes the incentive to invest comparatively weaker. This contrast explains why GPT investment tends to be more attractive under market-based governance, particularly when β is low.

As β approaches zero, the incentive to invest in GPT becomes especially strong. This observation implies that the emergence of GPTs may ultimately be driven by venture firms or startups operating under loosely coordinated market governance. Historical cases such as early U.S. semiconductor firms including Fairchild Semiconductor and Intel or Apple in the personal computing industry exemplify this dynamic [Berlin, 2005; Isaacson, 2011; Lécuyer, 2006].

Of course, GPT development may also occur within the context of relationship-specific investments facilitated by market transactions—what is often termed relational contracts. This represents a novel interpretation of relational governance as a vehicle not only for safeguarding appropriability, but also for enabling GPT-oriented innovation. We return to this point in the Discussion section.

Regarding the effect of the GPT realization probability p, the ratio Δ decreases in p. As p increases, the GPT investment incentive grows more rapidly under organizational governance than under market-based governance. This is because, under market governance, the marginal gain from an increase in p is effectively discounted, as indicated by the presence of βb in the denominator on the right-hand side of Eq. (12).

This paper shows that governance interacts with the dynamic accumulation of asset specificity and with endogenous GPT spillovers, rather than acting as a static response to contractual hazards as in classical TCE. Propositions 1 and 2 demonstrate that, once dynamic GPT spillover effects are incorporated, the relationship between appropriation and governance may reverse. Such dynamic reversals cannot be derived from static TCE logic and constitute a central theoretical contribution of the model.

It is also important to distinguish the present analysis from Proposition 2. Proposition 2 assumes perfect foresight and asks which governance mode should be chosen to realize GPT, based on a comparison of $V^{*}_{GPT}(\beta)$ and $V^{*}_{GPT}(1)$. In contrast, the current analysis holds the governance structure fixed and evaluates whether GPT investment is justified by comparing $pV^{*}_{GPT}(\beta)$ against $V^{*}(\beta)$. This focus is justified by the uncertainty of GPT realization: when the outcome is uncertain, firms are more likely to evaluate investment under their existing governance rather than assuming structural change from the outset.

This analysis highlights a critical governance dilemma: even when GPT promises significantly higher long-term value, the choice of organizational governance—characterized by high asset specificity—may inhibit the necessary investment to realize it. In other words, the firm may become locked into a governance mode that maximizes short-term efficiency under current conditions but fails to support the transition to a more valuable long-term trajectory enabled by GPT.

This tension can be described as the asset specificity dilemma. Proposition 4 formalizes this idea by showing that market-based governance, especially when asset specificity is low, tends to create stronger incentives for GPT investment than organizational governance. In contrast, vertical integration is more likely to miss this transformative opportunity due to its already realized value under current coordination structures. This highlights the inherent asymmetry in how different governance modes support long-term innovation.

Fig. 1 illustrates the dynamics of the asset specificity dilemma. Before the emergence of a GPT, organizational governance yields higher levels of relationship-specific investment and correspondingly higher value. However, as shown in Proposition 2, after a GPT emerges, market governance delivers greater value when spillover effects are sufficiently strong. As a result, when comparing the pre-GPT optimal value with the post-GPT value, the gap is larger under market governance. This larger gap implies that firms operating under market governance have a stronger incentive to invest in GPTs, while firms under organizational governance are more likely to remain at their current position, as depicted in the figure.

3. Discussion

To clarify the contribution of the paper, this section organizes the discussion around three questions: how the model extends existing theories of governance, how it informs managerial decision-making under uncertainty, and how it reshapes policy perspectives on GPT diffusion.

This section highlights the broader implications of our model by moving beyond a confirmatory restatement of prior research. We emphasize three dimensions of contribution: (1) theoretical implications for the determinants of governance and the asset specificity dilemma, (2) managerial insights regarding innovation under uncertainty, and (3) policy implications for fostering the emergence and diffusion of GPTs.

3.1. Theoretical contributions: endogenizing asset specificity and thresholds

A first contribution lies in formally endogenizing asset specificity and demonstrating how its accumulation interacts with governance to shape innovation trajectories. While prior studies qualitatively noted that high specificity may sometimes foster, rather than hinder, technological generalization [Langlois, 2002; Rosenberg, 1998], our model shows how this mechanism operates dynamically. Specifically, we identify an endogenous threshold (β) that determines when market governance can generate GPT spillovers despite weaker appropriation. This clarifies the structural conditions under which static efficiency (appropriation protection) and dynamic efficiency (innovation enablement) diverge, thus formalizing what we call the asset specificity dilemma.

This perspective extends traditional Transaction Cost Economics [Williamson, 1985] by shifting the focus of analysis from hazard minimization to innovation trajectories, and it provides a bridge to innovation studies. It also complements the capabilities perspective [Langlois

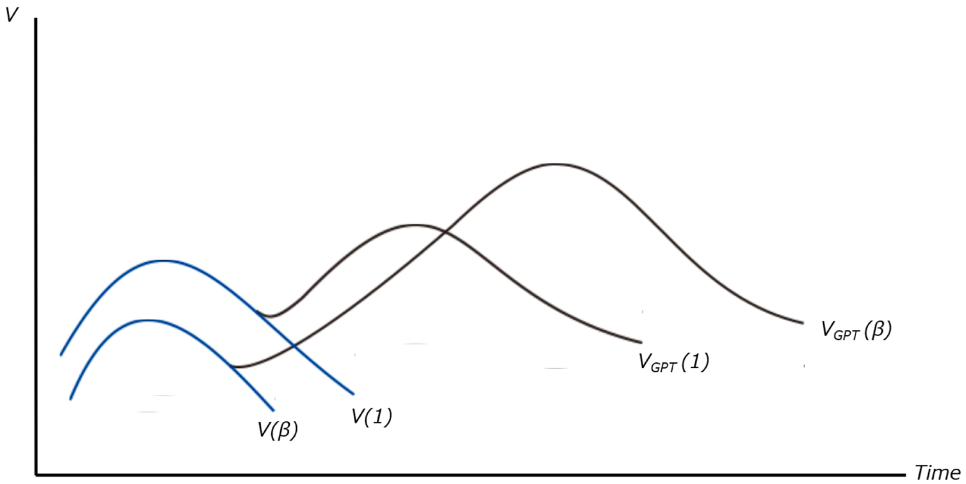

Fig. 1. Asset specificity dilemma (anticipation of GPT case).

and Foss, 1999; Teece et al., 1997], by modeling how firms' ability to reconfigure knowledge is conditioned by governance choices, specifically through investment dynamics. In this way, the paper provides a bridge between theories of the firm and innovation studies, offering a tractable formalization of dynamics that were previously discussed only qualitatively.

Several historical cases discussed above can be directly interpreted through the lens of the model's propositions. For example, Rosenberg's (1976) account of the machine tool industry corresponds closely to Proposition 2: as spillover potential increased, market governance enabled higher realization of GPT value, leading to vertical disintegration. Similarly, the emergence of semiconductor startups such as Fairchild and Intel illustrates Proposition 4, where low appropriation environments generate strong incentives to invest in GPT-oriented innovation. These cases do not merely illustrate the theory but help clarify the mechanisms formalized in the model.

3.2. Managerial implications: governance and innovation trade-offs

From a managerial standpoint, the model provides a novel perspective on the classic make-or-buy dilemma. While integration ("make") secures appropriation and raises short-term investment incentives, it may weaken incentives to pursue GPT-oriented innovation when spillover potential is high. By contrast, market governance ("buy"), despite weaker short-run appropriation, can sustain exploratory investment and enable long-run value creation through GPT diffusion.

This insight helps explain why relational contracts, often seen as mechanisms for trust and repeated exchange [Dyer and Singh, 1998; Zaheer and Venkatraman, 1995], can also function as dynamically efficient governance strategies. Classical interpretations emphasize that trust and reputation mitigate opportunism in repeated interactions. However, empirical observations complicate this narrative. Toyota's supplier network illustrates this point: contracts are frequently renegotiated, and underperformers are readily replaced, yet suppliers continue to make highly specific investments. A striking example is the 1997 Aisin fire, when Toyota's key brake-valve supplier suffered a plant shutdown. In response, >60 firms—including those without prior ties to Toyota—rapidly retooled production using Aisin's blueprints. Despite no guaranteed compensation, these firms undertook costly investments, supporting supply chain resilience and technological adaptation.

Such behavior is difficult to explain purely through hold-up avoidance or static trust. Instead, it aligns with our model's interpretation of relational contracts as dynamic investment platforms. Gulati and Nickerson [2008] show that trust can complement formal governance under high specificity and uncertainty, while Tiwana [2008] and Graebner [2009] demonstrate how strong ties enable coordination and bridging ties foster exploratory learning. Relational governance thus supports adaptive investment not only by mitigating opportunism but also by embedding firms into networks where knowledge recombination and capability signaling generate long-term innovation value.

This interpretation is further reinforced by the modularity perspective: Langlois [2002] shows that modular networks enable decentralized adaptation, while Hart and Moore [2008] emphasize that contracts serve as reference points shaping expectations and entitlements. Taken together, these insights suggest that relational contracts are effective not merely as equilibrium outcomes of repeated games, but as governance forms emerging from dynamic efficiency considerations under asset specificity and technological uncertainty.

3.3. Policy implications: enabling GPT diffusion

At the policy level, the findings underscore that governance structures influence not only transactional efficiency but also the systemic emergence of GPTs. Policies that encourage openness, modularity, and relational contracting—such as promoting interoperable standards, supporting innovation networks, and reducing switching costs—can enhance the likelihood of GPT diffusion. Conversely, overly protective or integration-biased institutional environments may secure short-term rents but inadvertently slow down the emergence of GPTs.

In particular, the model suggests that institutional design should balance appropriation with diffusion. For regulators, this implies the need to avoid overemphasizing intellectual property protections or hierarchical integration at the expense of fostering recombination and spillover. For industrial policy, the implication is to support ecosystems where relationship-specific investments can evolve into general-purpose innovations through decentralized experimentation.

3.4. Limitations and future research

While our model provides a novel formalization of the dynamic interaction between asset specificity and governance, it also entails several limitations that point to promising directions for future research. First, the framework is deliberately abstract and has not been calibrated with empirical data. Future work could test the model's predictions by exploiting patent data, industry-level investment patterns, or case-based evidence of GPT emergence. Second, the model focuses on investment incentives but abstracts from institutional and behavioral dimensions—such as regulatory interventions or cognitive constraints—that may critically shape governance outcomes. Extending the analysis to incorporate these factors would improve its explanatory scope. Third, our analysis has emphasized theoretical implications, but further research could explore the practical conditions under which relational contracting and modular governance translate into measurable innovation outcomes. Addressing these issues would strengthen the bridge between theory and empirical inquiry, and contribute to a deeper understanding of how governance influences long-term technological trajectories.

4. Conclusion

This paper develops a formal model that endogenizes asset specificity and examines its dynamic interaction with governance and innovation. By doing so, it introduces the concept of the asset specificity dilemma, which captures a fundamental trade-off: while hierarchical governance ensures static efficiency through appropriation protection, market governance may enhance dynamic efficiency by sustaining exploratory investment and enabling the emergence of GPTs.

Our analysis yields three key contributions. First, it provides a theoretical foundation by formalizing how relationship-specific investments, when accumulated under different governance modes, can probabilistically cross thresholds that trigger technological generalization. This extends Transaction Cost Economics beyond static hazard minimization and connects it with capabilities theory and innovation studies. Second, it offers practical insights for managers: premature integration may undermine innovation potential, whereas maintaining relational, market-based governance can preserve flexibility for GPT-oriented learning and spillovers. Third, it highlights policy implications, showing that institutional environments which encourage openness, modularity, and relational contracting are more conducive to GPT diffusion than those that overemphasize protective integration.

Future research could extend this framework by calibrating the model with empirical data, such as patent-based measures of GPT emergence, industry-level data on modularity and governance structures, or by simulating governance dynamics across industries with varying degrees of specificity and modularity. In this way, the model provides a foundation for bridging theoretical perspectives with empirical inquiry, offering a dynamic lens through which to study how governance choices shape long-term innovation trajectories.

Accountability statement

I confirm that I am solely responsible for all aspects of this work, including the accuracy and integrity of the analysis and presentation.

CRediT authorship contribution statement

Tsutomu Harada: Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Software, Resources, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Conceptualization.

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Data availability

No data was used for the research described in the article.

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