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AI Service Sourcing for Sustained Operational Value: A Two-Period Contracting Model

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Abstract

AI service sourcing requires firms to balance current operating efficiency against investment in future service value. We develop a two-period principal–agent model comparing internal teams and external providers with adverse selection. Early renewal generates client-usable capital, while public assessments inform contract design. We characterize optimal screening contracts within the specified class. Under unrestricted fixed transfers, proportional screening distortions depend on normalized risk. Renewal reverses an initial outsourcing advantage only when its relative internal value gain exceeds a certain threshold. In an illustrative baseline, internalization is preferred when external asset portability is below 0.6662. Under nonnegative fixed transfers, the portability threshold falls to 0.3477, making outsourcing preferable at the baseline portability of 0.40. Joint-parameter analyses reveal both reversals and nonreversals, while differences in agent surplus can separate principal-value and risk-adjusted relationship-surplus rankings. The findings clarify how renewal incentives and contractual constraints shape the economic conditions for sustaining AI service value.

Keywords: artificial intelligence; service outsourcing; economic sustainability; intertemporal incentives; operational efficiency

1. Introduction

Deploying an artificial intelligence (AI) application is an organizational decision as well as a technology purchase. Access to an algorithm does not by itself provide the data infrastructure, implementation expertise, and complementary organizational resources required to generate business value [1,2]. Evidence from AI-assisted customer support documents heterogeneous productivity gains across workers within a common application [3]. A further temporal distinction is that an application with strong initial performance still requires data pipeline maintenance, validation, and adaptation to sustain operational support. Research on machine-learning systems identifies persistent maintenance costs, data dependencies, and interactions between components as important sources of technical debt [4].

These considerations make the choice between an internal AI team and an external service provider more than a comparison of current implementation costs. An external provider offers a potential cost advantage through specialized expertise, whereas an internal team offers closer access to firm-specific information and potentially more usable renewal assets. Neither arrangement eliminates uncertainty about implementation capability or the incentive problem arising from unobservable effort. The organizational choice made before

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deployment therefore determines not only who supplies the current service, but also the incentives and productive conditions under which future service value is created.

One economic concern of sustainability in the intertemporal problem is the commitment of current resources to preserving the value of future services. The temporal perspective of Bansal and DesJardine [5] motivates this distinction, without making profitability a sufficient sustainability criterion. In software-intensive systems, Lago et al. [6] distinguish the preservation of economic value from technical support for continued use and evolution, within a broader multidimensional framework. Our model connects these two concerns through costly renewal capital.

This paper addresses three questions. How should a firm jointly reward current AI operation and future service performance when implementation capability is private, and effort is hidden? When does renewal investment alter the choice between internalization and outsourcing? Under what conditions does the sourcing decision maximizing the principal's value differ from the decision implied by risk-adjusted relationship surplus?

We construct a two-period contracting model with a risk-neutral firm and a risk-averse implementation agent. In the first period, the agent supplies current operating effort and invests in renewal. The latter creates a stock of client-usable service capital that enters the second period's operating benefit. The agent then supplies a separate second-period operating effort. Capability is a fixed, privately known binary type and is not redrawn between periods. A public capability assessment precedes a single menu of fully committed, two-period linear contracts. Capability remains privately known under either arrangement. The two arrangements differ in setup cost, assessment technology, operating efficiency, and the usefulness of renewal assets to the client.

The absence of additional screening distortions for high types is a standard result in adverse-selection models. Our contribution is to connect established screening mechanisms with endogenous, client-usable renewal capital and a matched sourcing comparison. Future performance incentives jointly induce subsequent operation and early renewal investment, affecting productive potential, screening distortions, and relative sourcing value. Comparing the full model with a two-period no-renewal benchmark isolates the renewal mechanism from the effect of extending the operating horizon. All optimality results are derived within the specified linear-contract class.

The organizational implications depend on both technology and contractual feasibility. Under unrestricted fixed transfers, productive renewal can reverse an initial outsourcing advantage when external asset portability is sufficiently low. Imposing nonnegative fixed transfers changes this comparison. Under a sufficient condition, an optimal pooling contract eliminates the gross informational value of capability assessment. At the illustrative baseline, this restriction restores outsourcing as the preferred sourcing mode. Joint-parameter analyses further document both reversals and nonreversals, highlighting the conditional nature of these findings.

The remainder of this paper is organized as follows. Section 2 reviews the related literature. Section 3 develops the two-period principal–agent model of AI service internalization and outsourcing. Section 4 derives the optimal intertemporal contracts and examines capability assessment, organizational choice, and their implications for sustained operating value. Section 5 presents numerical analyses to illustrate the theoretical results and explore the effects of key parameters. Section 6 discusses the main findings and concludes the paper. Detailed mathematical proofs are provided in Appendix A.

2. Related Literature

2.1. AI Capabilities and Firm Performance

The economic value of AI applications depends on more than access to a model. Research on information technology emphasizes complementary investments in organizational processes and human capital as important conditions for realizing productive gains [7,8]. Building on this perspective, Mikalef and Gupta [1] conceptualize AI capability as a combination of technological, human, and organizational resources. Raisch and Krakowski [2] distinguish automation from augmentation and highlight the managerial challenges of combining them. These contributions imply that adopting AI tools and organizing the work required to use them are related but distinct decisions.

Recent economic evidence provides a further reason to study this distinction. Brynjolfsson et al. [3] document heterogeneous productivity effects following the introduction of generative AI in customer support. Babina et al. [9] associate firm-level AI investment with growth and product innovation, whereas Acemoglu et al. [10] study changes in hiring and skill requirements at establishments adopting AI. These studies examine different outcomes and empirical settings, rather than a common measure of AI deployment efficiency. Gu and Jin [11] distinguish internal AI capability from external AI tool utilization in an export-performance setting. Their resource measures do not directly identify the governance boundary between an internal implementation team and an external service contractor. Our model explicitly identifies the party responsible for operating effort and the creation of client-usable renewal assets.

2.2. Organizational Boundaries and Contracting Hazards

The make-or-buy question originates in the distinction between the costs of market exchange and those of internal coordination [12]. Property-rights theories explain how ownership reallocates residual control and hence influences investment incentives [13,14]. Aghion and Tirole [15] further distinguish formal authority from effective control grounded in information. We use these theories to motivate the governance problem. Both organizational modes in our model face private capability information and hidden effort.

Knowledge-based accounts explain how organizational boundaries shape the creation and transfer of productive assets. Kogut and Zander [16] examine how firms replicate and recombine knowledge, while Nickerson and Zenger [17] link governance choices to the organization of problem solving. The complementary-assets argument of Teece [18] highlights that value capture depends on assets beyond the underlying innovation. In our setting, renewal investment generates assets with sourcing-specific usability to the client. The external portability parameter captures this difference in productive usability.

Empirical work on information services and technological production cautions against ranking integration and outsourcing independently of transaction attributes. Poppo and Zenger [19] compare transaction-cost, knowledge-based, and measurement explanations for information-service sourcing. Leiblein et al. [20] find that technological performance depends on alignment between governance and contractual hazards. Mayer and Salomon [21] show that technological capabilities interact with contracting hazards when firms organize service transactions. These findings support a conditional comparison of organizational modes. Relational contracting provides a distinct perspective on repeated interaction and enforcement [22,23]. Our two-period relationship instead uses an enforceable, fully committed lifetime contract, without reputational enforcement or renegotiation.

Studies of IT and business-process outsourcing further highlight the importance of property rights, monitoring, contractual flexibility, renegotiation, and information structures in governance design [24–26]. These considerations motivate our analysis, but ownership,

authority, and renegotiation decisions are not endogenized. Instead, we compare sourcing modes through differences in productive efficiency, costs, and capability information under the maintained full-commitment assumption. External portability captures the client-specific productive usability of supplier-generated renewal assets rather than an explicitly modeled allocation of legal rights.

2.3. Intertemporal Incentives

Dynamic agency research distinguishes long-term contracting under persistent private information from settings involving limited commitment or sequential information revelation. Baron and Besanko [27] examine long-term regulation with privately known costs. Laffont and Tirole [28] analyze ratchet incentives. Broader dynamic mechanism models accommodate private information arriving over time [29,30]. Our model instead assumes a persistent capability type, a single initial report, and full commitment to a two-period linear-contract menu. After the initial public information stage, the firm commits to a two-period linear-contract menu whose coefficients are not revised in response to subsequent performance histories. The analysis therefore involves two period-specific incentive shares for each reported type. Under unrestricted transfers and full type coverage, the absence of additional high-type screening distortion, downward distortion for low types, and information rents follow established adverse-selection logic. Our contribution is to link future performance incentives to both subsequent operation and earlier renewal investment, thereby generating client-usable capital that affects relative sourcing value.

With hidden effort and risk aversion, stronger performance incentives encourage effort but require compensation for outcome risk [31,32]. Imperfectly measured outputs further complicate incentive provision [33]. Multitask contracting examines how incentives for measured activities interact with other tasks, including across organizational arrangements [34,35]. Our framework differs in that first-period operation and renewal have separable cost components, while renewal creates an asset productive in the second period. The resulting intertemporal linkage allows future performance pay to induce both later operating effort and earlier capital formation, rather than operating through an explicit within-period capacity trade-off.

2.4. Renewal Investment and Economic Sustainability

Research on deployed machine-learning systems documents why strong launch performance does not eliminate subsequent maintenance requirements. Documented sources of technical debt include data dependencies, feedback loops, and changes in the operating environment. Amershi et al. [4] describe organizational and engineering challenges in machine-learning development, while Breck et al. [36] provide tests and monitoring considerations for production readiness. Concept-drift research examines adaptation when the underlying data-generating process changes [37]. The AI Risk Management Framework similarly treats governance as a lifecycle activity [38]. These conclusions motivate renewal as a productive but costly action. An internal team does not necessarily renew an application more effectively than a specialist provider.

Organizational learning research identifies a trade-off between attention to existing operations and investment in adaptation. Levinthal and March [39] examine short-term and local myopia in organizational learning. Benner and Tushman [40] develop a contingency perspective on the tension between process efficiency and exploratory adaptation. In the sustainability literature, Bansal and DesJardine [5] place time and intertemporal trade-offs at the center of business sustainability. Eccles et al. [41] document differences in governance practices and long-term performance across firms with different sustainability policies.

Broader treatments caution against equating corporate sustainability with a single financial outcome [42,43].

Building on these studies, we examine an economic mechanism through which sourcing and contractual incentives shape renewal investment and subsequent AI service value. Costly renewal generates client-usable service capital, while external portability affects the productive usability of supplier-generated assets. A matched two-period no-renewal comparison isolates this investment channel from the effect of extending the operating horizon. Consistent with the multidimensional perspective of sustainability discussed by Lago et al. [6], our analysis provides insights into the economic conditions supporting sustained service value, but does not establish long-run organizational viability, disruption resilience, or environmental and social sustainability outcomes.

3. Model Setup

3.1. Organization, Capability, and Information

A risk-neutral firm chooses internal provision $g = I$, external provision $g = O$, or no AI project. The agent is the manager or representative of the implementation team. An external provider has already been shortlisted, and there is no supplier auction. Each potential agent has a fixed capability

$$\theta_g \in \{\theta_L, \theta_H\}, \qquad 0 < \theta_L < \theta_H, \qquad \Pr(\theta_g = \theta_H) = \mu_g \in (0,1).$$

The agent knows its type. The firm knows the support and prior but not the realization. Capability remains fixed across periods.

Both sourcing modes are analyzed within the same fully committed linear-contract framework, while contractual and assessment decisions are optimized separately for each mode. Organizational differences are represented by setup and effort costs, capability priors, assessment technologies, operating productivity, and renewal-asset usability. These parameters capture the effects of organizational conditions in reduced form; ownership, authority, and residual control rights are not endogenously determined.

Internal readiness of the firm is $h \in [0,1]$. Internalization requires a sunk setup cost $F(h) \geq 0$, with $F'(h) \leq 0$, and has high-capability probability $\mu_I(h)$, with $\mu_I'(h) \geq 0$. Establishing the internal organization provides a public assessment of accuracy $\lambda_I \in [0.5,1]$. Its cost is included in F. External market maturity $m \in [0,1]$ affects the external prior $\mu_O(m)$, the accuracy $\lambda_O(m)$ of an optional assessment, and its cost $K(m)$. The baseline channels satisfy $\mu_O', \lambda_O' \geq 0$ and $K' \leq 0$. The firm chooses $A \in \{0,1\}$ before observing the external assessment.

A signal $z \in \{+,-\}$ is public, non-manipulable, and conditionally independent of operating shocks, with

$$\Pr(+ \mid H) = \Pr(- \mid L) = \lambda.$$

Writing μ for the relevant prior,

$$\pi_+ = \mu\lambda + (1-\mu)(1-\lambda), \quad \pi_- = 1 - \pi_+, \qquad q_+ = \frac{\mu\lambda}{\pi_+}, \quad q_- = \frac{\mu(1-\lambda)}{\pi_-}.$$

Zero-probability signals are omitted. Without an external assessment, $q = \mu_O$. The provider's type is not changed by a better signal.

Conditional on market maturity m, the accuracy $\lambda_O(m)$ and cost $K(m)$ of the available external assessment are predetermined. The firm chooses whether to purchase the assessment ($A \in \{0,1\}$), rather than optimizing its accuracy. The public signal is observed before contract selection and effort, and the committed two-period payment rule is not revised in response to subsequent performance observations.

3.2. Two-Period Operation and Renewal Capital

Periods are indexed by $t = 1, 2$, with date 1 as the numeraire and common discount factor $d \in (0, 1]$. After contracting, the agent chooses first-period operating effort $e_1 \geq 0$ and renewal investment $a \geq 0$. Renewal creates a stock of client-usable service capital k_2 that is available in period 2

$$Y_1 = \phi_g \theta e_1 + \varepsilon_1, \qquad k_2 = \eta_g \theta a,$$
$$Y_2 = \phi_g \theta e_2 + k_2 + \varepsilon_2, \qquad C_1 = \frac{c_g e_1^2 + \ell_g a^2}{2\theta}, \quad C_2 = \frac{c_g e_2^2}{2\theta}.$$

The agent chooses $e_2 \geq 0$ in the second period after observing the first-period history. The state k_2 summarizes usable renewal assets such as validated updates, maintainable data pipelines, and application-specific adaptation. It is not separately verifiable for payment. The first-period investment cost is incurred even though its operating return arrives only in period 2. An application without new renewal still has the baseline productive term $\phi_g \theta e_2$. The variable k_2 measures incremental service capital.

The cost coefficients $c_g, \ell_g > 0$ ensure strictly convex effort costs. Unlike the persistent capability parameter θ, the capital stock k_2 is endogenous to first-period renewal investment and represents client-usable productive assets rather than an evolution in agent capability.

The outcomes Y_t are verifiable monetary-equivalent operating benefits relative to a specified no-project baseline. They count distinct period-specific benefits, before remuneration and organization costs. Conditional on type, the disturbances are independent normals with variances $\sigma_{g1}^2, \sigma_{g2}^2 > 0$. Negative realizations represent losses relative to the baseline. Neither effort nor the renewal investment is observable. Separable costs exclude direct capacity crowding between e_1 and a. Early investment is costly before its productive return is realized.

We normalize internal organizational fit, ϕ_I, to 1 and assume that external organizational fit, $\phi_O(s)$, decreases proportionally with business specificity s at rate κ. That is,

$$\phi_I = 1, \qquad \phi_O(s) = 1 - \kappa s, \qquad s \in [0, 1], \quad 0 < \kappa < 1.$$

The parameter s measures business specificity. Renewal productivity is $\eta_I \geq 0$ internally and

$$\eta_O = \bar{\eta}_O p, \qquad \bar{\eta}_O \geq 0, \quad p \in [0, 1],$$

externally. The portability parameter p measures how usable supplier-generated renewal assets are in the client's application.

3.3. Committed Contracts and Preferences

After the information stage, the firm offers a menu. One type of report selects one contract covering both periods

$$w_1 = \alpha_1 + \beta_1 Y_1, \qquad w_2 = \alpha_2 + \beta_2 Y_2, \qquad \alpha := \alpha_1 + d\alpha_2 \in \mathbb{R}, \quad \beta_t \in [0, 1].$$

There is full commitment to this menu, with no interim termination, switching, or renegotiation. Participation is voluntary after the initial public signal, before either period's effort. The agent has constant absolute risk aversion (CARA) $\rho_g > 0$ over lifetime present-value net compensation

$$\mathbb{E}\Big[-\exp\Big\{-\rho_g[w_1 + dw_2 - C_1 - dC_2]\Big\} \mid \theta\Big].$$

Its reservation certainty equivalent is $\bar{u}_g \geq 0$, independent of capability. The firm maximizes expected discounted benefits net of payments, setup, and assessment costs.

Linearity and full commitment are maintained modeling assumptions. Linear contracts permit an explicit mean–variance reduction and comparable incentive analysis across sourcing modes, but CARA preferences and normally distributed shocks do not establish their global optimality among nonlinear contracts. Full commitment rules out renegotiation and ratchet effects arising from information revealed during the relationship [28]. Although contractual adaptation is important in practice [25], these mechanisms lie outside the present framework.

The fixed-transfer present value α is identified, but its division between α_1 and α_2 is not. Without liquidity constraints, any timing with the same present value is equivalent. Reported contracts use $\alpha_1 = \alpha$, $\alpha_2 = 0$. Transfers are unrestricted, so neither limited liability nor a wage floor is imposed.

Negative fixed transfers in the unrestricted benchmark may represent up-front net payments from the agent to the firm, although such arrangements need not be institutionally feasible. Section 4.7 therefore imposes $\alpha_j \geq 0$ and reoptimizes the contract menu. This restriction applies only to the fixed component; because realized performance is normally distributed, it does not guarantee nonnegative remuneration in every state.

The timing is as follows. The firm first chooses a mode or rejects the project. It pays the associated sunk cost, obtains the chosen public information, and offers the lifetime menu. The agent accepts or rejects and selects a menu item. First-period operation and renewal are then undertaken, and Y_1 is observed. Finally, the same agent supplies second-period operating effort, and Y_2 is realized. Performance observations permit belief updating, but the committed contract rules out renegotiation. First-period renewal, not the repeated type selection, connects the two production periods. All notations adopted in the model are listed in Table 1.

Table 1. Main notation and economic interpretation.

Notation	Interpretation
h, s, m, p	Internal readiness, business specificity, market maturity, and external portability
F, K, A, λ_g	Internal setup cost, external assessment cost, assessment decision, and signal accuracy
θ_i, μ_g, q_z	Persistent capability, prior high-type probability, and posterior belief
e_1, a, k_2, e_2	First-period operation, early renewal, carried service capital, and second-period operation
$\phi_g, \eta_g, c_g, \ell_g$	Current fit, renewal productivity, and operating and renewal cost coefficients
d, ρ_g, σ_{gt}^2	Discount factor, lifetime absolute risk aversion, and outcome-noise variance
α, β_1, β_2	Fixed-transfer present value and period-specific performance shares
$\bar{u}_g$	Outside-option certainty equivalent
u_i,R_H	Contract certainty equivalent and high-type information rent in the unrestricted benchmark
X_{ti}, ω_t	Reduced productive potential and risk cost
$\Delta_t = X_{tH} - X_{tL}$	Type-dependent productive-potential difference
V_g, S_g, W_g	Principal value, monetized project surplus, and risk-adjusted relationship surplus
R_g	Expected agent surplus above reservation; information rent in the unrestricted optimum

4. Optimal Intertemporal Contracts

4.1. Sequential Effort and the Observable-Capability Benchmark

For a fixed mode, suppress the subscript g, and define

$$x_1 = \frac{\phi^2}{c}, \qquad x_2 = d\frac{\phi^2}{c} + d^2\frac{\eta^2}{\ell},$$
$$X_{ti} = \theta_i^3 x_t, \qquad \omega_1 = \rho\sigma_1^2, \quad \omega_2 = \rho d^2\sigma_2^2, \quad \Delta_t = X_{tH} - X_{tL} > 0.$$

The second-period performance share induces both later operating effort and earlier renewal investment, with the latter generating client-usable capital that contributes directly to second-period output.

Proposition 1 (Sequential Implementation and Remuneration)**.** *Given a contract* $(\alpha, \beta_1, \beta_2)$*, a true type i has unique optimal choices*

$$e_{1i} = \frac{\theta_i^2 \phi}{c}\beta_1, \qquad a_i = \frac{d\theta_i^2 \eta}{\ell}\beta_2, \qquad e_{2i} = \frac{\theta_i^2 \phi}{c}\beta_2, \quad k_{2i} = \frac{d\theta_i^3 \eta^2}{\ell}\beta_2. \tag{1}$$

Second-period effort is optimal after every first-period history. The indirect certainty equivalent, expected present-value remuneration, and principal payoff are

$$u_i = \alpha + \frac{1}{2}\sum_{t=1}^{2}(X_{ti} - \omega_t)\beta_t^2, \tag{2}$$

$$\mathbb{E}[w_1 + dw_2 \mid i] = u_i + \frac{1}{2}\sum_{t=1}^{2}(X_{ti} + \omega_t)\beta_t^2, \tag{3}$$

$$\Pi_i(\boldsymbol{\beta}, u_i) = \sum_{t=1}^{2}\left[X_{ti}\beta_t - \frac{1}{2}(X_{ti} + \omega_t)\beta_t^2\right] - u_i. \tag{4}$$

The future-performance coefficient rewards later operation and encourages the early renewal investment that generates capital contributing directly to second-period output. In particular, restricting β_2 to zero eliminates both e_2 and a in the model. A contract based only on launch-period performance therefore cannot implement positive renewal.

The square on η in (1) follows directly from the calculations

$$k_{2i} = \eta\theta_i a_i = \eta\theta_i\left(\frac{d\theta_i^2\eta}{\ell}\beta_2\right) = \frac{d\theta_i^3\eta^2}{\ell}\beta_2.$$

The quadratic dependence on renewal productivity arises because a higher η increases both the agent's optimal renewal investment and the client-usable capital generated per unit of investment.

When capability is observable, the participation constraint binds at $u_i = \bar{u}$. Define

$$\beta_{ti}^{MH} = \frac{X_{ti}}{X_{ti} + \omega_t}, \qquad J_i = \frac{1}{2}\sum_{t=1}^{2}\frac{X_{ti}^2}{X_{ti} + \omega_t}. \tag{5}$$

The optimal fixed-transfer present value is

$$\alpha_i^{MH} = \bar{u} - \frac{1}{2}\sum_t (X_{ti} - \omega_t)(\beta_{ti}^{MH})^2, \qquad \mathbb{E}[w_1 + dw_2 \mid i] = \bar{u} + J_i. \tag{6}$$

The firm implements the relationship only if $J_i \geq \bar{u}$. The superscript MH denotes a hidden-action benchmark, not a first-best allocation. With observable actions, full insurance and contractible effort yield the choices in (1) evaluated at $\beta_1 = \beta_2 = 1$, and net productive value $\frac{1}{2}\sum_t X_{ti} - \bar{u}$. Positive risk costs make (5) strictly less than one. Proofs of the sequential reduction and the benchmark are in the appendices.

4.2. Single Screening Menu for a Persistent Type

Let $q \in (0, 1)$ be the posterior probability of high capability. A menu item j contains a pair $\boldsymbol{\beta}_j = (\beta_{1j}, \beta_{2j})$ and one fixed-transfer present value α_j. A type imitating the other item reoptimizes all three actions using its own capability. With u_i denoting the certainty equivalent from the intended item, lifetime incentive compatibility is

$$\frac{1}{2}\sum_t \Delta_t \beta_{tL}^2 \;\leq\; u_H - u_L \;\leq\; \frac{1}{2}\sum_t \Delta_t \beta_{tH}^2, \qquad u_L, u_H \geq \bar{u}. \tag{7}$$

Proposition 2 (Optimal lifetime menu under full coverage)**.** *Conditional on serving both types, the unique optimal performance vector satisfies*

$$\beta^*_{tH}(q) = \frac{X_{tH}}{X_{tH}+\omega_t}, \beta^*_{tL}(q) = \frac{(1-q)X_{tL}}{D_t(q)}, D_t(q) = (1-q)(X_{tL}+\omega_t) + q\Delta_t. \tag{8}$$

The low-type participation constraint and high-type downward incentive constraint bind

$$u^*_L = \bar{u}, \qquad u^*_H = \bar{u} + R_H(q), \qquad R_H(q) = \frac{1}{2}\sum_t \Delta_t[\beta^*_{tL}(q)]^2. \tag{9}$$

Fixed transfers and expected remuneration are

$$\alpha^*_i = u^*_i - \frac{1}{2}\sum_t (X_{ti}-\omega_t)(\beta^*_{ti})^2, \tag{10}$$

$$\mathbb{E}[w_1 + dw_2 \mid i] = u^*_i + \frac{1}{2}\sum_t (X_{ti}+\omega_t)(\beta^*_{ti})^2. \tag{11}$$

The gross principal value is

$$B(q) = qJ_H + \frac{1}{2}\sum_t \frac{(1-q)^2 X^2_{tL}}{D_t(q)}, \tag{12}$$

so the full-coverage value is $B(q) - \bar{u}$.

The high type has no additional screening distortion but still bears the hidden-action distortion associated with risk sharing. The low type has lower incentive coefficients than its own observable-capability benchmark in both periods. Substitution into (1) shows that this distortion lowers current operation, future operation, and renewal.

Let $M(q) = (1-q)J_L + qJ_H$. The full-coverage information loss admits the decomposition

$$\begin{aligned} M(q) - B(q) &= \frac{1-q}{2}\sum_t (X_{tL}+\omega_t)(\beta^{MH}_{tL} - \beta^*_{tL})^2 + qR_H(q) \\ &= \frac{1}{2}\sum_t \frac{q(1-q)X^2_{tL}\Delta_t}{(X_{tL}+\omega_t)D_t(q)}. \end{aligned} \tag{13}$$

The first term is the loss of risk-adjusted productive surplus from distorted incentives. The second is a transfer to the high type. Only the former changes the total certainty-equivalent relationship value at a fixed allocation benchmark.

Proposition 3 (Endogenous coverage)**.** *With a common lifetime reservation certainty equivalent within a mode, the complete continuation value is*

$$\mathcal{U}(q) = \max\{B(q) - \bar{u},\ q(J_H - \bar{u}),\ 0\}. \tag{14}$$

The second option serves only the high type using (5) *and no information rent. For* $0 < q < 1$ *and* $\bar{u} < J_H$*, full coverage is preferred to high-only service if and only if*

$$\bar{u} \le T(q) := \frac{1}{2}\sum_t \frac{(1-q)X^2_{tL}}{D_t(q)}. \tag{15}$$

If $\bar{u} \ge J_H$*, rejecting the relationship is weakly optimal. If* $\bar{u} = 0$*, full coverage is strictly optimal at every interior posterior.*

A positive outside opportunity enters the service-coverage decision. In particular, an assessment moves the firm between full coverage and high-only service. Serving only the low type cannot exclude the high type under a positive-incentive linear contract because the high type has a greater indirect payoff from the same item.

4.3. The Screening Distortion

Direct effort comparisons across organizational modes confound screening distortions with differences in agent capability, production technology, and risk sharing. To isolate the additional incentive distortion caused by private capability information, we normalize the low-capability agent's effort by the corresponding optimal effort when capability is observable, but effort remains unobservable, holding other conditions constant. Let

$$r_t = \frac{\omega_t}{x_t}, \qquad v(q) = \theta_L^3 + \frac{q}{1-q}(\theta_H^3 - \theta_L^3), \qquad \beta_{tL}^* = \theta_L^3/[v(q) + r_t]$$

Proposition 4 (Temporal composition of the screening distortion)**.** *Under full coverage, the fraction of observable-capability effort retained by the low type is*

$$\frac{\beta_{tL}^*}{\beta_{tL}^{MH}} = \frac{\theta_L^3 + r_t}{\theta_L^3 + r_t + q(\theta_H^3 - \theta_L^3)/(1-q)}. \tag{16}$$

For $\eta > 0$, renewal and second-period operation experience a strictly greater proportional screening reduction than first-period operation if and only if $r_2 < r_1$. Moreover, for any $0 < q < 1$, increasing renewal productivity η strictly increases renewal and the lifetime high-type rent while weakly increasing the proportional screening reduction in the second-period stream. The last comparison is strict when $\omega_2 > 0$.

The result in Proposition 4 concerns proportional screening distortions rather than absolute incentive levels. Equation (16) implies that the proportional reduction in the low type's incentive, relative to its observable-capability benchmark, decreases with normalized risk r_t. Thus, lower normalized risk raises the absolute incentive coefficient but also increases the fraction lost to screening. Renewal investment can strengthen this effect by increasing second-period productive potential and reducing r_2. However, $r_2 < r_1$ may also arise without renewal because of discounting or differences in outcome noise. Therefore, the temporal ordering of proportional screening distortions is conditional on $r_2 < r_1$ and should not be attributed exclusively to the renewal mechanism.

4.4. Capability Assessment and the Organizational Boundary

For each mode, we define the value of a public capability assessment

$$G_g(\mu, \lambda) = \pi_+ \mathcal{V}_g(q_+) + \pi_- \mathcal{V}_g(q_-). \tag{17}$$

Both G_g and $\mathcal{V}_g$ include endogenous coverage. The internal and outsourced values before selecting the organizational mode are

$$V_I = G_I(\mu_I(h), \lambda_I) - F(h), \tag{18}$$

$$V_O = \max\{\mathcal{V}_O(\mu_O(m)),\ G_O(\mu_O(m), \lambda_O(m)) - K(m)\}. \tag{19}$$

The initial choice solves $V^* = \max\{0, V_I, V_O\}$. Setup and assessment costs are paid before the signal and cannot be recovered if the subsequent relationship is rejected.

Proposition 5 (Information value and renewal)**.** *The continuation value $\mathcal{V}_g$ is continuous, convex, and nondecreasing in the high-capability posterior. In the full-coverage region,*

$$B_g''(q) = \sum_{t=1}^{2} \frac{X_{tL}^2 \Delta_t^2}{D_t(q)^3} > 0. \tag{20}$$

For the binary symmetric signal, G_g is nondecreasing in λ. External assessment is optimal precisely when

$$G_O(\mu_O, \lambda_O) - \mathcal{V}_O(\mu_O) > K. \tag{21}$$

We resolve ties in favor of no assessment. If the relevant posteriors remain in full coverage, improving public information weakly increases expected renewal conditional on the agent truly being low capability. Internal value is also nondecreasing in λ_I, holding its cost fixed.

This comparison evaluates a given internal information technology. More accurate governance is not assumed to be free. In both modes, the signal improves knowledge of capability, whereas a creates productive capital. For a true low type,

$$\mathbb{E}[a_L \mid L] = (1-\lambda)a_L(q_+) + \lambda a_L(q_-), \tag{22}$$

not $\pi_+ a_L(q_+) + \pi_- a_L(q_-)$. Conditional evaluation is necessary to avoid attributing a compositional change in suppliers to improved investment by a fixed type.

Proposition 6 (Conditional organizational boundaries)**.** *Let $\Delta V = V_I - V_O$. Hold the type support, risk parameters, outside opportunities, internal signal accuracy, and other technologies fixed. Under the specified channels for h, s, m, p,*

$$\Delta V \text{ is weakly increasing in } h \text{ and } s, \quad \text{and weakly decreasing in } m \text{ and } p. \tag{23}$$

If $\Delta V(0,s,m,p) < 0 < \Delta V(1,s,m,p)$ and internal value is strictly increasing over the relevant readiness interval, there is a unique threshold $h^*(s,m,p)$. Conditional on adoption, internalization is optimal above it. On a differentiable threshold branch,

$$\frac{\partial h^*}{\partial p} = -\frac{\Delta V_p}{\Delta V_h} \geq 0, \quad \frac{\partial h^*}{\partial m} = -\frac{\Delta V_m}{\Delta V_h} \geq 0, \quad \frac{\partial h^*}{\partial s} = -\frac{\Delta V_s}{\Delta V_h} \leq 0. \tag{24}$$

Portability changes the external renewal return while leaving its initial operating fit unchanged. Increasing portability narrows an internal renewal advantage without assuming that external providers become more productive at every task. The result concerns the stated channels, not a general claim that more developed markets always favor outsourcing. One omitted channel is an increase in suppliers' outside opportunities as external markets develop. On a smooth policy branch, allowing $\bar{u}_O = \bar{u}_O(m)$ adds

$$-\Pr(\text{implementation})\, \bar{u}_O'(m) \tag{25}$$

to the derivative of external value, potentially offsetting the favorable quality, information, and assessment-cost effects. Similarly, an increase in internal information accuracy must be evaluated net of any additional cost of generating it.

The highest setup cost consistent with internalization is

$$F^{\text{crit}} = G_I(\mu_I, \lambda_I) - V_O, \tag{26}$$

provided this amount is nonnegative, and adoption is worthwhile. If an endpoint sign change does not occur, the parameter interval need not contain a sourcing threshold. At switches in assessment or coverage, the optimized values need not be differentiable; the local derivatives in (24) are therefore restricted to smooth branches.

A renewal-specific comparison is obtained by keeping both operating periods, priors, information technologies, and costs, but setting $\eta_I = \eta_O = 0$. Write the resulting mode values as V_g^0, and define $N_g = V_g - V_g^0$. The monotonicity of the solved continuation values in renewal productivity implies $N_g \geq 0$. The integration premium decomposes exactly as

$$\Delta V = (V_I^0 - V_O^0) + (N_I - N_O). \tag{27}$$

Thus, if outsourcing is initially preferred, renewal reverses the ordering precisely when its relative internal gain exceeds the original external advantage. This comparison isolates the cross-period investment channel from the mechanical benefit of adding a second operating period. It is a decomposition, not a claim that internal renewal must have the larger gain.

4.5. Intertemporal Incentives

Discounting affects both the return to early investment and the present-value exposure to future payment risk. For a fixed posterior in the full-coverage region, let

$$A_0 = \phi^2/c, G_0 = \eta^2/\ell, \Omega = \rho\sigma_2^2, (z_H, v_H) = (\theta_H^3, \theta_H^3), (z_L, v_L) = (\theta_L^3, v(q)). \tag{28}$$

The future coefficient becomes

$$\beta_{2i}^*(d) = \frac{z_i(A_0 + dG_0)}{v_i(A_0 + dG_0) + d\Omega}. \tag{29}$$

Proposition 7 (Discounting and early renewal)**.** *Hold the posterior and all non-discount primitives fixed, with $\eta > 0$, and remain in the full-coverage region. Under lifetime present-value CARA preferences,*

$$\frac{\partial \beta_{2i}^*}{\partial d} = -\frac{z_i A_0 \Omega}{[v_i(A_0 + dG_0) + d\Omega]^2} < 0, \tag{30}$$

whereas

$$\frac{\partial (d\beta_{2i}^*)}{\partial d} = \frac{z_i\{v_i A_0^2 + 2v_i d A_0 G_0 + d^2 G_0(v_i G_0 + \Omega)\}}{[v_i(A_0 + dG_0) + d\Omega]^2} > 0. \tag{31}$$

Consequently, first-period renewal and the carried service capital increase with d, although the second-period performance share and operating effort decrease. The first-period share and operating effort do not change at a fixed posterior.

Proposition 7 reflects the intertemporal trade-off between productive returns and risk exposure under the maintained lifetime CARA specification. Importantly, the comparative statics are derived within a fixed contractual regime. Changes in the discount factor may also alter the optimal assessment or coverage policy, so the result does not necessarily extend to globally reoptimized organizational decisions.

The negative effect of the discount factor on the nominal second-period performance share is specific to the lifetime present-value CARA specification, under which future outcome risk enters the certainty equivalent with a squared discount factor. To illustrate this dependence, we consider an alternative preference criterion based on the discounted sum of period-specific certainty equivalents in Appendix A.2. Under this specification, the optimal second-period performance share increases with the discount factor when renewal productivity and outcome risk are positive. This comparison highlights the importance of intertemporal risk aggregation without altering the baseline model or the validity of Proposition 7 under its maintained assumptions.

4.6. Economic Sustainability

For a mode and its chosen assessment and coverage policy, let $b \in \{0, 1\}$ indicate implementation. Define the monetized project surplus

$$S_g = \mathbb{E}[b(Y_1 + dY_2 - C_1 - dC_2)] - F(h)\mathbf{1}_{\{g=I\}} - AK(m). \tag{32}$$

Remuneration is a transfer within the relationship and cancels from this account. Define the risk-bearing adjustment P_g, forgone outside opportunity U_g^0, and agent certainty-equivalent surplus above reservation R_g by

$$P_g = \frac{1}{2}\mathbb{E}\left[b\sum_t \omega_t \beta_t^2\right], \qquad U_g^0 = \bar{u}_g \mathbb{E}[b], \qquad R_g = \mathbb{E}[b(u - \bar{u}_g)]. \tag{33}$$

The risk-adjusted relationship surplus is $W_g = S_g - P_g - U_g^0$.

Proposition 8 (Private and relationship-level sourcing criteria)**.** *For any feasible policy,*

$$V_g = W_g - R_g, \qquad W_I - W_O = (V_I - V_O) + (R_I - R_O). \tag{34}$$

Thus, the organizational choices maximizing principal value and risk-adjusted relationship surplus need not coincide under the same mode-specific continuation policies. With imperfect capability information in both modes, information rents are not confined to external providers, so the direction of disagreement depends on the relative rents.

Both value accounts are evaluated under each sourcing mode's principal-optimal contract, assessment, and coverage policy. Risk premia represent the certainty-equivalent costs of bearing outcome risk. Moreover, the identity $W_g = V_g + R_g$ shows that agent surplus reduces the value captured by the principal without constituting a direct loss of relationship surplus. Consequently, when $0 < V_I - V_O < R_O - R_I$, the principal prefers internalization even though outsourcing generates greater risk-adjusted relationship surplus.

In the unrestricted-transfer benchmark, R_g represents information rent. Under the nonnegative fixed-transfer constraint, it may also include surplus that cannot be extracted even when capability is observable. Thus, although the accounting identity remains valid, the difference between principal value and relationship surplus cannot always be attributed solely to asymmetric information.

An additional measure of sustained operating performance is the probability that the second-period benefit reaches a predetermined target $\underline{Y}$:

$$Q_g = \mathbb{E}\left[b\, \Phi\left(\frac{\phi_g \theta e_2 + k_2 - \underline{Y}}{\sigma_{g2}} \right) \right]. \tag{35}$$

This is an unconditional implementation-and-attainment probability. When all types implement, it is also the attainment probability among projects. When coverage differs, the conditional measure is $Q_g/\mathbb{E}[b]$, provided $\mathbb{E}[b] > 0$, and both implementation incidence and conditional attainment should be reported. Equation (35) measures a specified service outcome, not corporate survival or bankruptcy risk.

The model captures an intertemporal mechanism through which costly renewal investment creates client-usable service capital and supports subsequent operating performance. The measures of renewal effort a, accumulated capital k_2, and second-period target attainment Q_g characterize different aspects of this mechanism, linking current resource allocation and contractual incentives to future service outcomes. Meanwhile, the value accounts V_g, S_g, and W_g distinguish resource costs, risk-bearing costs, and the distribution of economic surplus. Together, these results provide a limited perspective on the economic and technical dimensions of sustaining AI service value, as discussed in Section 2.4. However, the two-period framework does not establish long-term organizational viability, operational resilience, or environmental and social sustainability.

4.7. Nonnegative Fixed Transfers

To examine whether the unrestricted-transfer benchmark depends on the ability to impose negative fixed payments, we consider a restricted contract class in which the fixed-transfer present value satisfies $\alpha_j \geq 0$. This extension preserves the original production technology, risk preferences, information structure, and full-commitment assumption.

Under the payment-timing convention $\alpha_{1j} = \alpha_j$ and $\alpha_{2j} = 0$, the restriction rules out negative fixed payments but does not impose a state-contingent wage level. Setting

$z_{tj} = \beta_{tj}^2 \in [0,1]$, the certainty equivalent of type i selecting contract j and the principal's expected payoff from the intended type i can be written as follows

$$CE_i(j) = \alpha_j + \frac{1}{2}\sum_t (X_{ti} - \omega_t) z_{tj}, \tag{36}$$

$$\Pi_i = \sum_t X_{ti}(\sqrt{z_{ti}} - z_{ti}) - \alpha_i. \tag{37}$$

The full-coverage problem maximizes $(1-q)\Pi_L + q\Pi_H$ subject to $CE_i(i) \geq \bar{u}$, $CE_i(i) \geq CE_i(j)$, and the stated bounds. It has a concave objective and affine constraints. High-only service instead requires $CE_H(H) \geq \bar{u}$ and $CE_L(H) \leq \bar{u}$, with the low type rejecting at indifference.

Although the risk-cost terms do not appear explicitly in the principal's payoff expression, they continue to affect contract feasibility through the participation and incentive-compatibility constraints.

Proposition 9 (Optimal pooling under nonnegative fixed transfers)**.** *Suppose*

$$\bar{u} \leq \frac{1}{8}\sum_t (X_{tL} - \omega_t). \tag{38}$$

Then, the common contract $\alpha_L = \alpha_H = 0$, $\beta_{tL} = \beta_{tH} = 1/2$ is globally optimal within the nonnegative-fixed-transfer linear class, including endogenous coverage. The conditional continuation value is

$$\mathcal{U}^+(q) = \tfrac{1}{4}[(1-q)\theta_L^3 + q\theta_H^3]\sum_t x_t. \tag{39}$$

Both types participate, and $u_i = \frac{1}{8}\sum_t (X_{ti} - \omega_t)$. Public assessment has zero gross value whenever (38) holds for the mode. A positive-cost external assessment is therefore not purchased.

Proposition 9 establishes a sufficient condition under which a common half-share contract attains the principal's type-by-type profit upper bound. Because both capability types participate and receive the same contract, screening cannot further increase the principal's expected payoff, and public assessment has no gross informational value. Economically, the nonnegative fixed-transfer constraint prevents the principal from extracting agent surplus through negative fixed payments, fundamentally changing the optimal incentive structure relative to the unrestricted benchmark.

The result is conditional on (38). When this condition fails, the optimal menu and coverage decisions must be determined from the constrained optimization problem. Section 5.6 examines how the payment restriction affects sourcing outcomes under the illustrative baseline parameters.

5. Numerical Analysis

5.1. Parameter Settings

Table 2 reports the illustrative parameters. Let $J_{OH}^{(0)}$ denote the gross continuation value of a high-capability external agent under observable capability and hidden effort, evaluated from (5) at the baseline parameters. For the coverage sensitivity analysis, we vary $\bar{u}_O/J_{OH}^{(0)}$ while holding other parameters fixed. The baseline functions are

$$F(h) = 0.08 + 0.65(1-h)^2, \qquad \mu_I(h) = 0.20 + 0.60h,$$
$$\mu_O(m) = 0.35 + 0.50m, \qquad \lambda_O(m) = 0.55 + 0.40m,$$
$$K(m) = 0.04(1 - 0.80m), \qquad \phi_O(s) = 1 - 0.40s.$$

Table 2. Baseline parameters, one-factor ranges, and functional forms.

Parameter	Baseline	Range	Role
θ_L, θ_H	$1, 1.3$	Fixed	Persistent capability types
d	0.90	$[0.05, 1]$	Discount factor
h, s, m	$0.60, 0.45, 0.50$	$[0, 1]$	Readiness, specificity, market maturity
c_I, c_O	$1.25, 0.85$	Fixed	Operating-effort cost
ℓ_I, ℓ_O	$1.00, 0.85$	Fixed	Renewal-effort cost
$\eta_I, \bar{\eta}_O$	$0.85, 1.00$	Fixed	Renewal productivity before portability
p	0.40	$[0, 1]$	External usability of renewal assets
ρ_I, ρ_O	$0.50, 0.50$	Fixed	Lifetime absolute risk aversion
σ_1^2, σ_2^2	$0.50, 0.80$	$\sigma_2^2 \in [0.05, 2]$	Same noise across modes in the baseline
λ_I	0.90	$[0.5, 1]$	Imperfect internal public assessment
$\bar{u}_I, \bar{u}_O$	$0, 0$	$\bar{u}_O / J_{OH}^{(0)} \in [0, 1.15]$	Service-coverage sensitivity
$\underline{Y}$	1.00	Fixed	Illustrative second-period performance target
$\kappa;\ \phi_I, \phi_O$	$0.40;\ 1, 0.82$	$\phi_O = 1 - \kappa s$	Operating fit
$\mu_I(h)$	0.56	$0.20 + 0.60h$	Internal prior
$\mu_O(m)$	0.60	$0.35 + 0.50m$	External prior
$F(h)$	0.184	$0.08 + 0.65(1 - h)^2$	Sunk internal setup cost
$\lambda_O(m)$	0.75	$0.55 + 0.40m$	Available external test accuracy
$K(m)$	0.024	$0.04(1 - 0.80m)$	Cost of purchasing that test

The illustrative baseline combines lower operating-effort costs under outsourcing with greater client-usable renewal productivity under internalization, while allowing for imperfect internal capability assessment. We vary external renewal-asset portability to examine how these competing advantages affect organizational choice. The sensitivity analyses of risk and discounting hold posterior beliefs fixed to isolate their effects on contractual incentives, whereas the organizational-choice analyses reoptimize assessment and type coverage at each parameter configuration. In the baseline, outcome-noise variances are assumed to be identical across organizational modes, such that $\sigma_{It}^2 = \sigma_{Ot}^2 = \sigma_t^2$.

The parameterization is illustrative rather than empirically calibrated. Monetary benefits and costs are expressed in common normalized units, and the capability and effort scales are normalized for analytical convenience. In particular, external renewal productivity is determined by $\eta_O = \bar{\eta}_O p$, where p measures the client-specific usability of supplier-generated renewal assets. Accordingly, neither the baseline value $p = 0.40$ nor the resulting sourcing thresholds are empirically established benchmarks. To assess the dependence of the numerical findings on the maintained assumptions, Sections 5.6 and 5.7 examine a nonnegative fixed-transfer constraint and joint variations in key model parameters, respectively.

All baseline parameters and functional forms are reported in Table 2. The outcome-noise parameters σ_1^2 and σ_2^2 represent variances. Unless otherwise specified, the coefficients in the functional forms remain fixed throughout the sensitivity analyses.

5.2. Optimal Lifetime Remuneration and Renewal

At the baseline, the internal prior is 0.56, and the external prior is 0.60. The internal assessment has accuracy 0.90, and its setup cost is 0.184. Outsourcing purchases the available assessment ($A = 1$), whose technology at $m = 0.50$ has accuracy 0.75 and cost 0.024. All types are implemented in both modes. Table 3 reports the signal-contingent lifetime menus, using the reporting convention $\alpha_1 = \alpha$ and $\alpha_2 = 0$.

Table 3. Baseline lifetime contracts.

Mode	Signal	q_z	Type	β_1	β_2	α	a	$\mathbb{E}[w_1 + dw_2]$
I	+	0.920	L	0.067	0.067	−0.003	0.051	0.006
I	+	0.920	H	0.875	0.898	−1.599	1.162	2.063
I	−	0.124	L	0.675	0.705	−0.369	0.540	0.645
I	−	0.124	H	0.875	0.898	−0.998	1.162	2.664
O	+	0.818	L	0.149	0.148	−0.012	0.063	0.025
O	+	0.818	H	0.874	0.854	−1.122	0.611	1.593
O	−	0.333	L	0.522	0.507	−0.143	0.215	0.295
O	−	0.333	H	0.874	0.854	−0.881	0.611	1.833

A favorable signal reduces the incentives attached to the low-type item in each menu. The high-type shares and renewal effort are unchanged across signals, while its rent changes. Figure 1 isolates the posterior effect using the internal technology. Under that technology, the future share is slightly larger than the current share, although Proposition 4 compares proportional distortions rather than these raw levels. Negative fixed transfers in Table 3 reflect the maintained unrestricted-payment benchmark.

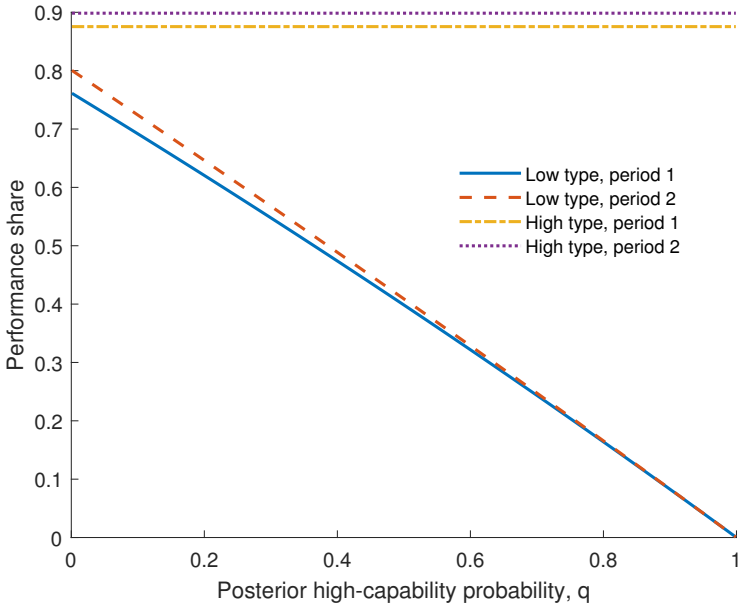


Figure 1. Performance shares under a single lifetime screening menu.

5.3. A Renewal-Specific Reversal of the Sourcing Choice

Table 4 distinguishes a one-period project, two operating periods without renewal, and the full two-period model. The two-period no-renewal case removes a by setting $\eta_I = \eta_O = 0$, leaving all other primitives unchanged. Assessment and coverage are reoptimized in every case.

Table 4. Adding a second period versus adding productive renewal under unrestricted fixed transfers.

Model	V_I	V_O	$\mathbb{E}[a_I]$	$\mathbb{E}[a_O]$	Sourcing Choice
One period	0.3549	0.5067	0.0000	0.0000	Outsource
Two periods, no renewal	0.8116	0.9456	0.0000	0.0000	Outsource
Two periods, renewal	1.2606	1.0585	0.8665	0.4375	Internal

Table 4 shows that outsourcing is preferred in both the one-period benchmark and the two-period model without renewal. Introducing renewal raises principal value by 0.4489 under internalization and 0.1129 under outsourcing, relative to their respective two-period no-renewal benchmarks. The resulting relative internal gain of approximately 0.3361 exceeds the initial outsourcing advantage of 0.1340, yielding an internalization premium of 0.2021.

The intertemporal trade-off is reflected in the allocation of costs and benefits across periods. Because the first-period cost C_1 includes renewal expenditure, the expected net monetary benefit $\mathbb{E}[Y_1 - C_1]$, before organizational setup and assessment costs, declines from 0.6284 to 0.2801 internally and from 0.6156 to 0.5363 externally when renewal is introduced. Under the renewal model, expected second-period benefits are 2.0126 internally and 1.2418 externally.

Figure 2 illustrates how external renewal-asset portability affects the sourcing decision under the unrestricted-transfer benchmark. Without renewal, outsourcing remains preferable across the entire portability range because p affects only the client-usable value of renewal assets. With renewal, internalization is preferred for $p \in [0, 0.6662)$, whereas outsourcing becomes preferable above this threshold, with the two modes yielding equal principal value at the boundary.

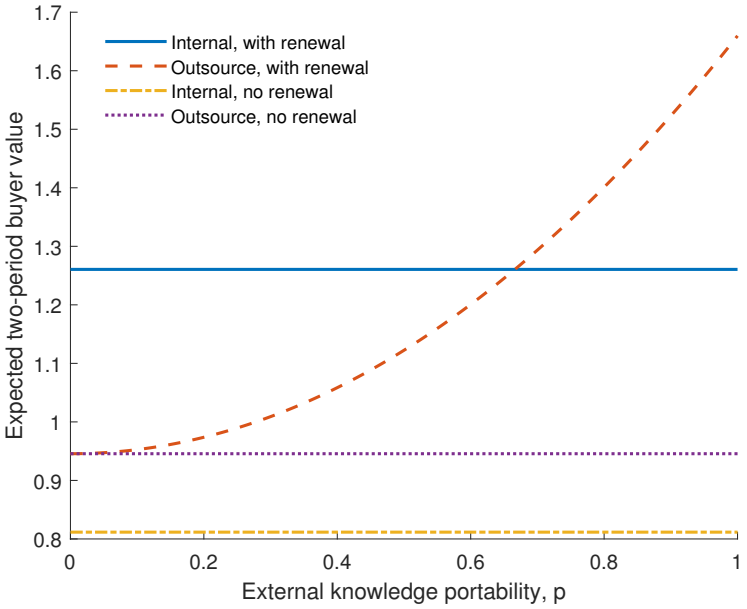


Figure 2. External portability and the renewal channel.

This reversal occurs precisely when the relative internal gain from renewal exceeds the original outsourcing advantage, that is, $N_I - N_O > V_O^0 - V_I^0$, as established in Equation (27). Hence, higher internal renewal productivity alone does not guarantee internalization. The reported threshold is conditional on the illustrative baseline parameters.

Figure 3 extends the organizational comparison to internal readiness and external market maturity. Higher renewal-asset portability or more favorable external market conditions increase the internal readiness required for internalization to be optimal, provided that an interior threshold exists. Gaps in the threshold curves indicate parameter regions without an interior solution.

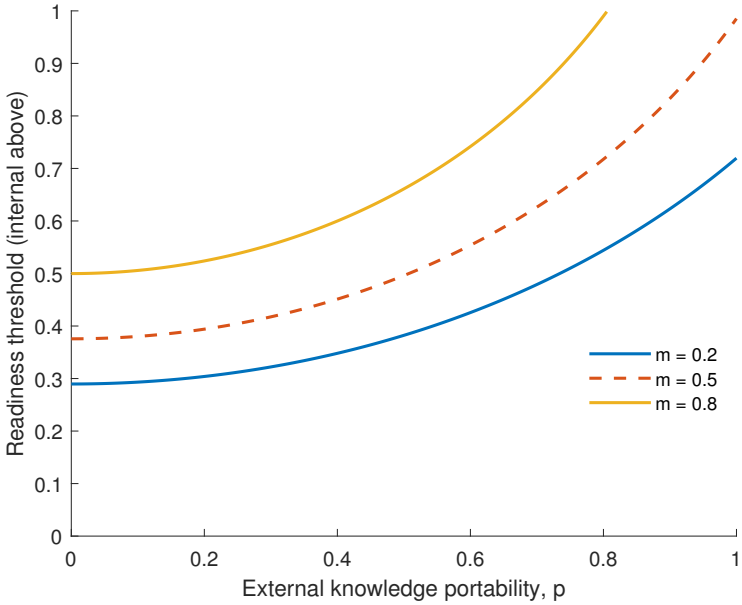


Figure 3. Readiness thresholds across external portability and market maturity.

5.4. Future Incentives, Capability Information, and Temporal Distortion

Figure 4 varies the common discount factor at posterior $q = 0.60$ using the internal technology. Renewal increases for both capability types. With all initial choices reoptimized instead, the baseline organizational switch occurs at $d \simeq 0.5689$. This latter threshold is an illustrative global policy comparison, not the fixed-posterior derivative in Proposition 7.

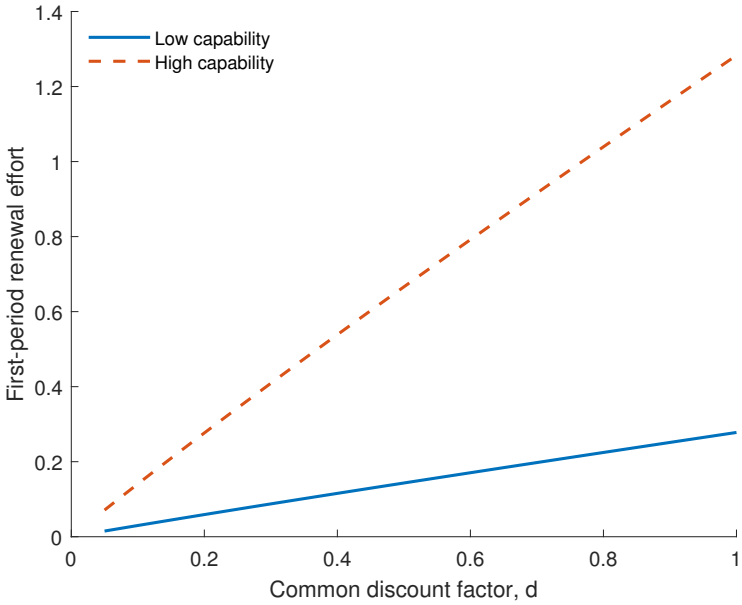


Figure 4. The discount factor and first-period renewal.

Figure 5 holds the external technology and prior fixed and improves the accuracy of the public capability signal. Expected renewal by a genuinely low-capability provider rises toward the observable-capability benchmark. The provider's type does not improve. The resulting incentive contract becomes less distorted on average conditional on that type. This separates the productive value of more accurate assessment from a change in the composition of suppliers.

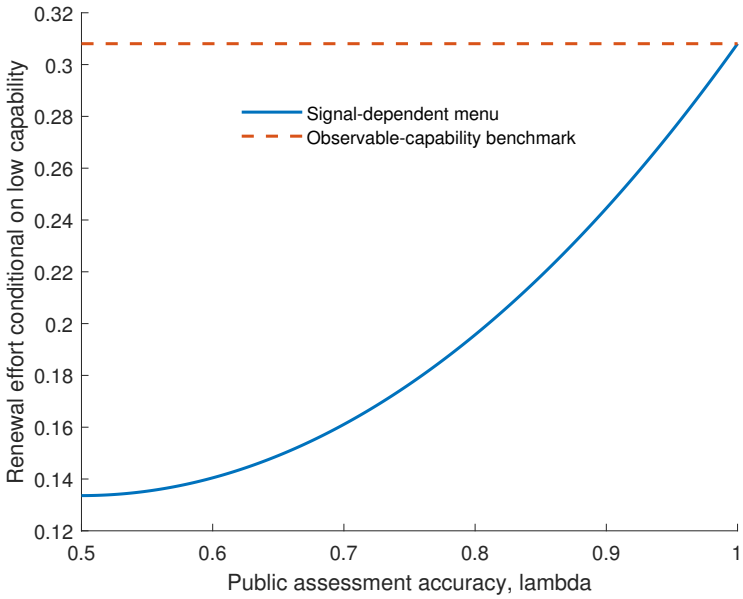


Figure 5. Public information and renewal by a true low-capability external provider.

Figure 6 changes the variance of second-period operating performance at fixed $q = 0.60$. Renewal and later operation are proportionally more distorted by screening when future normalized risk is lower. The two distortions coincide at $\sigma_2^2 \simeq 1.0071$, where $r_1 = r_2$. Increasing noise beyond this point reduces screening's proportional contribution but still weakens the absolute incentive to renew. Evaluating only the proportional loss would therefore give a misleading impression that poorer future measurement improves implementation.

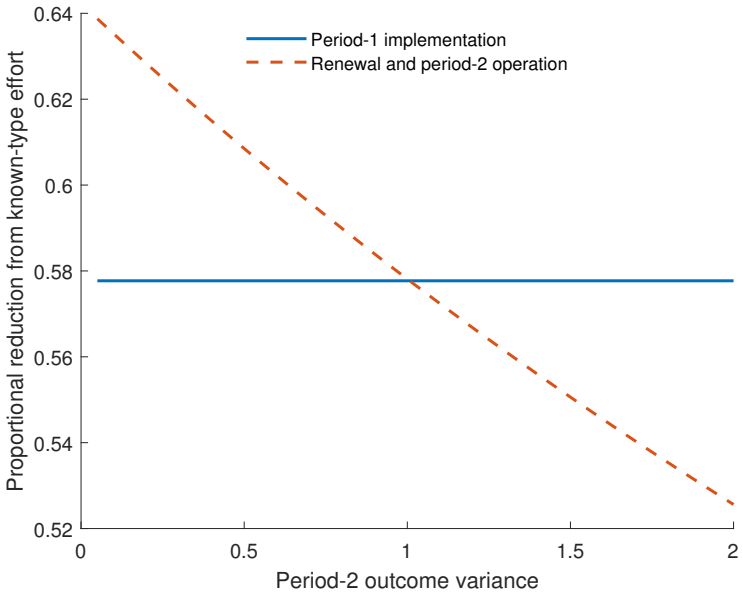


Figure 6. Proportional reductions from each period's own observable-capability effort.

5.5. Value Accounts and Imperfect Internal Governance

Table 5 reports the economic outcomes under each sourcing mode's principal-optimal policy. At the illustrative baseline ($p = 0.40$), all three value accounts favor internalization. The internal arrangement also generates more client-usable renewal capital and achieves a higher probability of meeting the second-period performance target.

Table 5. Baseline economic outcomes under principal-optimal policies.

Outcome	Internal	Outsourced
Principal value, V	1.2606	1.0585
Monetized surplus, S	1.4788	1.2592
Risk-adjusted surplus, W	1.2974	1.1076
Information rent, R	0.0368	0.0491
Usable renewal capital, k_2	0.9024	0.2190
Period-2 target probability	0.7585	0.5909

Figure 7 further examines how the relative rankings of the three value accounts change with external renewal-asset portability. Under the unrestricted-transfer benchmark, the internal-minus-external differences in risk-adjusted relationship surplus, principal value, and monetized project surplus cross zero at $p_W \approx 0.6430$, $p_V \approx 0.6662$, and $p_S \approx 0.6667$, respectively. For $p \in (p_W, p_V)$, the principal prefers internalization, whereas outsourcing generates greater risk-adjusted relationship surplus. As established in Equation (34), this disagreement arises because the additional information rent retained by the external agent exceeds the principal's internalization premium. The disagreement interval is relatively narrow, with a width of approximately 0.0232, while the principal-value and monetized-surplus thresholds are nearly identical, differing by only about 0.0005.

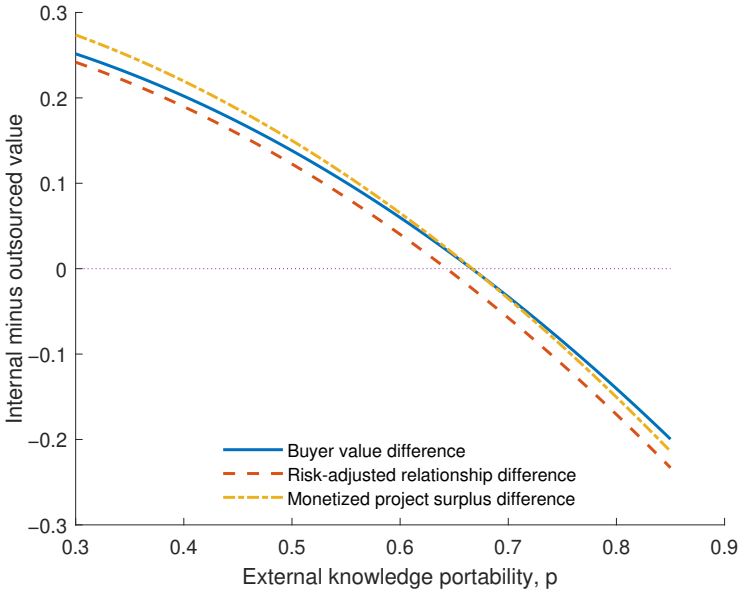


Figure 7. Different sourcing boundaries for principal value, monetized project surplus, and risk-adjusted relationship surplus.

To consider the role of internal information quality in organizational choice, Figure 8 varies internal assessment accuracy while holding external portability fixed at $p = 0.60$. The internalization premium increases with readiness, but inferior internal information raises the readiness necessary to justify internal provision. At baseline readiness and $p = 0.60$, the internal signal must have accuracy approximately 0.7908 for internalization to remain preferred. Conversely, at baseline readiness, even the no-information internal limit has a portability crossing near 0.5160, compared with 0.7377 under perfect internal information.

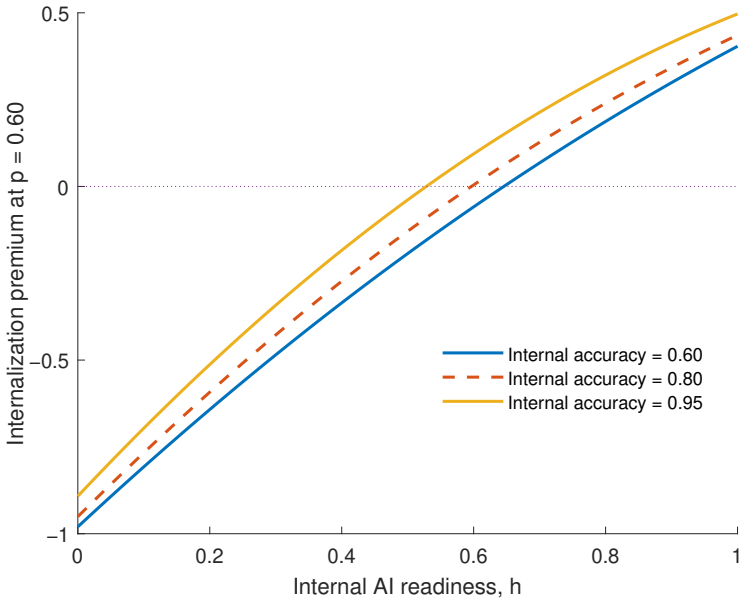


Figure 8. Internal readiness and imperfect governance.

5.6. Reoptimization with Nonnegative Fixed Transfers

The illustrative baseline satisfies condition (38) for both sourcing modes, with and without renewal, as well as in the one-period benchmark. Proposition 9 identifies the global optimum within the nonnegative-fixed-transfer linear-contract class. Because the optimal contract is independent of posterior beliefs, the optional external assessment has no gross informational value and is not purchased, whereas the internal setup cost remains unchanged. Table 6 reports the reoptimized outcomes under this payment restriction.

Table 6. Nonnegative fixed transfers ($p = 0.40$).

Model	V_I	V_O	$\mathbb{E}[a_I]$	$\mathbb{E}[a_O]$	Choice
One period	0.1501	0.3398	0	0	Outsource
Two periods, no renewal	0.4507	0.6456	0	0	Outsource
Two periods, renewal	0.6951	0.7111	0.5303	0.2994	Outsource

The payment restriction changes the sourcing comparison. At $p = 0.40$, the internalization premium of 0.2021 under unrestricted transfers becomes -0.0160 under nonnegative fixed transfers. Within the restricted model, outsourcing has a no-renewal advantage of 0.1949, whereas renewal generates a relative internal value gain of approximately 0.1789. Consequently, the latter is insufficient to reverse the original outsourcing advantage. Figure 9 further shows that, holding all other baseline parameters fixed, renewal induces internalization only for $p < 0.3477$ under nonnegative fixed transfers, compared with $p < 0.6662$ under unrestricted transfers. Thus, the sourcing reversal remains possible but depends on the feasible payment structure rather than renewal productivity alone.

The payment restriction also changes the relationship between alternative value accounts. Under nonnegative fixed transfers, principal value changes its sourcing ranking at $p_V \approx 0.3477$, whereas risk-adjusted relationship surplus and monetized project surplus share a threshold of approximately 0.5203. For $p \in (0.3477, 0.5203)$, the principal prefers outsourcing even though both surplus accounts favor internalization, reversing the direction of disagreement observed in the unrestricted-transfer baseline. The coincidence of the two surplus thresholds follows from identical performance shares, common risk parameters, and zero reservation utilities across the two sourcing modes. Moreover, agent surplus R_g

now includes surplus that cannot be extracted because of the payment restriction, rather than information rent alone.

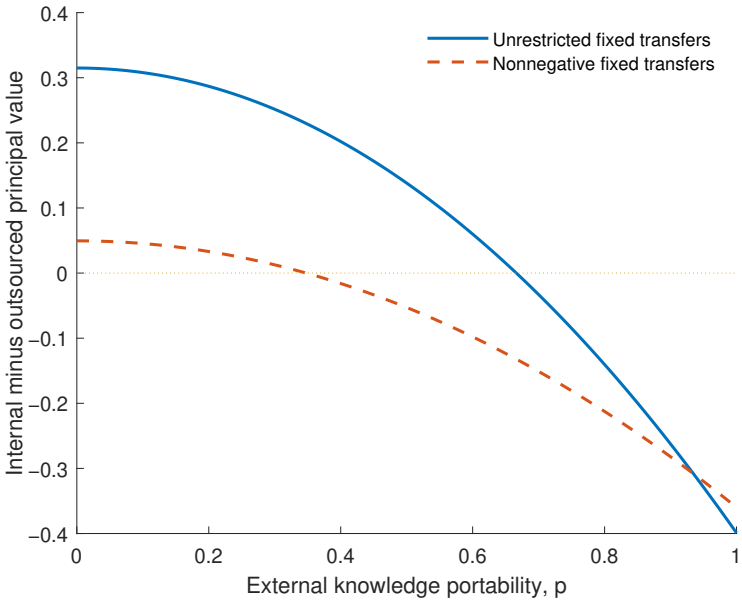


Figure 9. Reoptimized principal-value differences under unrestricted and nonnegative fixed transfers.

5.7. *Joint-Parameter Sensitivity Analysis*

To examine whether the renewal-induced sourcing reversal and the disagreement between alternative value accounts depend on the illustrative baseline, we conduct joint-parameter sensitivity analyses under both unrestricted and nonnegative fixed transfers. For sensitivity analysis, capability priors are varied independently of readiness and market maturity to represent alternative prior-information environments.

Nine parameters are varied jointly: $\eta_I \in [0.65, 1.05]$, $\bar{\eta}_O \in [0.80, 1.20]$, $\mu_I \in [0.46, 0.66]$, $\mu_O \in [0.50, 0.70]$, $\theta_H \in [1.20, 1.40]$, a common risk-aversion coefficient $\rho \in [0.35, 0.65]$, separate internal and external effort-cost multipliers $f_I, f_O \in [0.85, 1.15]$, and a common noise-variance multiplier $f_\sigma \in [0.80, 1.20]$. Each cost multiplier scales both c_g and ℓ_g in its corresponding sourcing mode, whereas f_σ scales the outcome variances in both periods. Other baseline primitives, including $\theta_L = 1$, the discount factor, setup costs, and assessment technologies, remain fixed.

We employ two complementary numerical designs. First, a 32-case factorial design combines five binary factors capturing differences in renewal productivity, capability priors, capability separation, risk aversion, and relative effort costs. Second, a deterministic 512-point Halton design varies all nine parameters over the specified multidimensional domain. For each parameter configuration and payment regime, assessment and type-coverage decisions are reoptimized. We then compare the renewal model with its corresponding two-period no-renewal benchmark and examine sourcing rankings over $p \in [0, 1]$.

Table 7 indicates that neither a renewal-induced sourcing reversal nor an interior portability threshold is universal. At $p = 0.40$, renewal reverses an initial outsourcing preference in 317 of the 512 Halton cases under unrestricted transfers and in 218 cases under nonnegative fixed transfers. Because the no-renewal benchmark is reoptimized separately under each payment regime, these counts are not the survival rate of an identical set of reversals. In the paired design, 126 cases exhibit reversals under both regimes, 191 only under unrestricted transfers, 92 only under nonnegative fixed transfers, and 103 under neither regime.

Table 7. Joint-parameter sensitivity of renewal-induced sourcing reversals.

Design	Fixed Payment	Cases	No-Renewal O	Reversals	Interior V Roots
Factorial	Unrestricted	32	18	6	12
Factorial	Nonnegative	32	24	6	10
Halton	Unrestricted	512	412	317	406
Halton	Nonnegative	512	506	218	322

Figure 10 compares the internalization premia under the two payment regimes for identical parameter configurations. The payment restriction changes not only the magnitude but also the sign of the internalization premium. Nevertheless, reversals remain possible under both regimes, and their occurrence depends on the underlying productive, informational, and contractual conditions.

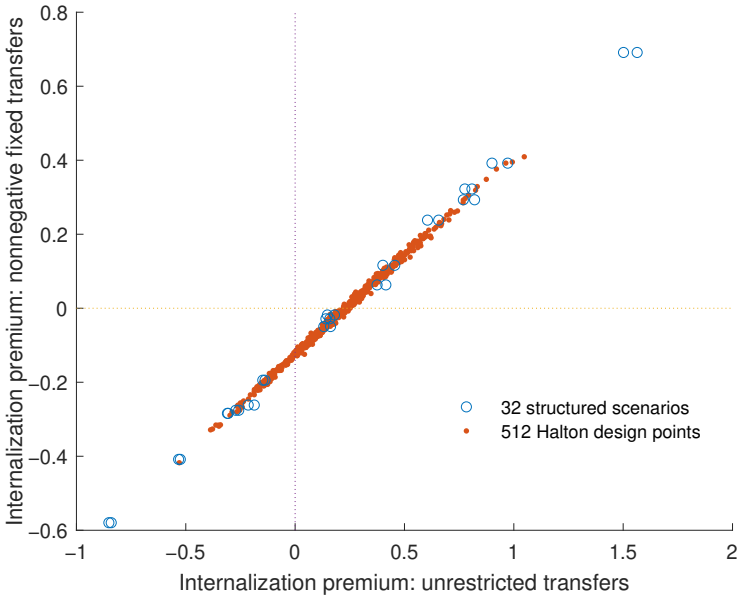


Figure 10. Paired internalization premia at $p = 0.40$ under unrestricted and nonnegative fixed transfers.

The portability thresholds also vary across parameter configurations. Among cases with a single interior principal-value crossing, p_V ranges from 0.0541 to 0.9980 under unrestricted transfers and from 0.0256 to 0.9879 under nonnegative fixed transfers. These findings indicate that the baseline portability threshold is conditional on the assumed parameter configuration.

We further examine the sensitivity of the disagreement between principal value and risk-adjusted relationship surplus. Table 8 jointly varies internal renewal productivity and risk aversion while scanning external portability. The disagreement interval is measured by $p_V - p_W$ for the reported configurations.

As shown in Table 8, both the locations of the sourcing boundaries and the width of the disagreement interval depend on renewal productivity and risk aversion. In the broader 512-point design, the total length of the V–W disagreement set ranges from zero to 0.1790 under unrestricted transfers and from zero to 0.4799 under nonnegative fixed transfers. Under the latter regime, the relevant difference reflects total agent surplus, including surplus arising from the payment restriction, rather than information rents alone. Thus, disagreement between private sourcing incentives and risk-adjusted relationship surplus is a conditional outcome.

Table 8. Sensitivity of sourcing boundaries to internal renewal productivity and risk aversion under unrestricted transfers.

η_I	ρ	p_V	p_W	p_S	Width
0.65	0.35	0.4368	0.4051	0.4344	0.0317
0.65	0.50	0.4246	0.3938	0.4318	0.0308
0.65	0.65	0.4133	0.3832	0.4289	0.0300
0.85	0.35	0.6740	0.6498	0.6684	0.0242
0.85	0.50	0.6662	0.6430	0.6667	0.0232
0.85	0.65	0.6592	0.6368	0.6648	0.0223
1.05	0.35	0.8876	0.8654	0.8796	0.0221
1.05	0.50	0.8817	0.8603	0.8783	0.0213
1.05	0.65	0.8763	0.8558	0.8769	0.0205

6. Discussion and Conclusions

This study develops a two-period contracting framework to examine how renewal investment affects AI service sourcing under persistent private capability and hidden effort. The central contribution lies in linking future performance incentives to both subsequent operation and early formation of client-usable service capital. A matched no-renewal comparison isolates this intertemporal investment channel from the effect of extending the operating horizon. While the screening structure builds on established adverse-selection theory, renewal changes productive potential, incentive distortions, and organizational value. Under unrestricted fixed transfers, renewal reverses an initial outsourcing advantage only when its relative internal value gain exceeds that advantage.

The extension with nonnegative fixed transfers reveals an important boundary of the benchmark results. Under a sufficient participation condition, a common half-share contract is optimal within the restricted linear-contract class, and public capability assessment has no gross informational value. At the illustrative baseline, this restriction changes the preferred sourcing mode from internalization to outsourcing. Joint-parameter analyses further identify configurations with and without renewal-induced reversals under both payment regimes, confirming that sourcing outcomes depend on contractual feasibility as well as productive and informational conditions.

Three conditional managerial implications follow. First, sourcing decisions should account for renewal costs and the client-specific usability of accumulated assets, rather than operating efficiency or initial expenditure alone. Second, capability assessment should be evaluated against its cost, considering prior information and feasible contractual arrangements. Third, future-oriented incentives should be assessed through their discounted effects on renewal investment and risk exposure, rather than nominal performance shares alone. Applying these implications requires reliable estimates of relevant technological, contractual, and informational parameters.

The findings contribute to understanding a specific economic dimension of sustaining AI service value. Current renewal investment creates productive assets that support future service performance. The distinctions among principal value, monetized project surplus, and risk-adjusted relationship surplus further clarify how resource costs, risk bearing, and agent surplus affect sourcing decisions. Although these measures do not provide a comprehensive assessment of sustainability, they offer useful insights into the economic conditions that may support sustained organizational value creation.

Several limitations qualify the analysis. Binary capability types, a two-period horizon, and separable effort costs restrict the representation of heterogeneity, repeated renewal, and competing tasks. The model also excludes supplier competition and renegotiation, while full commitment and linear contracts limit the admissible contractual arrangements. Future

research could relax these assumptions and examine longer-term service relationships, alternative contractual structures, and broader sustainability outcomes.

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Appendix A

Appendix A.1. Proofs of the Propositions

Proof of Proposition 1. Fix a true type i, a selected contract, and a first-period history. Previously realized compensation and effort costs multiply the conditional exponential objective by a positive factor. Conditional independence implies that the second-period optimization reduces to maximizing

$$d\left(\beta_2\phi\theta_i e_2 - \frac{ce_2^2}{2\theta_i}\right).$$

The term $d\beta_2 k_2$ and the second-period normal-risk adjustment are constant with respect to e_2. Strict concavity gives $e_{2i} = \theta_i^2\phi\beta_2/c$, regardless of the history. This establishes sequential optimality, not merely the optimality of an ex ante announced effort plan.

Substitute this continuation action into lifetime expected utility and integrate the two independent normal disturbances. Conditional on the known true type, their discounted remuneration variance is

$$\beta_1^2\sigma_1^2 + d^2\beta_2^2\sigma_2^2.$$

The certainty equivalent before first-period efforts is therefore

$$\alpha + \beta_1\phi\theta_i e_1 + d\beta_2\eta\theta_i a + d\left(\beta_2\phi\theta_i e_{2i} - \frac{ce_{2i}^2}{2\theta_i}\right) - \frac{ce_1^2 + \ell a^2}{2\theta_i} - \frac{1}{2}(\omega_1\beta_1^2 + \omega_2\beta_2^2).$$

The Hessian in (e_1, a) is $\mathrm{diag}(-c/\theta_i, -\ell/\theta_i)$, which is negative definite. Its first-order conditions yield (1). The nonnegative constraints hold since $\beta_t, \eta \geq 0$. If $\eta = 0$ or $\beta_2 = 0$, $a = 0$ is the unique optimum. Inserting the resulting actions gives

$$\mathbb{E}[Y_1 + dY_2 \mid i] = \sum_t X_{ti}\beta_t, \qquad C_1 + dC_2 = \frac{1}{2}\sum_t X_{ti}\beta_t^2,$$

and hence Equation (2). Rearranging (2) gives the fixed transfer associated with an intended certainty equivalent. Adding its expected variable payments gives (3). Subtracting this compensation from discounted operating benefits yields (4). The normal certainty-equivalent calculation is performed conditional on the agent's true type. No normal approximation is made to the firm's ex ante binary mixture. □

Observable-Capability Benchmark. At a known type, lowering α leaves effort unchanged, so participation binds. The principal then maximizes a sum of strictly concave quadratics,

$$\sum_t \left[X_{ti}\beta_t - \frac{1}{2}(X_{ti} + \omega_t)\beta_t^2\right] - \bar{u}.$$

The roots $X_{ti}/(X_{ti}+\omega_t)$ lie in $(0,1)$ and therefore are the unique global maximizers in the allowed coefficient interval. Substitution gives (5) and (6). A known type is employed only when $J_i-\bar{u}\geq 0$. With verifiable effort, the firm specifies the unique maximizers of expected benefit net of effort cost and insures the agent through a fixed payment. Differentiating that surplus gives $e_1=e_2=\theta_i^2\phi/c$ and $a=d\theta_i^2\eta/\ell$, for value $\sum_t X_{ti}/2-\bar{u}$. □

Proof of Proposition 2. From (2), the utility of true type H from the low item is

$$U_H(L)=u_L+\frac{1}{2}\sum_t \Delta_t\beta_{tL}^2.$$

Similarly, $U_L(H)=u_H-\frac{1}{2}\sum_t \Delta_t\beta_{tH}^2$. This proves (7), including the reoptimization of every action under imitation.

Consider a relaxation that retains both participation constraints and the high-type downward constraint but drops the low-type upward constraint. For any coefficient vectors, the smallest feasible utilities in this relaxation are $u_L=\bar{u}$ and $u_H=\bar{u}+\sum_t \Delta_t\beta_{tL}^2/2$. They maximize the principal value because the objective decreases strictly in each utility when $0<q<1$. Substitution gives

$$\max_{\boldsymbol{\beta}_L,\boldsymbol{\beta}_H\in[0,1]^2}\sum_{t=1}^{2}\left[(1-q)X_{tL}\beta_{tL}-\frac{1}{2}D_t(q)\beta_{tL}^2+qX_{tH}\beta_{tH}-\frac{q}{2}(X_{tH}+\omega_t)\beta_{tH}^2\right]-\bar{u}. \tag{A1}$$

The Hessian is diagonal, with strictly negative entries $-D_t(q)$ and $-q(X_{tH}+\omega_t)$. Its unique unconstrained roots are (8), and all belong to $(0,1)$. Moreover,

$$0<\beta_{tL}^*<\frac{X_{tL}}{X_{tL}+\omega_t}<\frac{X_{tH}}{X_{tH}+\omega_t}=\beta_{tH}^*.$$

The last inequality is strict for positive ω_t. Consequently, $\sum_t \Delta_t(\beta_{tL}^*)^2\leq\sum_t \Delta_t(\beta_{tH}^*)^2$, so the omitted upward constraint also holds. The relaxation's upper bound is attained in the original feasible set. Strict concavity and the strictly decreasing objective in the utilities establish uniqueness of the coefficients, intended utilities, and fixed-transfer present values. Individual payment dates' fixed transfers remain indeterminate subject to their present value.

Evaluating (A1) at its maximizer and using the rent in (9) gives (12), and (10) and (11) follow from Proposition 1. Completing the square in each known-type quadratic yields

$$J_L-\sum_t\left[X_{tL}\beta_{tL}^*-\tfrac{1}{2}(X_{tL}+\omega_t)(\beta_{tL}^*)^2\right]=\frac{1}{2}\sum_t(X_{tL}+\omega_t)(\beta_{tL}^{MH}-\beta_{tL}^*)^2.$$

Multiplying by $1-q$ and adding expected high-type rent proves the first equality of (13). Direct substitution of the two coefficients gives its second equality. □

Proof of Proposition 3. Full coverage has value $B(q)-\bar{u}$. If only the high type is served, offer its observable-capability contract. The high type receives $\bar{u}$. A low type selecting it receives

$$\bar{u}-\frac{1}{2}\sum_t \Delta_t(\beta_{tH}^{MH})^2<\bar{u},$$

so rejection is strict for the low type. The principal obtains $q(J_H-\bar{u})$. The observable-capability contract maximizes principal value among high-only contracts. Rejecting both types produces zero.

Conversely, if any positive-incentive item gives the low type at least $\bar{u}$, the high type obtains a strictly higher utility from that same item. Hence, the menu cannot serve the low type while excluding the high type. A zero-incentive item produces no positive net productive value and cannot improve on rejection. The full-coverage optimum, high-only

optimum, and rejection exhaust the profitable deterministic coverage choices, proving (14). Subtracting the high-only value from the full-coverage value gives

$$B(q) - \bar{u} - q(J_H - \bar{u}) = (1-q)\left[\frac{1}{2}\sum_t \frac{(1-q)X_{tL}^2}{D_t(q)} - \bar{u}\right],$$

which proves (15). Since $B(q) \le M(q) \le J_H$, $\bar{u} \ge J_H$ makes every implementation option nonpositive. For $\bar{u} = 0$, the additional low-type term in $B(q)$ is strictly positive at every $q \in (0,1)$.

At $q = 0$ or $q = 1$, the type that occurs is known. The value is respectively $[J_L - \bar{u}]_+$ or $[J_H - \bar{u}]_+$, also the limit of (14). Incentives for a zero-probability type need not be uniquely specified. Indifference is resolved in favor of truthful selection and, for an unproductive relationship, rejection. This does not change values. □

Proof of Proposition 4. Write $z = \theta_L^3$ and $\delta_\theta = \theta_H^3 - \theta_L^3$. Dividing (8) by x_t yields

$$\beta_{tL}^* = \frac{z}{z + r_t + q\delta_\theta/(1-q)}, \qquad \beta_{tL}^{MH} = \frac{z}{z + r_t}.$$

Their ratio is (16). For $q \in (0,1)$, its derivative with respect to r_t is

$$\frac{q\delta_\theta/(1-q)}{[z + r_t + q\delta_\theta/(1-q)]^2} > 0.$$

The operating-effort and renewal formulas in (1) are proportional to the relevant coefficient, so the same ratio applies to each activity. Thus, a smaller r_2 means a smaller retained fraction for renewal and second-period operation than for first-period operation.

An increase in η raises $x_2 = d\phi^2/c + d^2\eta^2/\ell$, leaving x_1 and both ω_t unchanged. For any positive ω_2, this lowers r_2 and increases each absolute future coefficient. Multiplication by the increasing renewal productivity in $a_i = d\theta_i^2\eta\beta_{2i}/\ell$ proves increasing investment. The second-period contribution to rent is

$$\frac{1}{2}\delta_\theta x_2\left[\frac{(1-q)\theta_L^3 x_2}{x_2\{(1-q)\theta_L^3 + q\delta_\theta\} + (1-q)\omega_2}\right]^2,$$

which is strictly increasing in $x_2 > 0$. Hence, lifetime rent rises as well. The retained-effort ratio falls when r_2 falls, establishing the stronger proportional distortion. With zero risk in the limit, shares are independent of a common productive scale, while the direct increase in η still raises renewal. □

Proof of Proposition 5. Twice differentiating (12) period by period yields (20). Each B is increasing as well. To see this, put $a = X_{tL}$, $\delta = \Delta_t$, $w = \omega_t$, and $j(x) = x^2/[2(x+w)]$. The derivative of the period-specific contribution to B at $q = 0$ is

$$j(a+\delta) - j(a) - \frac{a^2\delta}{2(a+w)^2} \ge 0.$$

Indeed, j is convex, with $j''(x) = w^2/(x+w)^3 \ge 0$, and $j'(a) = a(a+2w)/[2(a+w)^2] \ge a^2/[2(a+w)^2]$. Convexity of B then makes its derivative nonnegative for all q. The full-coverage branch is continuous and convex. If $J_H > \bar{u}$, the high-only branch is nondecreasing and affine, as is the rejection branch. Their pointwise maximum is continuous, convex, and nondecreasing. If $J_H \le \bar{u}$, rejection is optimal everywhere, so the same weak properties hold.

For $1/2 \le \lambda_1 < \lambda_2 \le 1$, the lower-accuracy binary signal is replicated by independently flipping the higher-accuracy signal with probability

$$\tau = \frac{\lambda_2 - \lambda_1}{2\lambda_2 - 1} \in [0, 1/2].$$

This produces conditional accuracy $\lambda_2(1-\tau)+(1-\lambda_2)\tau = \lambda_1$. The posterior after the coarser signal is the conditional expectation of the posterior after the finer signal. Conditional Jensen's inequality applied to $\mathcal{V}$ in (17) gives $G(\mu,\lambda_2) \geq G(\mu,\lambda_1)$. Comparing the two acquisition options and subtracting K gives (21). Subtracting the unchanged internal setup cost establishes the internal-information comparison. Perfect information also gives the bound

$$G_g(\mu,\lambda) \leq (1-\mu)[J_{gL} - \bar{u}_g]_+ + \mu[J_{gH} - \bar{u}_g]_+.$$

For low-type renewal under full coverage, combine (22) with Bayes' identity

$$\mathbb{E}[\beta^*_{2L}(q_z) \mid L] = \frac{\mathbb{E}[(1-q_z)\beta^*_{2L}(q_z)]}{1-\mu}.$$

The function $f(q) = (1-q)\beta^*_{2L}(q)$ satisfies

$$f''(q) = \frac{2X_{2L}\Delta_2^2}{D_2(q)^3} > 0.$$

The same garbling and Jensen argument therefore raises the low-type conditional coefficient, and multiplying by $d\theta_L^2\eta/\ell$ raises its expected renewal weakly. The comparison is strict for a nontrivial refinement with $\eta > 0$ in a strictly convex full-coverage region. Coverage changes require separate evaluation and are not included in this conditional-effort claim. □

Proof of Proposition 6. For fixed signal accuracy, both posteriors $q_+(\mu)$ and $q_-(\mu)$ are nondecreasing in the prior. Moreover, $\pi'_+(\mu) = 2\lambda - 1 \geq 0$ and $q_+ \geq q_-$. Since $\mathcal{V}$ is nondecreasing, increasing μ raises the value at both signals and shifts probability toward the higher posterior. Hence, G is nondecreasing in μ. This argument remains valid at kinks by monotone comparisons rather than differentiating $\mathcal{V}$ there.

For fixed type support, increasing a productive scale x_t raises J_i and the period-specific term of B. Each nonconstant term is a positive multiple of

$$\frac{x_t^2}{ax_t + b}, \qquad a > 0, \quad b \geq 0,$$

whose derivative $x_t(ax_t+2b)/(ax_t+b)^2$ is positive. The maximum in (14) is thus nondecreasing in each x_t, and so are its expectation and the optimized assessment value. Decreasing s increases ϕ_O and both external productive scales. Increasing p increases η_O and therefore x_{O2}, holding x_{O1} fixed. These establish $\Delta V_s \geq 0$ and $\Delta V_p \leq 0$ in the weak, global sense.

Readiness increases the internal prior and decreases F, giving nondecreasing V_I. The specified market channels improve the external prior and signal and lower its assessment cost. Both external options, and therefore their maximum, are nondecreasing in m. These facts establish (23). They do not require the optimal assessment indicator to be monotone. An endpoint sign change and continuity give existence of a readiness root. Strict monotonicity over the relevant interval gives uniqueness, and the implicit-function theorem gives (24) on a smooth branch. On a smooth coverage branch, increasing a common $\bar{u}$ reduces value by the implementation probability. This follows directly from the full-coverage and high-only branches in (14). Applying the envelope theorem to the selected assessment option yields (25). At branch changes, one uses one-sided comparisons.

The expression (26) follows from (18) and (19). For the renewal ablation, the monotonicity in x_2 gives $N_g \geq 0$ when η_g is increased from zero, including reoptimized information and coverage. Subtracting the two identities $V_g = V_g^0 + N_g$ proves (27). □

Proof of Proposition 7. The definitions in (28) imply that the second-period productive scale is $x_2 = d(A_0 + dG_0)$ and risk cost is $\omega_2 = d^2\Omega$. Insert these expressions into (8), using

$v_H = z_H$ and $v_L = \theta_L^3 + q(\theta_H^3 - \theta_L^3)/(1-q)$, and cancel $d > 0$. This gives (29). Denote the positive denominator by $D_i = v_i(A_0 + dG_0) + d\Omega$. Differentiation yields

$$\frac{\mathrm{d}\beta_{2i}}{\mathrm{d}d} = \frac{z_i G_0 D_i - z_i(A_0 + dG_0)(v_i G_0 + \Omega)}{D_i^2} = -\frac{z_i A_0 \Omega}{D_i^2}.$$

This verifies (30). Using the product rule for $d\beta_{2i}$ and expanding the numerator yields (31), which is positive. Inserting these derivatives into (1) gives increasing a_i and k_{2i} and decreasing e_{2i}, while x_1, ω_1, q and hence β_{1i}, e_{1i} remain unchanged. Positivity statements concerning renewal require $\eta > 0$. No claim about a globally optimized assessment path follows from this fixed-posterior calculation. □

Proof of Proposition 8. For an implemented type and signal, (3) gives

$$\mathbb{E}[w_1 + dw_2] = u + (C_1 + dC_2) + \frac{1}{2}\sum_t \omega_t \beta_t^2.$$

Subtract this identity from expected discounted operating benefits and average over implemented types and public signals. Using (32) and (33), with setup and assessment costs deducted once, gives

$$V_g = S_g - P_g - \mathbb{E}[bu] = S_g - P_g - U_g^0 - R_g = W_g - R_g.$$

Subtracting the two organizational accounts proves (34). Because internal agents also have private capability information, R_I need not vanish. For example, whenever $0 < V_I - V_O < R_O - R_I$, the principal prefers internalization but $W_I - W_O < 0$. A reverse disagreement requires the opposite relative rent ordering. These are comparisons at the specified feasible continuation policies, not claims of mechanism-wide welfare optimality. Finally, conditional normality of Y_2 with mean $\phi_g \theta e_2 + k_2$ gives (35). Averaging with the implementation indicator proves its stated interpretation. □

Proof of Proposition 9. For an implemented type, (37) and $\alpha_i \geq 0$ imply

$$\Pi_i = \sum_t X_{ti}(\beta_{ti} - \beta_{ti}^2) - \alpha_i \leq \frac{1}{4}\sum_t X_{ti},$$

since $\beta - \beta^2 = 1/4 - (\beta - 1/2)^2 \leq 1/4$. This bounds every feasible menu and every deterministic coverage choice, type by type. The common contract with half-shares and zero fixed payment attains both bounds. Under (38), the low type's certainty equivalent meets reservation; the high type's is larger because $X_{tH} > X_{tL}$. Both types are indifferent between identical menu entries, so both IC constraints hold. Rejection or excluding a positive-probability type cannot improve on an attained positive bound. Averaging over types gives (39). Since this value is affine in q and posterior means equal the prior, public information cannot improve gross expected value. A positive acquisition cost strictly favors no external assessment. The proof applies to a one-period version by summing only its operating stream. □

Appendix A.2. Alternative Risk Aggregation

For comparison only, replace lifetime expected exponential utility with the additive certainty-equivalent criterion

$$\widetilde{CE} = \mathbb{E}[w_1 + dw_2 - C_1 - dC_2] - \frac{\rho}{2}(\beta_1^2\sigma_1^2 + d\beta_2^2\sigma_2^2).$$

This explicitly changes the preference aggregation; it is not another expression for the original utility. Effort first-order conditions are unchanged because outcome variances do

not depend on effort. Consequently, $x_2 = d(A_0 + dG_0)$ remains unchanged, while $\widetilde{\omega}_2 = d\Omega$. Substitution in the same unrestricted full-coverage screening formulas gives

$$\tilde{\beta}_{2i} = \frac{z_i(A_0 + dG_0)}{v_i(A_0 + dG_0) + \Omega}, \quad \frac{\partial \tilde{\beta}_{2i}}{\partial d} = \frac{z_i G_0 \Omega}{[v_i(A_0 + dG_0) + \Omega]^2}.$$

The derivative is positive for $\eta > 0$ and positive risk, at a fixed posterior within full coverage. This establishes a concrete specification under which the nominal-share sign differs from Proposition 7. It does not establish that all alternative timing or utility formulations reverse the sign.

Appendix A.3. Computational Design

For each public posterior, the unrestricted-transfer problem compares full coverage, high-only service, and rejection. External assessment is selected by comparing the values with and without the public signal, net of assessment cost, while the internal setup cost is deducted once. Contract, assessment, and coverage decisions are optimized separately for each sourcing mode. All economic accounts are evaluated under the corresponding principal-optimal policies.

Under nonnegative fixed transfers, condition (38) is examined first. When it holds, the analytical pooling solution is applied. Otherwise, the constrained optimization problem defined by (36) and (37) is solved for full coverage and high-only service, with rejection as an additional alternative.

The joint sensitivity analysis varies nine parameters, ordered as $(\eta_I, \bar{\eta}_O, \mu_I, \mu_O, \theta_H, \rho, f_I, f_O, f_\sigma)$, over the intervals specified in Section 5.7. The 32-case factorial design uses all binary combinations $(a, b, c, d_r, e) \in \{0, 1\}^5$, mapped to the unit coordinates $(a, 1-a, b, 1-b, c, d_r, e, 1-e, d_r)$. Here, d_r denotes the risk-design factor rather than the discount factor. The 512-point Halton design uses radical inverses of integers 33 through 544 in bases $(2, 3, 5, 7, 11, 13, 17, 19, 23)$. Both designs employ affine transformations to the specified parameter intervals. Capability priors are varied directly while readiness and market maturity remain fixed. These deterministic designs are illustrative and do not represent empirical sampling distributions.

Throughout the specified parameter domain, the sufficient pooling condition holds for the nonnegative-fixed-transfer cases, including the matched no-renewal comparisons. The no-renewal benchmark is reoptimized separately under each payment regime. Portability thresholds are obtained by scanning 401 equally spaced values of $p \in [0, 1]$ and refining sign-change brackets. Potential discontinuities arising from policy switches are distinguished from genuine zero crossings. The length of the disagreement set between principal value and risk-adjusted relationship surplus is calculated using the intervals defined by their detected crossings. Cases without an interior threshold are retained.

References

1. Mikalef, P.; Gupta, M. Artificial intelligence capability: Conceptualization, measurement calibration, and empirical study on its impact on organizational creativity and firm performance. *Inf. Manag.* **2021**, *58*, 103434. [CrossRef]
2. Raisch, S.; Krakowski, S. Artificial Intelligence and Management: The Automation–Augmentation Paradox. *Acad. Manag. Rev.* **2021**, *46*, 192–210. [CrossRef]
3. Brynjolfsson, E.; Li, D.; Raymond, L. Generative AI at Work. *Q. J. Econ.* **2025**, *140*, 889–942. [CrossRef]
4. Amershi, S.; Begel, A.; Bird, C.; DeLine, R.; Gall, H.; Kamar, E.; Nagappan, N.; Nushi, B.; Zimmermann, T. Software Engineering for Machine Learning: A Case Study. In Proceedings of the 2019 IEEE/ACM 41st International Conference on Software Engineering: Software Engineering in Practice (ICSE-SEIP), Montreal, QC, Canada, 25–31 May 2019; pp. 291–300. [CrossRef]
5. Bansal, P.; DesJardine, M.R. Business sustainability: It is about time. *Strateg. Organ.* **2014**, *12*, 70–78. [CrossRef]
6. Lago, P.; Akinli Koçak, S.; Crnkovic, I.; Penzenstadler, B. Framing Sustainability as a Property of Software Quality. *Commun. Acm* **2015**, *58*, 70–78. [CrossRef]

7. Brynjolfsson, E.; Hitt, L.M. Beyond Computation: Information Technology, Organizational Transformation and Business Performance. *J. Econ. Perspect.* **2000**, *14*, 23–48. [CrossRef]
8. Bresnahan, T.F.; Brynjolfsson, E.; Hitt, L.M. Information Technology, Workplace Organization, and the Demand for Skilled Labor: Firm-Level Evidence. *Q. J. Econ.* **2002**, *117*, 339–376. [CrossRef]
9. Babina, T.; Fedyk, A.; He, A.; Hodson, J. Artificial Intelligence, Firm Growth, and Product Innovation. *J. Financ. Econ.* **2024**, *151*, 103745. [CrossRef]
10. Acemoglu, D.; Autor, D.; Hazell, J.; Restrepo, P. Artificial Intelligence and Jobs: Evidence from Online Vacancies. *J. Labor Econ.* **2022**, *40*, S293–S340. [CrossRef]
11. Gu, M.; Jin, C. Artificial Intelligence and Export Performance in Small and Micro-Enterprises: The Roles of Internal Capability and External Tools. *Sustainability* **2026**, *18*, 5846. [CrossRef]
12. Coase, R.H. The Nature of the Firm. *Economica* **1937**, *4*, 386–405. [CrossRef]
13. Grossman, S.J.; Hart, O.D. The Costs and Benefits of Ownership: A Theory of Vertical and Lateral Integration. *J. Political Econ.* **1986**, *94*, 691–719. [CrossRef] [PubMed]
14. Hart, O.; Moore, J. Property Rights and the Nature of the Firm. *J. Political Econ.* **1990**, *98*, 1119–1158. [CrossRef]
15. Aghion, P.; Tirole, J. Formal and Real Authority in Organizations. *J. Political Econ.* **1997**, *105*, 1–29. [CrossRef]
16. Kogut, B.; Zander, U. Knowledge of the Firm, Combinative Capabilities, and the Replication of Technology. *Organ. Sci.* **1992**, *3*, 383–397. [CrossRef]
17. Nickerson, J.A.; Zenger, T.R. A Knowledge-Based Theory of the Firm—The Problem-Solving Perspective. *Organ. Sci.* **2004**, *15*, 617–632. [CrossRef]
18. Teece, D.J. Profiting from Technological Innovation: Implications for Integration, Collaboration, Licensing and Public Policy. *Res. Policy* **1986**, *15*, 285–305. [CrossRef]
19. Poppo, L.; Zenger, T. Testing Alternative Theories of the Firm: Transaction Cost, Knowledge-Based, and Measurement Explanations for Make-or-Buy Decisions in Information Services. *Strateg. Manag. J.* **1998**, *19*, 853–877. [CrossRef]
20. Leiblein, M.J.; Reuer, J.J.; Dalsace, F. Do Make or Buy Decisions Matter? The Influence of Organizational Governance on Technological Performance. *Strateg. Manag. J.* **2002**, *23*, 817–833. [CrossRef]
21. Mayer, K.J.; Salomon, R.M. Capabilities, Contractual Hazards, and Governance: Integrating Resource-Based and Transaction Cost Perspectives. *Acad. Manag. J.* **2006**, *49*, 942–959. [CrossRef]
22. Baker, G.; Gibbons, R.; Murphy, K.J. Relational Contracts and the Theory of the Firm. *Q. J. Econ.* **2002**, *117*, 39–84. [CrossRef]
23. MacLeod, W.B. Reputations, Relationships, and Contract Enforcement. *J. Econ. Lit.* **2007**, *45*, 595–628. [CrossRef]
24. Chen, Y.; Bharadwaj, A. An Empirical Analysis of Contract Structures in IT Outsourcing. *Inf. Syst. Res.* **2009**, *20*, 484–506. [CrossRef]
25. Susarla, A. Contractual Flexibility, Rent Seeking, and Renegotiation Design: An Empirical Analysis of Information Technology Outsourcing Contracts. *Manag. Sci.* **2012**, *58*, 1388–1407. [CrossRef]
26. Mani, D.; Barua, A.; Whinston, A.B. An Empirical Analysis of the Contractual and Information Structures of Business Process Outsourcing Relationships. *Inf. Syst. Res.* **2012**, *23*, 618–634. [CrossRef]
27. Baron, D.P.; Besanko, D. Regulation and Information in a Continuing Relationship. *Inf. Econ. Policy* **1984**, *1*, 267–302. [CrossRef]
28. Laffont, J.J.; Tirole, J. The Dynamics of Incentive Contracts. *Econometrica* **1988**, *56*, 1153–1175. [CrossRef] [PubMed]
29. Pavan, A.; Segal, I.; Toikka, J. Dynamic Mechanism Design: A Myersonian Approach. *Econometrica* **2014**, *82*, 601–653. [CrossRef]
30. Bergemann, D.; Välimäki, J. Dynamic Mechanism Design: An Introduction. *J. Econ. Lit.* **2019**, *57*, 235–274. [CrossRef]
31. Holmström, B. Moral Hazard and Observability. *Bell J. Econ.* **1979**, *10*, 74–91. [CrossRef] [PubMed]
32. Holmström, B.; Milgrom, P. Aggregation and Linearity in the Provision of Intertemporal Incentives. *Econometrica* **1987**, *55*, 303–328. [CrossRef]
33. Prendergast, C. The Provision of Incentives in Firms. *J. Econ. Lit.* **1999**, *37*, 7–63. [CrossRef]
34. Holmström, B.; Milgrom, P. Multitask Principal–Agent Analyses: Incentive Contracts, Asset Ownership, and Job Design. *J. Law Econ. Organ.* **1991**, *7*, 24–52. [CrossRef]
35. Li, D.; Wang, H.; Li, Y. Incentive Mechanisms for Thermal Power Generation Enterprises with Conflicting Tasks: Electricity Production versus Carbon Emission Reduction. *Sustainability* **2023**, *15*, 10420. [CrossRef]
36. Breck, E.; Cai, S.; Nielsen, E.; Salib, M.; Sculley, D. The ML Test Score: A Rubric for ML Production Readiness and Technical Debt Reduction. In Proceedings of the 2017 IEEE International Conference on Big Data (Big Data), Boston, MA, USA, 11–14 December 2017; pp. 1123–1132. [CrossRef]
37. Gama, J.; Žliobaitė, I.; Bifet, A.; Pechenizkiy, M.; Bouchachia, A. A survey on concept drift adaptation. *ACM Comput. Surv.* **2014**, *46*, 44:1–44:37. [CrossRef] [PubMed]
38. Tabassi, E. *Artificial Intelligence Risk Management Framework (AI RMF 1.0)*; Technical Report NIST AI 100-1; National Institute of Standards and Technology: Gaithersburg, MD, USA, 2023. [CrossRef]
39. Levinthal, D.A.; March, J.G. The Myopia of Learning. *Strateg. Manag. J.* **1993**, *14*, 95–112. [CrossRef]

40. Benner, M.J.; Tushman, M.L. Exploitation, Exploration, and Process Management: The Productivity Dilemma Revisited. *Acad. Manag. Rev.* **2003**, *28*, 238–256. [CrossRef]
41. Eccles, R.G.; Ioannou, I.; Serafeim, G. The Impact of Corporate Sustainability on Organizational Processes and Performance. *Manag. Sci.* **2014**, *60*, 2835–2857. [CrossRef]
42. Dyllick, T.; Hockerts, K. Beyond the business case for corporate sustainability. *Bus. Strategy Environ.* **2002**, *11*, 130–141. [CrossRef]
43. Hahn, T.; Figge, F.; Pinkse, J.; Preuss, L. Trade-offs in corporate sustainability: You can't have your cake and eat it. *Bus. Strategy Environ.* **2010**, *19*, 217–229. [CrossRef]

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