Optimal Debt Policy: New Insights from Innovation

Chang-Chih Chen

Providence University, E-mail: 3131403394@qq.com

Kung-Cheng Ho

Zhongnan University of Economics and Laws, E-mail: z0004531@zuel.edu.cn

Jinqiang Yang*

Shanghai University of Finance and Economics, E-mail: yang.jinqiang@mail.shufe.edu.cn

Abstract

We build an integrated model of innovation and capital structure. In the model, firms choose leverage, invest in R&D, and pay wages determined by the balance between the value of inventors' employment contract and available R&D benefit. Firms' desire for R&D benefit limits and could even destroy their willingness to use debt. The concavity of marginal R&D-value loss due to debt use makes firms react more to tax rises than to tax cuts when adjusting toward the target leverage ratio. Our model implications help explain puzzling leverage phenomena: the zero-leverage anomaly, the mixed leverage-wage relation, and the asymmetric leverage-to-tax sensitivity.

Keywords: leverage; wages; R&D intensity; innovation strategy; inventor mobility;

JEL classification: G32; J31; O32; J60; O31;

---

* Yang: Corresponding author. Chen will serve as the presenter in 2021 Real Options annual conference.

I. Introduction

Firms' desire for benefits from R&D and innovation has profound consequences for capital structure decisions. Between 1950 and 2018, more than 76% of U.S. firms have experience in doing R&D. Substantial evidence reveals that R&D investment is a major determinant of the cross-sectional variation in corporate leverage (e.g., Graham and Leary, 2011). The theoretical literature on financial economics, however, pays little attention to how firms' involvement in R&D or innovation affects leverage choice.

This paper proposes an integrated model of firm innovation and capital structure (for a detailed structure of the model, see Figure 1 in Section 3 on page 10). The model provides a novel method of assessing the value of innovation with taking the effects of debt use, R&D investment, human capital costs, and product pricing into account. Our method is more generalized and has a rich set of advantages over traditional methods (descriptions about model advantages are given in the end of Section 1). In the model, firms choose leverage, invest in R&D, absorb R&D/innovation benefit through product pricing, and pay wages determined by the balance between available R&D benefit and the value of inventors' employment contract. Model implications can reconcile capital structure tradeoff theories with three puzzling leverage features in the cross section: (i) the zero-leverage anomaly; (ii) the asymmetric tax sensitivity of leverage; and (iii) the mixed leverage-wage relation. Model implications also enable us to formulate several new capital structure empirical predictions about firm innovation stylized facts.

In the base-case model, we consider only technology innovation for brevity. This parsimonious model generates three sets of implications. First, firms' desire for R&D/innovation benefits limits and could even destroy their willingness to use leverage. In the model, debt use delivers financial distress risk that could make firms lose inventive human capital in place as well as R&D benefits attached to human capital. As debt use rises, the expected duration of inventor employment shortens, and the value of available R&D benefits decreases. When choosing the debt level, firms trade off traditional leverage value (tax benefits on debt less bankruptcy costs) against R&D-value loss due to debt use. Optimal leverage predicted by our model, therefore, is lower than that by traditional models that ignore innovation. The negative effect of debt use on available R&D benefits particularly increases with R&D efficiency and the reaction of earnings to technology progress. If inventors in place possess high R&D efficiency or earnings react to innovation success strongly, firms will choose almost-zero leverage and invest heavily in R&D. To our knowledge, we are the first to replicate zero-leverage capital structure phenomena in a tradeoff framework under *reasonable* parameterizations. Our model provides an R&D-incentive-based explanation for the zero-leverage anomaly studied by Strebulaev and Yang (2013), Ghoul et al. (2018), and others. Our model also captures a widely-documented but unexplained empirical regularity that innovating and R&D firms maintain relatively lower leverage (see, e.g., Bena and Garlappi, 2019).

Second, the relation between optimal leverage and wages is complex, depending on the tradeoff between human capital loss (HCL) effect and risk compensation (RC) effect. In the model, we determine wages by using inventors' outside-option condition characterized as a fixed pay-performance ratio.[1] On the one hand, since the expected duration of inventor employment is shorter (the possibility of human capital loss due to financial distress is larger), raising leverage makes firms derive less R&D benefit from inventors. In view of this negative effect on *performance*, firms taking more leverage tend to pay lower wages. On the other hand, increasing leverage makes inventors bear a higher unemployment risk, which will generate a higher expected unemployment cost associated with employment contract as well as a lower employment contract value. In view of this negative effect on *pay*, firms choosing higher leverage pay higher wages

[1] The pay-performance ratio is defined as the proportion of the value of inventors' contract to the firm's expected innovation benefit contributed by inventors. We use this ratio as a proxy for the value of inven -tors' outside option. The role of this ratio is similar to the surplus-sharing rule in Michaels et al. (2019).

as risk compensation that ensures the balance between pay and performance (holding performance fixed). Changes in firms' and labors' characteristics both simultaneously affect the outcomes of leverage decision and the tradeoff between the aforementioned two effects. Along characteristic changes, this simultaneity shapes the relation between wages and optimal leverage. This relation is positive (negative) when marginal changes in the RC (HCL) effect due to leverage changes outweigh those in the HCL (RC) effect. We find that along product market risk and the pay-performance ratio (R&D efficiency and the product demand growth rate), this relation is positive (negative). Such complexities settle the empirical debate over the cross-sectional relation between leverage and human capital costs (i.e., employees' wages or compensation).

Empirical studies document that leverage has a mixed relation with human capital costs. It can be negative (Hanka, 1998; Simintzi et al., 2015; and Michaels et al., 2019) or positive (Agrawal and Matsa, 2013; and Chemmanur et al., 2013). The mixture of those empirical outcomes might arise from the fact that leverage or wages are simply taken as an exogenous regressor. They in fact are both endogenous and simultaneously influenced by changes in exogenous economic factors. This regression misspecification causes estimation results to be tainted by simultaneity bias that makes the interpretation of corresponding empirical evidence controversial.

Third, marginal R&D-value loss due to debt use is concave in the debt level, and its concavity alters the shape of the leverage-tax sensitivity. This concavity makes firms react more to tax rises than to tax cuts when adjusting toward the target leverage ratio that equates marginal R&D-value loss with marginal leverage value. This concavity suggests that the sensitivity of marginal R&D-value loss to debt cuts is higher than that to debt rises. When tax-rate changes result in the imbalance between marginal leverage value at the current debt level and corresponding marginal R&D-value loss, firms offset the tax rise (cut)-caused imbalance by increasing (lowering) debt use in a relatively larger (smaller) size. In traditional models, tax cuts deliver a relatively larger effect on leverage, because marginal leverage value is more sensitive to tax cuts than to tax rises. The shape of the leverage-tax sensitivity predicted by our model is contrary to that by traditional models but consistent with the empirical findings of Heider and Ljungqvist (2015). They document that a rise in the tax rate motivates firms to raise leverage but a drop in the tax rate causes an insignificant corresponding effect. We further show that since R&D value and total expected R&D expenses both have a 1-to-1 inverse relation with debt use, these two R&D-related quantities and optimal leverage share the feature of asymmetric sensitivities to tax-rate changes. The negative reaction of available R&D benefit to tax rises is stronger than the corresponding positive reaction to tax cuts. Our results capture empirical phenomena in Mukherjee et al. (2017), which document that tax rises significantly hinder corporate innovation but tax cuts weakly boost innovation. The effect of taxes on R&D decision is largely ignored in existing innovation theories.

We extend the base-case model in two directions: innovation strategy switches and inventor mobility. Model extensions generate several novel capital structure empirical predictions. We show that firms use less leverage when inventors in place have a higher mobility intensity. Hedging human capital risk due to inventor mobility raises leverage and reduces available R&D benefits. Moreover, innovation strategy switches twist the influence of product price competition on optimal leverage. In response to a rise in price competition, technology-innovation (product-innovation) firms reduce (raise) leverage. In mixed-innovation firms, the leverage-competition relation has an inverted-U shape.[2]

Our paper is at the intersection of several strands of the literature. First of all, our paper is related to the vast literature on capital structure tradeoff theories (e.g., Abel, 2018; Kumar and Yerramilli, 2018; Antill and Grenadier, 2019; etc.). We are the first to introduce issues on innovation and R&D into theoretical capital structure research. The

[2] Mixed innovation refers to the case when firms do technology and product innovation simultaneously.

proposed model captures several puzzling cross-sectional features of leverage; i.e., the zero-leverage anomaly, the mixed wage-leverage relation, and the asymmetric leverage -tax sensitivity. These features are not explained by or at odds with existing models. Our models further deliver new capital structure empirical predictions about human capital risk management and the coordination between innovation strategy and product pricing.

Also, our paper relates to a growing stream of the literature on the implication of human capital mobility for corporate finance and innovation. Lustig et al. (2011) study the effect of technical capital loss due to employee mobility on executive compensation. Donangelo (2014) analyzes the cross-sectional relation between stock returns and labor mobility. Israelsen and Yonker (2017) estimate the loss in firm value attributed to key-employee departures. Liu et al. (2017) examine the consequence of inventor mobility for firms' innovation outputs. We complement this literature by studying how inventor mobility and related risk management affect debt policies via innovation valuation.

Finally, our paper makes a methodological contribution to the long list of papers on R&D/innovation theories and related applications (e.g., Klette and Kortum, 2004; Lentz and Mortensen, 2008; Lin, 2012; Malamud and Zucchi, 2019) with proposing a new generalized corporate innovation model. In contrast to existing models, our model has several attractive and unique features. First, it endogenizes the negative influence of debt use on corporate R&D value. This is the key that enables the model to bridge the gap between innovation and capital structure theories. Second, it allows for product and technological innovation simultaneously, and permits the separation between these two types of innovation effects. Third, it captures the empirical implications of human capital market friction (inventor mobility) as well as the asymmetric effect of corporate tax changes on R&D decision. Fourth, it provides an explicit formula for the expected value of R&D/innovation, which makes its comparative statics analysis more tractable. For a detailed comparison among various innovation models, see online Appendix A.

II. An Integrated Model of Innovation and Capital Structure

Consider a continuous-trading economy supported by a filtered probability space $(\Omega, \mathcal{F}, (\mathcal{F}_t)_{t\geq 0}, \mathbb{Q})$ satisfying the usual conditions. Agents are risk-neutral, and discount cash flows at the fixed riskless interest rate $r > 0$. Time is continuous and varies over $[0, \infty)$. The representative firm is unlevered at the initial time. It intends to adjust capital structure by selling a perpetual debt at its par value *D*, and meanwhile, hires a group of inventive labors (inventors) to undertake R&D on productivity technology innovation. Financial markets are frictionless.[3] In labor markets there exist job-switching frictions. These frictions are quantified using the duration of temporary unemployment $Du > 0$.

A. Production function

The firm engages in producing outputs. The production function, $F : \mathbb{R}_+ \to \mathbb{R}_+$, is in the form $F(k(t)) \equiv (k(t))^{\gamma}$ where $\gamma \in (0,1)$ is the return-to-scale parameter and $k(t)$ is the input at time *t* with a fixed unit cost $\delta > 0$ set by the firm's supplier.

B. Productivity technology innovation driven by R&D investment

The firm does R&D that continuously creates new technology. Implementing new technology generates fluctuations in productivity. Therefore, we specify the effect of innovation on productivity by using the following productivity (technology) dynamics:

$$dA(t)/A(t) = \mu_A(RD)dt + \sigma_A(RD)dW(t).^{4} \qquad (1)$$

In (1) $\mu_A(\cdot)$ is the expected rate of technology progress driven by R&D investment.

[3] A common way of modelling financial frictions is to consider financial constraints or debt transaction costs. Financial frictions reduce firms' willingness to use leverage but do not affect the marginal effect of debt use on available R&D benefit. In the presence of financial frictions, our results of comparative statics remain unchanged. Therefore, for brevity, we adopt the setting of frictionless financial markets.

[4] Physical investment (capital investment) is another channel through which firms improve productivity. Firms doing R&D investment need to additionally pay wages to inventors, whereas firms doing physical investment do not. This indicates the distinction between these two types of corporate investment. In the model physical investment is not considered. Allowing for physical investment does not alter the results of comparative statics as well as the direction of the influence of debt use on expected innovation value, but makes the model become more complicated. Since issues related to physical investment are beyond the scope of our research, we put the focus on R&D investment when specifying productivity dynamics.

$\sigma_A(\cdot)$ is innovation risk that captures the implication of uncertainty on the outcomes of innovation driven by R&D. Without loss of generality, we specify $\mu_A(\cdot)$ and $\sigma_A(\cdot)$ as two linear functions of R&D investment; i.e., $\mu_A(RD) \equiv \Lambda_\mu RD$ and $\sigma_A(RD) \equiv \Lambda_\sigma RD$.[5] The ratio of the marginal technology progress rate to marginal technology innovation risk can be employed as a natural measure of R&D efficiency—— $\Lambda_\mu / \Lambda_\sigma$.[6] $W(\cdot)$ is a Brownian motion. *RD* denotes the amount invested in R&D.

Our specifications of the technology progress rate and innovation uncertainty are inspired by Lin (2012) and Caggese (2012), respectively. Without allowing for uncertainty over the outcomes of innovation, Lin assumes that R&D investment can be fully converted into intangible capital, and therefore, R&D creates endogenous technology progress. Caggese specifies the effect of innovation success (failure) on technology as technological advantages (disadvantages). In his model, innovation uncertainty has no explicit relation with R&D investment. Our specifications seem more generalized than those two works. Following Li (2011) and Gu (2016), we assume the amount of R&D investment is fixed. Although this amount is fixed, it is endogenously determined in the model. Pennetier et al. (2019) offer evidence that firms with a persistent R&D spending allocation policy (allocations remain constant) achieve better R&D performance than firms with a dynamic R&D spending allocation policy. Firms pursuing the optimization of R&D performance would prefer the strategy that maintains a fixed R&D spending level to the strategy that adjusts R&D spending frequently. Such empirical implications rationalize our assumption of fixed R&D investment.

C. Product demand

As in Pichler et al. (2008), the firm's aggregate product demand is expressed as

---

5 We can easily extend the model by using the generalized nonlinear specifications of innovation risk and technology progress; e.g., $\mu_A(RD) \equiv RD^{\Lambda_\mu}$ and $\sigma_A(RD) \equiv RD^{\Lambda_\sigma}$. Using such nonlinear specifications does not alter our main results but makes model solutions more complicated.

6 In our model, the partial derivative of the expected sales growth rate with respect to R&D investment, equivalent to R&D ability defined by Cohen et al. (2013), strictly increases (decreases) with Λ_μ (Λ_σ).

$$\hat{Q}_D(p(t), Q_d(t)) \equiv q(p(t))Q_d(t) \equiv p(t)^{-\varepsilon} Q_d(t)$$

where $p(t)$ is the product price at time t, $q(\cdot)$ is the size of the customer base, ε is the customer-to-price elasticity, and $Q_d(t)$ is the average demand per customer. This demand evolves according to $dQ_d(t)/Q_d(t) = \mu_q dt + \sigma_q dB(t)$ where μ_q is the growth rate and σ_q denotes volatility. Product demand is unaffected by the outcomes of technology innovation (since these outcomes do not alter product features), so that the two Brownian motions, $B(\cdot)$ and $W(\cdot)$, are mutually independent.

D. Operating earnings and assets' aggregate value

Instantaneous before-tax operating earnings at time *t* are expressed as:

$$\hat{\pi}(p(t), Q_d(t), A(t)) = \underbrace{p(t)\hat{Q}_D(p(t), Q_d(t))}_{\text{total sales revenue}} - \underbrace{\delta k^*(p(t), Q_d(t), A(t))}_{\text{total production costs}} \qquad (2)$$

where $k^*(t) = [p(t)^{-\varepsilon} Q_d(t)/A(t)]^{1/\gamma} \equiv k^*(p(t), Q_d(t), A(t))$ is the equilibrium demand for inputs and can be solved from $\hat{Q}_D(p(t), Q_d(t)) = \hat{Q}_S(A(t), k^*(t)) \equiv A(t)F(k(t))$ (i.e., the market-cleaning condition). Therefore, the aggregate value of the firm's assets takes a standard form as the total present value of future earnings flows:

$$V(p(t), Q_d(t), A(t); RD) = \mathbb{E}_t \int_t^{\infty} \hat{\pi}(p(s), Q_d(s), A(s)) \mathrm{e}^{-r(s-t)} ds \equiv V(t; RD).$$

Note that as in Leland (1994), payout decisions are not considered in our model. Any net cash outflow associated with R&D spending, debt service, and wage payments should be financed by selling additional equity.[7,8]

E. Separation between tangible asset value and intangible asset value

Tangible assets and intangible assets are essentially different. The former refers to property, plant, or equipment, while the latter refers to goodwill or the advantages of

[7] Financing R&D spending with retained earnings is common in the literature. The adoption of such a financing mechanism would make research involve the issues of optimal dividend policy and financial constraints. Since these two issues are beyond the scope of our paper, we assume there are no retained earnings and financial frictions in stock markets. Funds for R&D are financed from new stock issuance.

[8] Several of empirical papers have documented that equity is preferable to debt in financing innovative projects. For example, Stigliz (1985) finds that the uncertainty and volatile return of innovative projects will make them unattractive to creditors. Hall and Lerner (2010) argue that intangible assets created by innovation are difficult to quantify as collateral for debt financing. Equity capital is a favorable way to finance innovation since it allows equity holders to share upside returns and does not require collateral.

technology progress attached to employees' human capital. Generally, the latter will be lost in the event of bankruptcy, because employers' financial distress causes employee departures. In view of these facts, we treat tangible asset value as the firm's liquidation value. To separate tangible asset value from total asset value, we consider an industrial technology benchmark $\boldsymbol{A} \equiv A(0)$. This benchmark level helps us measure how large the advantages of the firm's technology progress in asset valuation are.

Similar to the fashion of aggregate value, tangible asset value has the expression:

$$V_T(p_T(t), Q_d(t), \boldsymbol{A}) = \mathbb{E}_t \int_t^\infty \hat{\pi}(p_T(s), Q_d(s), \boldsymbol{A}) \mathrm{e}^{-r(s-t)} ds \equiv V_T(t)$$

where $p_T(\cdot)$ is the corresponding product price. Note that p_T must be distinguished from the real price p and is used for deriving tangible asset value only (product pricing strategy is drawn in Section 3). Also, we note that since the valuation of tangible assets should not include the effect of innovation, technology is fixed at its industrial benchmark level. Intangible asset value simply equals asset aggregate value minus the value of tangible assets; i.e., $V_I(p(t), Q_d(t), A(t); RD) \equiv V_I(t; RD) = V(t; RD) - V_T(t)$.

F. Employment contract

Managers hire a group of inventive labors by committing to a long-term contract that pays fixed wages I continuously. The wage level is determined according to a fixed pay-performance ratio $\beta \in [0,1]$ (for its detailed definition, see footnote 1 on page 2).[9] The contract requires labors to abandon all outside job options. The contract does not provide severance pay and will be unilaterally abrogated if the firm goes bankrupt.[10]

---

[9] The pay-performance ratio manifests labors' power of bargaining over wages, and therefore, this ratio captures information about the hidden value of labors' outside job options. In reality the variations of this ratio could be attributed to several economic factors; e.g., idiosyncratic differences in union bargaining power and permanent fluctuations in labor supply and demand. These factors affect the determination of the pay-performance ratio through labor market competition. Issues on labor market competition, however, are beyond the scope of our research. In view of this fact, we adopt the setting of the predetermined pay-performance ratio and treat labor market competition as an exogenous condition.

[10] In the present model, managers' tolerance toward innovation failure is unlimited. This assumption can be released by taking limited tolerance for innovation failure into account. Our results remain unchanged in the case of limited innovation failure tolerance. Moreover, imposing the assumption of no severance pay is for tractability in deriving the closed-form solution to endogenous wages. Our main results do not rely on this assumption. We can easily extend the model by allowing for a positive severance pay.

G. Debt contract

Consider a standard non-callable perpetual debt contract. The debt continuously pays interest d that shields firm earnings from taxes at the rate τ. As in Black and Cox (1976), Ju et al. (2005), and the exogenous bankruptcy case of Leland (1994), the debt has a protective covenant specifying that if after-tax asset liquidation value falls below par, the firm is forced into bankruptcy. Debt holders recover a portion α of remaining liquidation value after the bankruptcy process.

III. Solving the Model and Characterizing Firm Policies

Section 3 solves the model in four steps. The first step derives the optimal product price and further incorporates optimal pricing strategies into the specification of firms' earnings. Given this specification, the second step offers the pricing formula for R&D on technology innovation. The third step solves endogenous wages for inventive labors hired by innovating firms. The first three stages take debt usage as given. The final step characterizes firms' debt policy with taking R&D investment optimization into account. Technical proofs for model solutions are given in online Appendix B. For convenience in understanding the structure of the model, Figure 1 is plotted.

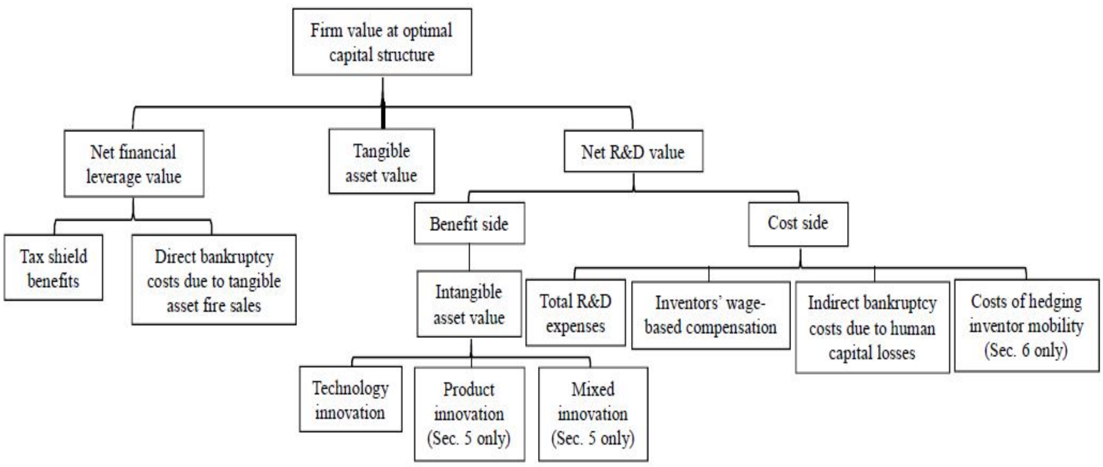

Figure 1: The structure of the firm value model.

A. Product pricing strategy

We derive the optimal product price from the objective of earnings maximization. Differentiating the earnings function (2) with respect to $p(t)$, setting this expression being zero with $p(t) = p^*(t)$, and solving for $p^*(t)$ yields the following proposition.

Proposition 1. (Optimal Product Pricing) *Given earnings as expression* (2)*, the firm sells products at* $p^*(t) \in \arg\max \hat{\pi}(p(t), Q_d(t), A(t)) = Q_d(t)^{(1-\gamma)/\eta} A(t)^{-1/\eta} (\frac{\delta\varepsilon}{\varepsilon-\eta})^{\gamma/\eta}$ *where* $\eta \equiv \varepsilon + \gamma - \varepsilon\gamma$. *The optimal product price decreases with productivity technology* ($\partial p^*(t)/\partial A(t) < 0$) *but increases with product demand* ($\partial p^*(t)/\partial Q_d(t) > 0$).

In the model product pricing plays twofold roles. First, it is a key channel through which firms convert intangible innovation benefits into tangible operational earnings (because $p^*(t)$ is a function of productivity technology). Second, it helps us clarify how changes in product price competition affect the firm's optimal leverage decision through innovation incentive. Plugging $p^*(t)$ into expression (2) has the explicit form of operating earnings under optimal product pricing:

$$\hat{\pi}(p^*(t), Q_d(t), A(t)) = Q_d(t)^{1/\eta} A(t)^{(\varepsilon-1)/\eta} \left(\frac{\delta\varepsilon}{\varepsilon-\eta}\right)^{1-\varepsilon/\eta} \frac{\eta}{\varepsilon} \equiv \hat{\pi}^*(Q_d(t), A(t)),$$

which implies the corresponding expression of asset aggregate value

$$V(p^*(t), Q_d(t), A(t); RD) = \mathbb{E}_t \int_t^\infty \hat{\pi}^*(Q_d(s), A(s)) \mathrm{e}^{-r(s-t)} ds \equiv V^*(Q_d(t), A(t); RD).$$

Note that technology improvement and product demand growth both positively affect operating earnings. The extent of their positive influences depends on price elasticity. The influence of technology progress (product demand growth) on earnings increases (decreases) with price elasticity, because $\partial((\varepsilon-1)\eta^{-1})/\partial\varepsilon > 0$ ($\partial\eta^{-1}/\partial\varepsilon < 0$). The form of operating earnings under optimal product pricing in the absence of innovation $\hat{\pi}(p_T^*(t), Q_d(t), \boldsymbol{A})$ can be derived in a similar manner. For notational consistency, we let $V_T^*(Q_d(t), \boldsymbol{A})$ denote tangible asset value under optimal product pricing.

B. Innovation (or R&D) valuation

Consider next the valuation of innovation (or R&D).[11] Undoubtedly, the problem of R&D investment decisions is at the heart of innovation valuation. To solve optimal R&D investment, we formulate its decision program under optimal product pricing as:

$$\max_{RD\geq 0} V^{RDTV}(A(0), Q_d(0); D, RD) \tag{3}$$

where $V^{RDTV}(\cdot) \equiv \mathbb{E}_{0_+} \int_{0_+}^{T_d} (\hat{\pi}^*(Q_d(t), A(t)) - \hat{\pi}^*(Q_d(t), \boldsymbol{A}) - RD) \mathrm{e}^{-rt} \, dt$ is the expected value of R&D contributed by inventors in place and $T_d := \inf(t > 0 : (1-\tau)V_T^*(t) \leq D)$ denotes the random default time. Note that the measurement of R&D value consists of the output-side effect and the input-side effect on cash flows. We assess the output-side effect by computing the marginal effect of the implementation of new technology (i.e., R&D outputs) on earnings. This effect is positive $\hat{\pi}^*(Q_d(t), A(t)) - \hat{\pi}^*(Q_d(t), \boldsymbol{A}) > 0$ when the implementation of new technology delivers a good outcome that stimulates productivity or enhances technological advantages. This effect will become negative $\hat{\pi}^*(Q_d(t), A(t)) - \hat{\pi}^*(Q_d(t), \boldsymbol{A}) < 0$ if the outcome of innovation is bad and such a bad outcome destroys technology advantages ($A(t) < \boldsymbol{A}$). The input-side effect is quantified using R&D investment RD (i.e., R&D inputs).

To better understand the economic implication behind R&D value, we decompose its expression into three parts: (a) intangible asset value $V_I^*(A(0), Q_d(0); RD)$; (b) indirect bankruptcy costs due to inventor departures $V^{RDIBC}(A(0), Q_d(0); D, RD)$; and (c) total expected R&D expenses $V^{RDC}(Q_d(0); D, RD)$. Their expressions are given by

$$\begin{aligned} V^{RDTV} &= V_I^* - V^{RDIBC} - V^{RDC} \\ &\equiv \mathbb{E}_{0_+} \int_{0_+}^{\infty} (\hat{\pi}^*(Q_d(t), A(t)) - \hat{\pi}^*(Q_d(t), \boldsymbol{A})) \mathrm{e}^{-rt} \, dt \\ &\quad - \mathbb{E}_{0_+} \mathrm{e}^{-rT_d} \mathbb{E}_{T_d} \int_{T_d}^{\infty} (\hat{\pi}^*(Q_d(t), A(t)) - \hat{\pi}^*(Q_d(t), \boldsymbol{A})) \mathrm{e}^{-r(t-T_d)} dt - \mathbb{E}_{0_+} \int_{0_+}^{T_d} RD \mathrm{e}^{-rt} dt \end{aligned}.$$

The first two terms form R&D benefits, equaling intangible asset value minus indirect

[11] We use the terms “innovation valuation (value)” and “R&D valuation (value)” interchangeably, since R&D and innovation are not separable in the model.

bankruptcy costs. The last term refers to R&D costs.

Intangible asset value has its own explicit solution:

$$V_I^*(A(0),Q_d(0);RD)=Q_d(0)^{1/\eta}\,[A(0)^{(\varepsilon-1)/\eta}K(RD)-A^{(\varepsilon-1)/\eta}L] \tag{4}$$

where $K(RD)\equiv\left(\frac{\delta\varepsilon}{\varepsilon-\eta}\right)^{1-\varepsilon/\eta}\frac{\eta}{\varepsilon}\left[r-\frac{(\varepsilon-1)RD\Lambda_\mu}{\eta}-\frac{0.5(\varepsilon-1)}{\eta}\times\frac{(\varepsilon-1-\eta)RD^2\Lambda_\sigma^2}{\eta}-\frac{\mu_q}{\eta}-\frac{0.5(1-\eta)\sigma_q^2}{\eta^2}\right]^{-1}$ and $L\equiv\left(\frac{\delta\varepsilon}{\varepsilon-\eta}\right)^{1-\varepsilon/\eta}\frac{\eta}{\varepsilon}\left[r-\frac{\mu_q}{\eta}-\frac{0.5(1-\eta)\sigma_q^2}{\eta^2}\right]^{-1}$. The term inside the square brackets in (4) represents the aggregate enhancement effect of technology advantages due to innovation success on operating earnings. Intangible assets' value can be thought of as expected available R&D benefits without allowing for the consequences of debt use.

In contrast, the role of indirect bankruptcy costs is to capture the influence of debt use on available R&D benefits. Specifically, these costs represent intangible-asset loss due to inventor departures accompanying financial distress. Debt use delivers financial distress risk that could cause firms to lose inventive human capital in place as well as R&D-related benefits (e.g., intangible asset formed by technology advantages) attached to human capital. Briefly speaking, the occurrence of financial distress forces inventors to leave and to take away remaining intangible assets. When assessing expected R&D benefits enjoyed by a firm with debt use, therefore, indirect bankruptcy costs should be deducted from intangible asset value.

Indirect bankruptcy costs are measured as the present value of losses in intangible assets at the bankruptcy point:

$$V^{RDIBC}(A(0),Q_d(0);D,RD)=\mathbb{E}_{0_+}\mathrm{e}^{-rT_d}\,V_I^*(A(T_d),Q_d(T_d);RD).$$

These costs resemble a financial security that pays no interest, but has the value equal to intangible asset value at default. Their formula is given by

$$V^{RDIBC}(A(0),Q_d(0);D,RD)=J(A(0),Q_d(T_d;D))\int_{0_+}^{\infty}H(t)\,f_{0_+}^{T_d}(t;D)\,dt$$

$$-D(1-\tau)^{-1}\left(\frac{Q_d(0)}{Q_d(T_d;D)}\right)^{-x-y} \tag{5}$$

where

$$J(A(0), Q_d(T_d; D)) = Q_d(T_d; D)^{1/\eta} A(0)^{(\varepsilon-1)/\eta} K(RD),$$

$$Q_d(T_d; D) = \frac{(D(1-\tau)^{-1})^{\eta}(r-\mu_q\eta^{-1}-0.5\sigma_q^2(\eta^{-1}-1)\eta^{-1})^{\eta}}{A^{\varepsilon-1}(\frac{\delta\varepsilon}{\varepsilon-\eta})^{\eta-\varepsilon}(\frac{\eta}{\varepsilon})^{\eta}}, \quad H(t) \equiv \mathrm{e}^{\{[\Lambda_\mu RD - 0.5(\Lambda_\sigma RD)^2(1-(\varepsilon-1)\eta^{-1})][(\varepsilon-1)\eta^{-1}-r\}t},$$

$$f_{0_+}^{T_d}(t; D) \equiv \mathrm{n}\left(\frac{-z(D)+\sigma_q^2 xt}{\sigma_q\sqrt{t}}\right)\frac{-z(D)}{\sigma_q\sqrt{t^3}}, \quad x \equiv \frac{\mu_q - 0.5\sigma_q^2}{\sigma_q^2}, \quad y \equiv \frac{\sqrt{(x\sigma_q^2)^2 + 2r\sigma_q^2}}{\sigma_q^2}, \quad z(D) \equiv \ln\frac{Q_d(T_d; D)}{Q_d(0)},$$

and $\mathrm{n}(\cdot)$ is the standard normal density function.

We next discuss the implication of R&D costs. In the model, RD is equivalent to the firm's instantaneous R&D expenses. Total expected R&D expenses, therefore, can be calculated as the total present value of instantaneous R&D expenses in the future:

$$V^{RDC}(Q_d(0); D, RD) = RD\, r^{-1}\left[1 - \left(\frac{Q_d(0)}{Q_d(T_d; D)}\right)^{-x-y}\right]. \tag{6}$$

The term outside (inside) the square brackets represents the capitalized value of total R&D expenses (the firm's survival probability conditional on initial product demand). At the bankruptcy point, the value of total expected R&D expenses approaches zero; i.e., $V^{RDC}(Q_d(T_d; D); D, RD) \to 0$. This means that the occurrence of bankruptcy gives rise to inventor departures, and hence, forces managers to suspend R&D investment.

We finish Section 3B by summarizing the implication of optimal R&D investment as the following proposition.

Proposition 2. (Optimal R&D Investment) *Given an arbitrary debt level D and the objective function as program* (3)*, inventors choose R&D investment amounts at:*

$$RD^*(D) \in \arg\max V^{RDTV}(A(0), Q_d(0); D, RD),$$

which satisfies the following first-order condition (*FOC*)*:*

$$\partial V_I^*(A(0), Q_d(0); RD^*(D)) \,/\, \partial RD^*(D) - \partial V^{RDIBC}(A(0), Q_d(0); D, RD^*(D)) \,/\, \partial RD^*(D)$$
$$= \partial V^{RDC}(Q_d(0); D, RD^*(D)) \,/\, \partial RD^*(D).$$

The optimization of R&D investment equates marginal expected R&D benefits (*the first line in the FOC*) *with marginal expected R&D costs* (*the second line in the FOC*)*.*

C. Human capital costs

Next derive the level of wages at equilibrium I^*. Since inventors are risk-neutral, the net present value of their employment contract has the following expression:

$$V^{RDW}(Q_d(0);D) \equiv \mathbb{E}_{0_+}\int_{0_+}^{T_d} I\, \mathrm{e}^{-rt}\,dt - \mathbb{E}_{0_+}\mathrm{e}^{-rT_d}\int_{T_d}^{T_d+Du} I\,\mathrm{e}^{-r(t-T_d)}\,dt \tag{7}$$

Note that the first term on the right side of equation (7) refers to the total present value of wage flows. The second term refers to the present value of aggregate wage loss over the period of temporary unemployment triggered by the firm's bankruptcy. This loss, equivalent to inventors' wealth loss arising from job-switching frictions, plays a role as the unemployment cost associated with their employment contract.

From Section 2F, it is known that inventors and equity holders share R&D value in accordance with the outside-option condition characterized by the pay-performance ratio. Endogenous wages, hence, can be solved from $\beta V^{RDTV}(\cdot) = V^{RDW}(\cdot)$.

Proposition 3. (Endogenous Wages) *Given the formula for R&D value* (*expressions* (4)-(6))*, Proposition 2, inventors' employment contract as expression* (7)*, and the pay-performance ratio* β*, endogenous wages take an explicit form:*

$$I^* \equiv I^*(D;A(0),Q_d(0),\beta) = \beta V^{RDTV}(A(0),Q_d(0);D,RD^*(D))[V^{Multi}(Q_d(0);D)]^{-1}$$

where $V^{Multi}(Q_d(0);D) \equiv r^{-1}[1+(\mathrm{e}^{-rDu}-2)(\frac{Q_d(0)}{Q_d(T_d;D)})^{-x-y}]$ *denotes the value multiplier for pricing employment contract. This value multiplier satisfies* $V^{RDW}(\cdot) = I^* V^{Multi}(\cdot)$. *The influence of changes in debt use on endogenous wages consists of two parts:*

$$\frac{\partial I^*(\cdot)}{\partial D} = \underbrace{\frac{\partial I^*(\cdot)}{\partial V^{RDTV}(\cdot)}\times\frac{\partial V^{RDTV}(\cdot)}{\partial D}}_{\text{human capital loss effect}} + \underbrace{\frac{\partial I^*(\cdot)}{\partial V^{Multi}(\cdot)}\times\frac{\partial V^{Multi}(\cdot)}{\partial Q_d(T_d;D)}\times\frac{\partial Q_d(T_d;D)}{\partial D}}_{\text{risk compensation effect}}$$

where the human capital loss (*HCL*) *effect is negative* (*since* $\frac{\partial V^{RDTV}(\cdot)}{\partial D} < 0$) *and the risk compensation* (*RC*) *effect is positive* (*since* $\frac{\partial V^{Multi}(\cdot)}{\partial Q_d(T_d;D)} < 0$ *and* $\frac{\partial Q_d(T_d;D)}{\partial D} > 0$).

In the model changing debt use affects endogenous wages through two channels, including R&D value (available R&D benefit) and employment contract value. On the one hand, increasing debt use will make firms derive less R&D benefit from inventors $\frac{\partial V^{RDTV}(\cdot)}{\partial D} < 0$. This is because as debt use rises, the likelihood of human capital loss due to financial distress rises, and the expected duration of inventor employment shortens. Such a negative effect on R&D value motivates firms to decrease wages. On the other hand, since the occurrence of bankruptcy inevitably forces inventors to lose their jobs, raising debt use makes them bear a higher unemployment risk and makes the expected unemployment cost higher. The net value of employment contract displays a negative sensitivity to debt increases (if holding wages fixed), which means $\frac{\partial V^{Multi}(\cdot)}{\partial Q_d(T_d;D)} \times \frac{\partial Q_d(T_d;D)}{\partial D} < 0$. In view of this fact, firms tend to pay higher wages as risk compensation that maintains the balance between R&D value (*performance*) and employment contract value (*pay*). The debt-wage relation is determined by the tradeoff between the HCL effect and the RC effect. More detailed discussions about the implications of the HCL effect, the RC effect, and the debt-wage endogenous relation are available in Section 4C.

D. Capital structure

We have been aware that debt use may lower R&D value via raising the likelihood of human capital loss due to financial distress. When making debt choice, firms should consider the tradeoff between R&D value and traditional leverage value. The objective is to choose a target debt level that maximizes the firm's total value equaling the sum of after-tax tangibility value, traditional leverage value, and after-tax net R&D value:

$$\max_{D\geq 0}((1-\tau)V_T^*(0)+V^{FLV}(Q_d(0);\boldsymbol{A},D)+(1-\tau)V^{RDV}(A(0),Q_d(0);D,RD^*(D))) \quad (8)$$

where $V^{RDV} \equiv V^{RDTV} - \mathbb{E}_0\int_0^{T_d} I^* e^{-rs}\,ds = V^{RDTV} - I^* r^{-1}[1-(Q_d(0)/Q_d(T_d;D))^{-x-y}]$ and V^{FLV} denote net R&D value (expected R&D value less the wage-based compensation to inventors) and leverage value, respectively. Following Leland (1994), we measure leverage value as debt's tax benefits less direct bankruptcy costs due to asset fire sales:

$$V^{FLV}(Q_d(0);\boldsymbol{A},D)=\underbrace{\tau\, d\, r^{-1}-\tau\, d\, r^{-1}\left(\tfrac{Q_d(0)}{Q_d(T_d;D)}\right)^{-x-y}}_{tax-shield\ benefits}-\underbrace{\alpha\, D\left(\tfrac{Q_d(0)}{Q_d(T_d;D)}\right)^{-x-y}}_{direct\ bankruptcy\ costs}.$$

The optimal rule of capital structure decision making is presented below.

Proposition 4. (Optimal Debt Use) *The tradeoff between R&D value and traditional leverage value reaches equilibrium if and only if their marginal rates of substitution are equal. This tradeoff equilibrium determines optimal debt use* D^*, *which satisfies*

$$\partial V^{FLV}(Q_d(0);\boldsymbol{A},D^*)\,/\,\partial D^*=-\partial\left((1-\tau)V^{RDV}(A(0),Q_d(0);D^*,RD^*(D^*))\right)/\,\partial D^*. \quad (9)$$

The right side of equation (9) represents marginal R&D-value loss due to debt use, while the left side denotes marginal traditional leverage value. Equation (9) holds only if the simultaneous optimization of R&D investment and capital structure is achieved. Because the closed-form solution to decision program (8) is unavailable, we solve D^* by invoking numerical technique.

IV. Model Implications

This section conducts numerical analysis to study the quantitative implications of technology innovation for leverage choice. We use the exogenous bankruptcy case in Leland (1994) as our benchmark model (setting $\Lambda_\sigma=\Lambda_\mu=0$) for comparison.

A. Parameter calibration

We calibrate baseline parameters at the values that roughly reflect a typical U.S. corporation (the baseline parameter values are summarized in Table 1). We choose the initial average product demand for customer $Q_d(0)$ at 100, the input unit cost δ at \$1, and industrial technology benchmark $\boldsymbol{A}$ at 1. Although these parameter choices

Table 1: Parameter Definition and Baseline Values.

Parameter Value	Parameter Definition
$Q_d(0)=100$	Initial product demand per customer
$\mu_q=1.6\%$	Product demand growth rate
$\sigma_q=26.4\%$	Product demand volatility rate
$\boldsymbol{A}=1$	Industrial technology (productivity) benchmark
$A(0)=1$	Initial technology (productivity) level
$\Lambda_\mu=5\%$	Marginal technology progress rate
$\Lambda_\sigma=16.5\%$	Marginal technology innovation risk
$\varepsilon=1.25$	Price elasticity of the customer base
$\gamma=0.6$	Return-to-scale parameter
$\delta=\$1$	Input unit price
$r=6\%$	Riskless interest rate
$Du=23$ weeks	Duration of temporary unemployment
$\tau=32\%$	Corporate tax rate
$\alpha=25\%$	Bankruptcy cost rate
$\beta=5\%$	Pay-performance ratio

can be motivated in more details, we omit this for brevity. Our main results only vary quantitatively but not qualitatively with them. Following Chu (2012), we set the return -to-scale parameter γ at 0.6. We choose the price elasticity of the customer base ε at 1.25, which is in the range of empirical estimates from Hoch et al. (1995) and Foster et al. (2008). The duration of temporary unemployment Du is set at 23 weeks. The 2019 annual report of the U.S. Bureau of Labor Statistics shows that the average duration of unemployment is 22.1 weeks. Similarly, the survey commissioned by Randstad in 2018 finds that U.S. job applicants take an average of five months to get a new job.

Next calibrate the parameters governing corporate innovation and product demand. We choose the marginal technology progress rate Λ_μ at 5%, marginal innovation risk Λ_σ at 16.5%, the product demand growth rate μ_q at 1.6%, and product demand risk σ_q at 26.4%, respectively. Given these parameter choices, our model at optimization generates several financial variables that roughly match the following numbers. First, the cash flow growth rate is equal to 2.5%, in line with the target value used by Miao (2005). Second, cash flow volatility is moderately targeted at 25.5%. Strebulaev (2007) finds the estimated volatility of firm-level cash flows to be 25.5%. Third, the ratio of optimal R&D expenditures to total sales (R&D intensity) is 4.64%. This value roughly matches empirical estimates for the mean R&D intensity of U.S. firms (see, e.g., Cazier, 2011; and Kusnadi and Wei, 2017). Fourth, the annualized elasticity of productivity to innovation (proxied by cumulative R&D investment) equals 0.114, which is within the range estimated by Kogan et al. (2017).[12, 13]

We set the fixed pay-performance ratio β at 5%. In the model this parameter can be regarded as the fixed pay-performance sensitivity (PPS). Our choice is close to the calibration results of PPS in He (2011), about 5.33%. Following Leland (1994), we set the riskless interest rate r at 6%. The corporate tax rate τ is set at 32%. This number follows from the facts that the estimated marginal tax rate is roughly in a range from 31.4% to 32% (see Carlson and Lazrak, 2010; and Graham and Leary, 2011). We set the bankruptcy cost parameter α at 25%. While this number is higher than the results in Andrade and Kaplan (1998) that report the distress costs of 10%-20% (as a fraction of firm value), it is in the range of recent empirical estimates. Korteweg (2010) finds the estimated distress cost to be 15%-30% of asset value. Davydenko et al. (2012) estimate that the distress cost in large firms is sizeable, at least 20%-30% of asset market value.

B. Influence of firm innovation on optimal leverage

Consider first the influence of firm innovation on optimal leverage. For facility in our discussion, we define financial leverage as the ratio of debt value to firm value:

---

[12] The annualized elasticity of expected productivity to innovation is computed as:

$$[\partial \mathbb{E}_0 A(T) / \partial V^{RDC\_Tyear}] V^{RDC\_Tyear} [\mathbb{E}_0 A(T)]^{-1} T^{-1}, \quad V^{RDC\_Tyear} \equiv \mathbb{E}_{0_+} \int_{0_+}^{T \wedge T_d} RD^*(D^*) e^{-rt} dt \cdot$$

This elasticity is independent of the choice for T, since R&D investment, the drift rate, and the volatility of productivity are all time-independent.

[13] Kogan et al. (2017) estimate that, on average, a one-standard deviation increase (around 12.45%) in innovation is associated with a 0.6% to 3.5% increase in total factor productivity (TFP), depending on the specification. Such results imply a range of the TFP-innovation elasticities from 0.0468 to 0.2734.

Table 2: Simultaneous Optimization of Debt and R&D Policies.

The table gives various model outputs at the simultaneous optimization of R&D investment and capital structure. In the upper panel the columns (from left to right) report market leverage, debt choice, equity value, coupon level, tax benefits scaled by firm value, direct bankruptcy costs scaled by firm value, and net leverage value scaled by firm value. In the lower panel the columns (from left to right) present the ratio of R&D expenditure to sales, the annualized elasticity of expected productivity to cumulative R&D investment, total expected after-tax R&D expenses scaled by firm value, after-tax indirect bankruptcy costs scaled by firm value, wages, and net after-tax R&D value scaled by firm value.

Model type	Capital structure outputs						
	Market leverage	Debt choice	Equity value	Coupon level	TB scaled by FV	DBC scaled by FV	Net FL value scaled by FV
Benchmark	33.84%	\$219.2	\$428.71	\$14.56	8.391%	2.538%	5.852%
Basic	14.01%	\$116.2	\$712.95	\$7.258	4.005%	0.498%	3.507%
$\Lambda_\mu = 7\%$	3.06%	\$39.2	\$1242.71	\$2.374	0.949%	0.030%	0.919%
$\Lambda_\sigma = 12\%$	3.77%	\$45.9	\$1172.31	\$2.789	1.163%	0.045%	1.118%
$\varepsilon = 1.5$	1.65%	\$13.9	\$828.21	\$0.836	0.521%	0.007%	0.513%

Model type	R&D/innovation outputs					
	R&D intensity	Prod.-R&D elasticity	R&D cost scaled by FV	IBC scaled by FV	Wages	Net R&D value scaled by FV
Basic	4.641%	0.114	2.682%	1.661%	\$1.033	22.916%
$\Lambda_\mu = 7\%$	6.677%	0.230	2.794%	0.586%	\$3.195	51.493%
$\Lambda_\sigma = 12\%$	8.964%	0.221	3.913%	0.738%	\$2.904	48.807%
$\varepsilon = 1.5$	10.029%	0.156	4.117%	0.351%	\$2.411	60.555%

$D^*/((1-\tau)V_T^*(0)+V^{FLV}(Q_d(0);A,D^*)+(1-\tau)V^{RDV}(A(0),Q_d(0);D^*,RD^*(D^*)))$. Major model outputs are compiled as Table 2.

Observe from this table that the firm's desire for R&D benefit heavily reduces its willingness to use debt. In the absence of firm innovation, the model delivers a 33.84% leverage ratio accompanied with 5.852% net tax benefits as a fraction of firm value (FL value in Table 2). Leverage and net tax benefits respectively fall to 14.01% and 3.507% after taking innovation into account. The numbers obtained from our model are close to corresponding empirical counterparts, while those from the benchmark model seem counterfactually high. Bena and Garlappi (2019) find that the median market leverage ratios of innovating firms and non-innovating firms in the U.S. equal 16% and 20%, respectively. As for tax benefits on debt, Graham (2000) estimates that the capitalized value of net interest deduction is about 4.3% of firm value. Van Binsbergen et al. (2010) find net tax benefits to be 3.5% of asset value. These suggest that the inclusion of firm innovation can improve the tradeoff model's performance in predicting firms' leverage usage and the value of debt's tax benefits enjoyed by firms.

In contrast with the benchmark model, leverage ratios from our model are much lower. There are two reasons. The first is that debt use delivers a negative influence on available R&D benefit. Financial distress risk due to debt use could make firms lose inventive human capital in place as well as R&D benefit attached to human capital. As debt use increases, the expected duration of inventor employment shortens and indirect bankruptcy costs due to inventor departures become higher. These consequences of deb use make firms earn less R&D benefit from inventors in place, and hence, marginally lower firms' incentive to use debt. The other reason is that financing R&D investment with debt is unachievable, because intangible technology capital generated by R&D is always attached to inventors and never taken as collateral. Such financing constraints cause the opportunities of R&D investment to deliver an asymmetric effect on equity and debt. The inclusion of R&D opportunities marginally increases the expected value of equity but lowers the optimal debt issuance amount. This asymmetric effect further enhances the negative influence of R&D on market leverage.

The above implications provide an alternative explanation for the so-called low-leverage puzzle. Miller (1977) firstly proposes this puzzle, which refers to the stylized facts that on average firms have low leverage ratios relative to what we would predict from tradeoff theories. Our key reasoning is that firms' desire for R&D (or innovation) benefits marginally lowers their willingness to use debt, and hence, ignoring the effect of innovation causes traditional tradeoff models to overstate optimal leverage usage. In fact, many other attempts have been made to resolve the low-leverage puzzle by using various economic forces; e.g., agency costs (Leland, 1998), asset liquidity (Morellec, 2001), dynamic restructurings (Goldstein et al., 2001), business cycle risk (Chen, 2010), etc. Those economic forces achieve great success in explaining this puzzle, but might have limited abilities to improve the tradeoff model's performance in fitting the cross-sectional distribution of corporate leverage. This is because after taking those economic forces into account, existing tradeoff models under reasonable parameterizations still fail to capture the capital structure features of firms with zero or almost-zero leverage.

Strebulaev and Yang (2013) document the relevance of almost-zero-leverage and zero-leverage firms in shaping the low-leverage puzzle. They find that in the past five decades, around 10% of U.S. firms are zero-levered and 23% of U.S. firms are almost zero-levered (with book leverage lower than 5%). Excluding these firms increases the sample mean of book (market) leverage ratios from 25% to 32% (28% to 37%). Such a result partially replaces the low-leverage puzzle with the zero-leverage anomaly. To better resolve the low-leverage puzzle and better improve the tradeoff model's ability to explain leverage variations in the cross section, researchers must explain why some firms use little or have zero debt instead of why firms on average have lower debt than expected. Motivated by these facts, we next examine whether and how the inclusion of innovation reconciles tradeoff models with the zero-leverage anomaly.

A noteworthy stylized fact documented by Strebulaev and Yang (2013) is that the prevalence of zero leverage has a positive association with corporate R&D. Besides, in their sample, the average of R&D intensities chosen by zero-leverage and almost-zero-leverage firms exceeds 20%, far higher than our parameter calibration target. To make parameter calibration closer to almost-zero-leverage firms' characteristics, we reset the values of the parameters involving R&D efficiency and price competition before proceeding. We reset the price elasticity of the customer base at 1.5, the marginal technology progress rate at 7%, and marginal technology innovation risk at 12%. Model-generated R&D intensity is especially sensitive to changes in these three parameters.

We find that our model under the aforementioned parameter choices well captures the zero-leverage anomaly. As Table 2 presents, the model can generate extremely low leverage, from 1.65% to 3.77%. The corresponding expected R&D value is large (over 50% of firm value) and R&D intensity is high (from about 6.6% to 10%). Such results mean that when operating earnings react to innovation success strongly[14] or the quality of available inventive human capital is high, doing R&D delivers a large value-creation effect on equity. A large R&D value-creation effect naturally accompanies a substantial marginal R&D-value loss due to debt use, which implies an extremely high marginal cost of debt use. Because of such concerns, firms with innovation-sensitive earnings or high R&D efficiency tend to use debt as little as possible (choose almost-zero leverage) and invest heavily in R&D (R&D intensity is much higher). These model implications are supported by related empirical findings. For example, Strebulaev and Yang (2013) and Bessler et al. (2013) document that R&D-intensive firms are more likely to adopt a zero-leverage policy. Cohen et al. (2013) and Islam and Zein (2020) find that firms and CEOs with better R&D ability will invest more in R&D.

In the present model, firms always adopt an almost-zero or zero leverage policy when R&D intensity is very high. This, however, does not mean that our results rely on parameter choice manipulation that generates a counterfactually high R&D intensity. The model-produced R&D intensity at almost-zero optimal leverage moderately ranges between 6.6% and 10%. By using a large U.S. firm sample, Graham and Leary (2011) present that firms in the lowest quintile of book leverage on average choose the book leverage ratio at 1% and R&D intensity at 36%. Strebulaev and Yang (2013) report a 21.4% mean R&D intensity in their sample of U.S. almost-zero-leverage firms. In our sample of firms with market leverage less than 5%, median R&D intensity is 14.9%.[15]

---

[14] The sensitivity of operating earnings under optimal product pricing $\hat{\pi}(\cdot)$ with respect to technology progress can be derived as $(\varepsilon-1)\eta^{-1}=(1-\gamma+(\varepsilon-1)^{-1})^{-1}$, which increases with price elasticity ε.

[15] In order to empirically estimate the R&D intensity of almost-zero-leverage and zero-leverage firms,

Table 3: Model Predictions about Almost-Zero Leverage Phenomena.

This table presents the robustness of numerical predictions with respect to almost-zero leverage along various parameter combinations. The numbers show optimal market leverage ratios. Except for indicated parameters and marginal technology innovation risk, model parameters are set at their baseline levels. We calibrate marginal technology innovation risk to make model-generated R&D intensity at optimal leverage match the median R&D intensity in our sample of almost-zero and zero leverage firms (about 14.9%). Our sample includes U.S. non-financial unregulated R&D firms with market leverage less than 5%. The sample covers the period from 1950 to 2018.

The ranges of parameters	Parameter level				
	Quintile 1	Quintile 2	Quintile 3	Quintile 4	Quintile 5
τ (20% to 40%)	1.467e-04	2.101e-04	2.826e-04	3.637e-04	4.529e-04
α (20% to 40%)	3.131e-04	3.129e-04	3.128e-04	3.127e-04	3.126e-04
β (10% to 50%)	3.516e-04	4.101e-04	4.578e-04	5.180e-04	1.253e-03
γ (0.4 to 0.6)	6.408e-03	4.004e-03	2.181e-03	1.001e-03	3.129e-04
ε (1.2 to 1.3)	1.646e-03	7.195e-04	3.129e-04	1.347e-04	6.079e-05
μ_q (1% to 2%)	8.801e-04	6.247e-04	3.988e-04	2.009e-04	6.153e-05
σ_q (20% to 30%)	1.923e-03	9.376e-04	4.541e-04	2.427e-04	1.681e-04
Du (0 yr to 1 yr)	3.183e-04	3.152e-04	3.122e-04	3.093e-04	3.074e-04

Our choice for the price elasticity of the customer base $\varepsilon = 1.5$ also seems moderate. In Hoch et al. (1995) and Foster et al. (2008), the estimated commodity price elasticities typically lie in the range from 1.2 to 3.5. We further check the robustness of our results on almost-zero leverage along various parameter combinations and show the results of robustness tests in Table 3. We show that if the parameters involving R&D efficiency are calibrated to make model-generated R&D intensity match median R&D intensity in our almost-zero-leverage firm sample, the optimal market leverage ratios are generally lower than 1%. These outcomes justify the robustness of our results.

C. Complexity of the leverage-wage relation

Firms' involvement in R&D and innovation inevitably incurs costs for financing inventive human capital; i.e., inventors' wages. In the model, wages are determined by

we construct a U.S. firm sample covering the period from 1950 to 2018.

the balance between available R&D benefit and inventors' employment contract value. Both the values of R&D benefit and employment contract are influenced by the firm's leverage choice. Two interesting issues thus arise here. How do leverage use changes affect wage payments? How does the model shape the endogenous interaction between optimal leverage and wages? This subsection aims at studying these two issues.

Figure 2 plots the HCL effect $\frac{\partial I^*(\cdot)}{\partial V^{RDTV}(\cdot)} \times \frac{\partial V^{RDTV}(\cdot)}{\partial D}$ (the lines in Panels A and C) and the RC effect $\frac{\partial I^*(\cdot)}{\partial V^{Multi}(\cdot)} \times \frac{\partial V^{Multi}(\cdot)}{\partial Q_d(T_d;D)} \times \frac{\partial Q_d(T_d;D)}{\partial D}$ (the lines in Panels B and D) against leverage by using various parameter combinations. The patterns in Figure 2 validate our insight from Proposition 3 about the influence of leverage changes on endogenous wages. This influence consists of the positive RC effect and the negative HCL effect. The former emerges from the case where leverage changes affect wages via the value multiplier for pricing employment contract (*pay*). The latter emerges from the case where leverage changes affect wages via available R&D benefit (*performance*).

The mechanism through which firms determine the directions of the RC and the HCL effect on wage payment relies on the balance between pay and performance. This balance is characterized using an exogenous fixed pay-performance ratio that manifests the condition of inventors' outside job option. On the one hand, since the occurrence of bankruptcy forces inventors in place to lose jobs, raising leverage makes them bear a higher unemployment risk and makes the expected unemployment cost associated with employment contract greater. Increases in leverage decrease the value of employment contract through lowering the value multiplier $\frac{\partial V^{Multi}(\cdot)}{\partial Q_d(T_d;D)} \times \frac{\partial Q_d(T_d;D)}{\partial D} < 0$ (if holding wages fixed). In view of this negative unemployment risk effect on pay, firms taking higher leverage pay higher wages as risk compensation that ensures the balance between pay and performance. On the other hand, increasing leverage makes firms derive less R&D benefit from inventors $\frac{\partial V^{RDTV}(\cdot)}{\partial D} < 0$. This is because as leverage increases, the expected duration of inventor employment shortens, and the likelihood of human capital loss due

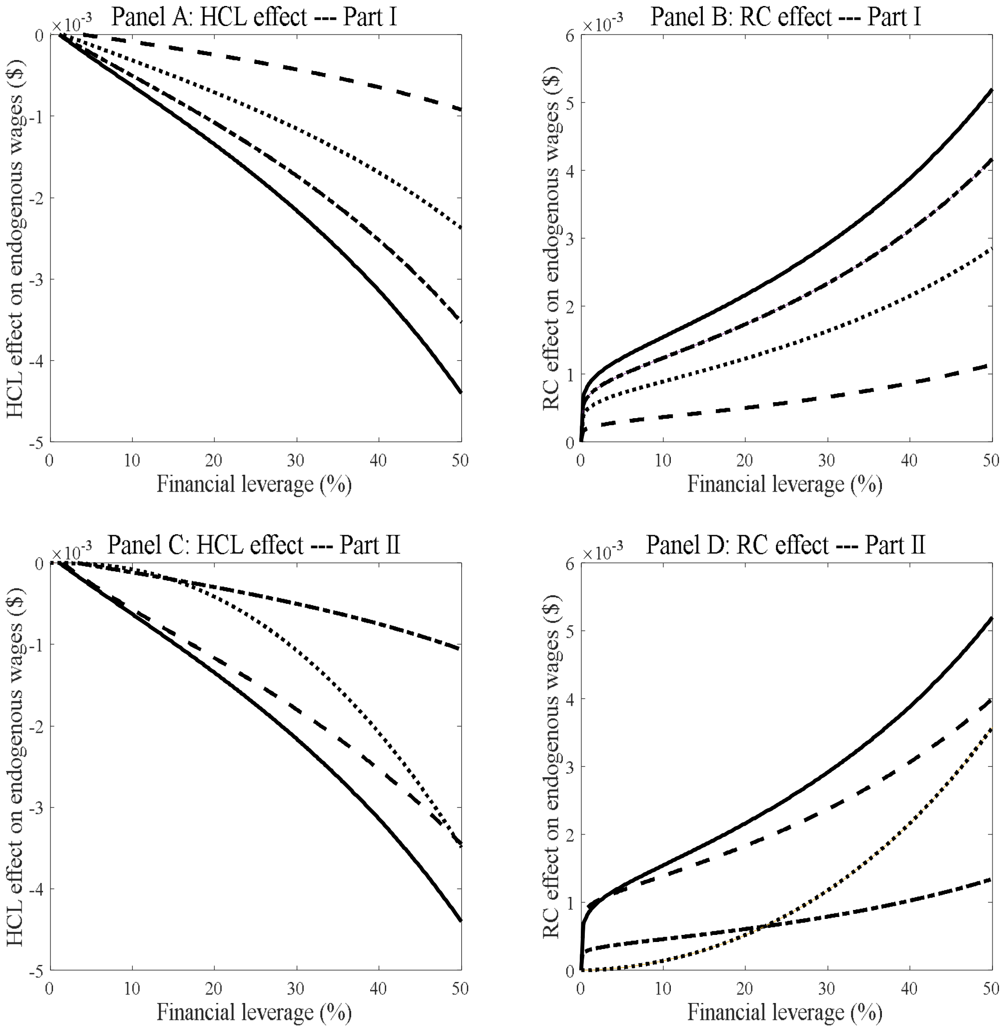

Figure 2: Risk compensation effect, human capital loss effect, and various model parameters. In Panels A and B the solid, dashed, dotted, and dash-dotted lines are based on baseline parameters, $\Lambda_\mu = 3\%$, $\Lambda_\sigma = 20\%$, and $\beta = 4\%$, respectively. In Panels C and D the solid, dashed, dotted, and dash-dotted lines are based on baseline parameters, $\mu_q = 0.8\%$, $\sigma_q = 15\%$, and $\varepsilon = 1.1$, respectively.

to financial distress rises. The influence of human capital loss on performance motivates firms to maintain the pay-performance balance by downwardly adjusting wages.

Another finding from Figure 2 is that the magnitude of the RC and HCL effects is sensitive to changes in the parameters involving R&D efficiency and product demand. When R&D efficiency is lower, product demand is less sensitive to the product price, product demand is more stable, or the growth of product demand is slower, the RC and HCL effects both are less pronounced and exhibit weaker reactions to leverage changes. Such results are attributed to the fact that the RC and HCL effects respectively have a

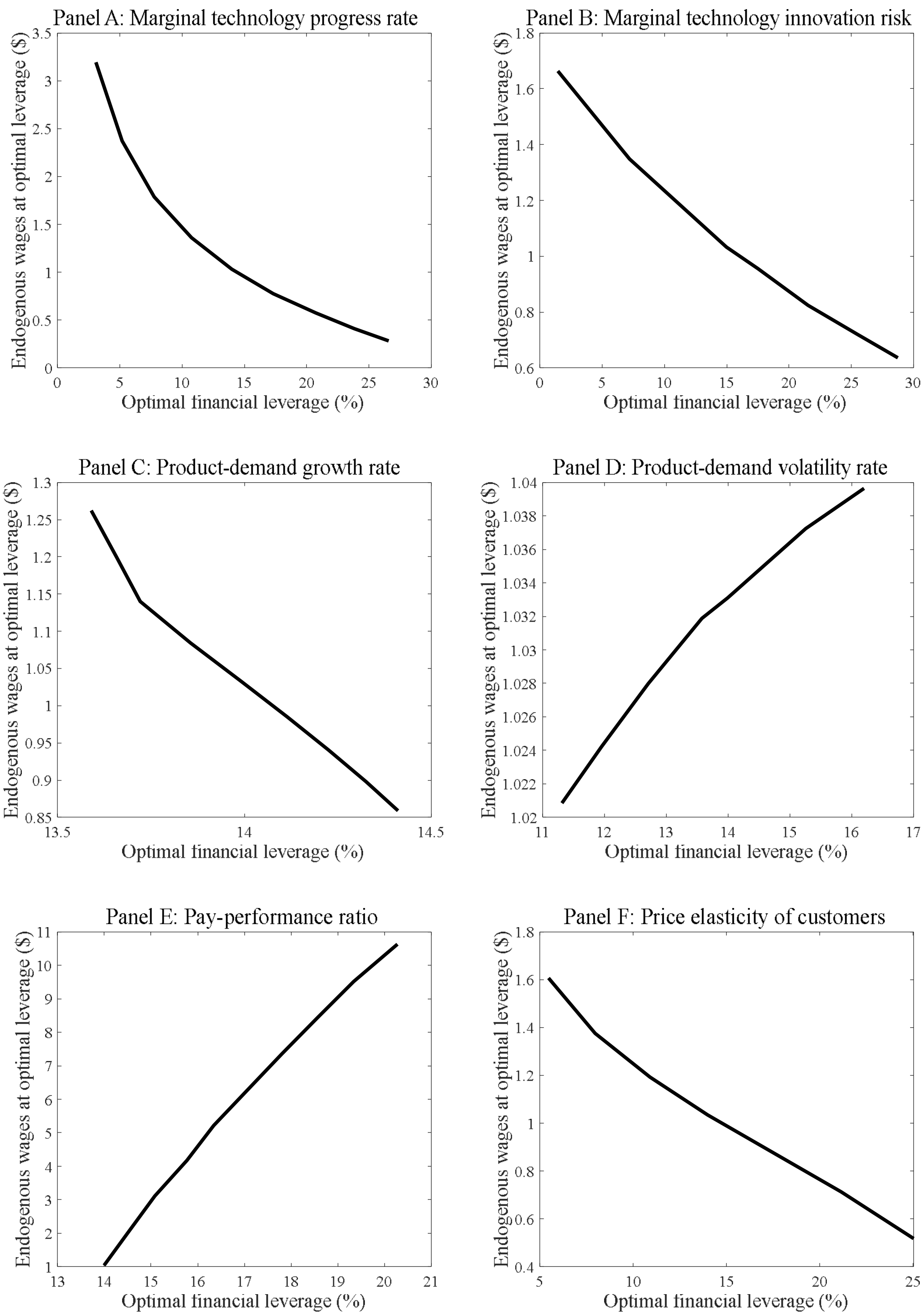

Figure 3: Endogenous relation between endogenous wages and optimal leverage. Lines respectively depict the relation along Λ_μ (from 3% to 7%), Λ_σ (from 14% to 20%), μ_q (from 1.2% to 2%), σ_q (from 24% to 30%), β (from 5% to 50%), and ε (from 1.1 to 1.4) in Panels A-F.

strict positive relation with available R&D value and marginal R&D-value loss due to debt use. These two R&D-value-related quantities increase with R&D efficiency, price competition, and product demand risk, but decrease with product demand growth.

Consider next the interaction between wages and *optimal* leverage. As shown in Figure 3, the shapes of the interaction are complex, depending on the tradeoff between the RC effect and the HCL effect.[16] This complexity means that optimal leverage and wages are jointly but asymmetrically influenced by changes in firm characteristics or exogenous factors. Take Panel A as an example for illustration. Lowering the marginal technology progress rate simultaneously enhances the HCL and RC effects by raising optimal leverage. Marginal increases in the HCL effect outweigh those in the RC effect. Endogenous wages and optimal leverage, hence, have a negative relation along changes in the marginal technology progress rate. In most of circumstances, their relations are negative. Panels D and E oppositely present a positive relation. The reason is that the reactions of the RC effect to adjustments in optimal leverage induced by changes in the pay-performance ratio and product demand risk are greater than those of the HCL effect.

Our complex results on the leverage-wage relation in fact can be thought of as an integration of the results of Berk et al. (2010) and Michaels et al. (2019). Under labor market competitive equilibrium, Berk et al. solve market wages that maximize labors' expected utility. Raising debt use makes the expected timing of bankruptcy earlier, and lowers labors' total expected utility by reducing the expected duration of employment. Firms taking greater leverage should pay labors more to compensate them for bearing unemployment risk that accompanies firm bankruptcy. Such an insight is in line with the implications over our RC effect. In their model, the total expected utility of market wages, which corresponds to the value of inventors' employment contract (*pay*) in our model, reflects the value of labors' outside job option. Because productivity is used as the underlying state variable of labors' indirect utility, dynamic adjustments in market wages only depend on the current state of productivity, unaffected by debt use. Such a model feature makes them unable to isolate the *performance-side* influence of changes

[16] After introducing inventor mobility into the model, we find the endogenous leverage-wage relation along mobility intensity to be an inverted U. For detailed discussions, see Section 6.

in debt use on wages (if we treat productivity as labors' performance). Their analysis, hence, cannot capture the implication of the HCL effect in our model.

In the framework of the surplus-sharing arrangement, Michaels et al. (2019) solve endogenous wages using dynamic bargaining equilibrium. A central conclusion of that article is that because the total expected contribution of labors to the firm's cash flows decreases with leverage, increasing leverage enables the firm to improve the position of bargaining with labors. Following the bargaining outcomes, firms adjust wages downwardly as leverage increases. The implications of such a conclusion are very similar to those of our HCL effect, since labors' cash-flow contribution in Michaels et al. (2019) corresponds to inventors' innovation-benefit contribution $V^{RDTV}(\cdot)$ in our model. The model of Michaels et al. (2019) does not capture the *pay-side* influence of debt changes on wages. This can be attributed to the two features of their model. First, labors always receive full promised wages from the firm, no matter whether it subsequently defaults. Second, labors are assumed to have ability to perfectly insure their idiosyncratic wage risk that stems from productivity shock by relying on other household members' wage earnings or accessing government risk-transfer programs. Hence, in their model, labors have no incentive to do bargaining over the compensation for bearing the idiosyncratic risk on wage earnings.

The predictions of Berk et al. (2010) and Michaels et al. (2019) about the leverage -wage relation both are partly supported by empirical studies. Akyol and Verwijmeren (2013) and Chemmanur et al. (2013) find evidence on the positive relation that justifies the risk compensation hypothesis of Berk et al. (2010). Agrawal and Matsa (2013) find that labors' compensation for unemployment shocks increases with firm leverage. The negative bargaining effect of leverage on wages has been documented in Matsa (2010) and Michaels et al. (2019). Also, Hanka (1998) finds an inverse relation between debt and wages in the cross section. In comparison to Berk et al. (2010) and Michaels et al.

(2019), our model is more generalized and can simultaneously capture these two sorts of empirical regularities.

Our success relies on three important model features. First, the value of inventors' employment contract (pay) and the firm's available innovation benefits contributed by inventors (performance) can be measured separately. The influence of changes in debt use on them, hence, can be separately measured as well. Second, following Michaels et al. (2019), we assume inventors' outside job option to be an exogenous condition, and characterize this condition as a fixed pay-performance ratio. This condition simplifies the setting of competitive labor market, so that endogenous wages in partial equilibrium can be easily solved. The conception of the pay-performance ratio is in fact similar to the surplus-sharing rule used by Michaels et al. (2019). Third, the formula for the value of inventors' employment contract permits the separation between wage payments and the value multiplier. Using the outside-option condition, hence, we can express endogenous wages as a simple linear combination of the firm's available innovation benefit and the value multiplier. This expression is convenient for us to achieve the distinction between the performance-side effect of leverage changes on wages (HCL effect) and the pay-side effect on wages (RC effect).

In summary, we show that the tradeoff between the RC and HCL effects plays an important mechanism through which our structural model identifies the cross-sectional relation between wages and firm leverage. Changes in firms' and labors' characteristics both simultaneously affect the outcomes of leverage choice and of the aforementioned tradeoff. Along characteristic changes, this simultaneity shapes the endogenous interaction between optimal leverage and wages. When marginal changes in the RC (HCL) effect due to leverage changes outweigh those in the HCL (RC) effect, this interaction is positive (negative). Such complex results help us settle the debate on the leverage-wage relation in the empirical literature.

D. Asymmetries in the tax effect on firm innovation and leverage

As argued by tradeoff theories, government guides firms' debt policy by adjusting the tax rate and changing the value of tax benefits on debt. Marginal tax benefits due to debt increases are concave in the tax rate; so that optimal leverage is more sensitive to tax cuts than to tax rises (see the dashed line in Panel B of Figure 4). However, such a theoretical prediction is refuted by Heider and Ljungqvist (2015), who document that the tax-cut effect on leverage is little and weaker than the tax-rise effect. Mukherjee et al. (2017) correspondingly find the asymmetric reactions of innovation outputs and of R&D investment to tax changes. Tax rises impede innovation, while tax cuts deliver a little effect that laggedly boosts innovation.[17] Since R&D intensity and leverage have a robust monotonic relationship, we infer that there exists a common factor that shapes asymmetries in their tax sensitivities. We now explore the implications of this factor.

In the benchmark model, percent changes in optimal leverage due to tax cuts are larger than those due to tax rises. Surprisingly, such results are contrary to ours. As the solid lines in Panels B-F of Figure 4 show, optimal leverage in our model reacts more to tax rises than tax cuts.[18] This highlights the relevance of R&D investment decision in analyzing the tax sensitivity of leverage. To further study how the inclusion of R&D decision twists the shape of the tax sensitivity, we next move our attention to Figure 5.

Panel A of Figure 5 plots marginal leverage value and marginal R&D-value loss

---

[17] Contrary to empirical outcomes in Mukherjee et al. (2017), Atanassov and Liu (2020) document that corporate income tax cuts laggedly and significantly stimulate corporate innovation. A possible reason is that the data sample used by Atanassov and Liu (2020) only includes the events of large tax changes (at least exceed 100 basis points). Such a sample selection criterion enhances the statistical significance of tax cut effects on innovation. The samples used by Heider and Ljungqvist (2015) and Mukherjee et al. (2017) are relatively broader. Those two papers never impose any constraint on the size of tax changes when constructing their samples.

[18] The empirical finding of Mukherjee et al. (2017) shows that the sizes of adjustments in the state-level corporate income tax rate are small and the median of these sizes approaches 22 bps. The influence of a 1-unit change in the state-level tax rate on firm value is in fact smaller than that of a 1-unit change in the corporate effective tax rate. This is because in addition to state-level income taxes, the calculations of corporate effective tax rates should take into account the effects of federal and city-level income taxes, dividend taxes, and other taxes (e.g., property taxes). The elasticity of the corporate effective tax rate to the state-level tax rate is smaller than 1. In view of this fact, we consider a reasonable range of the effective tax rate from τ minus 20 bps to τ plus 20 bps when plotting Figures 4-6. The width of the interval of effective tax rate changes is set at 20 bps, close to the aforementioned sample median.

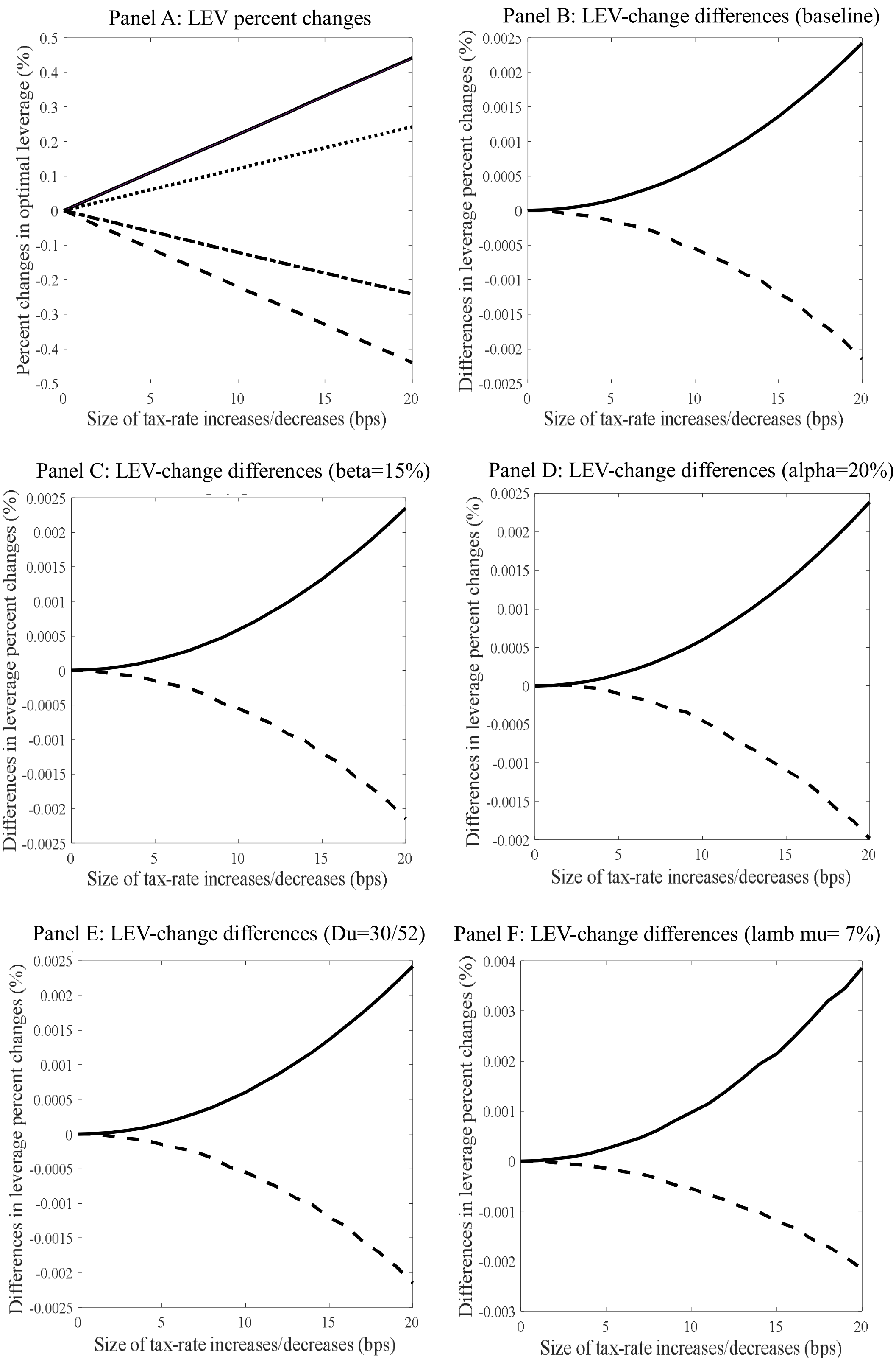

Figure 4: Comparisons of percent changes in optimal leverage between tax rises and tax cuts. In Panel A, the solid (dashed) and dotted (dash-dotted) lines depict percent increases (decreases) in optimal leverage due to tax rises (tax cuts) against the sizes of tax changes with using the basic model and the benchmark model, respectively. Panels B-F depict percent increases in the optimal leverage ratio due to tax rises less corresponding percent decreases due to tax cuts. The solid and dashed lines are plotted using the basic model and the benchmark model, respectively.

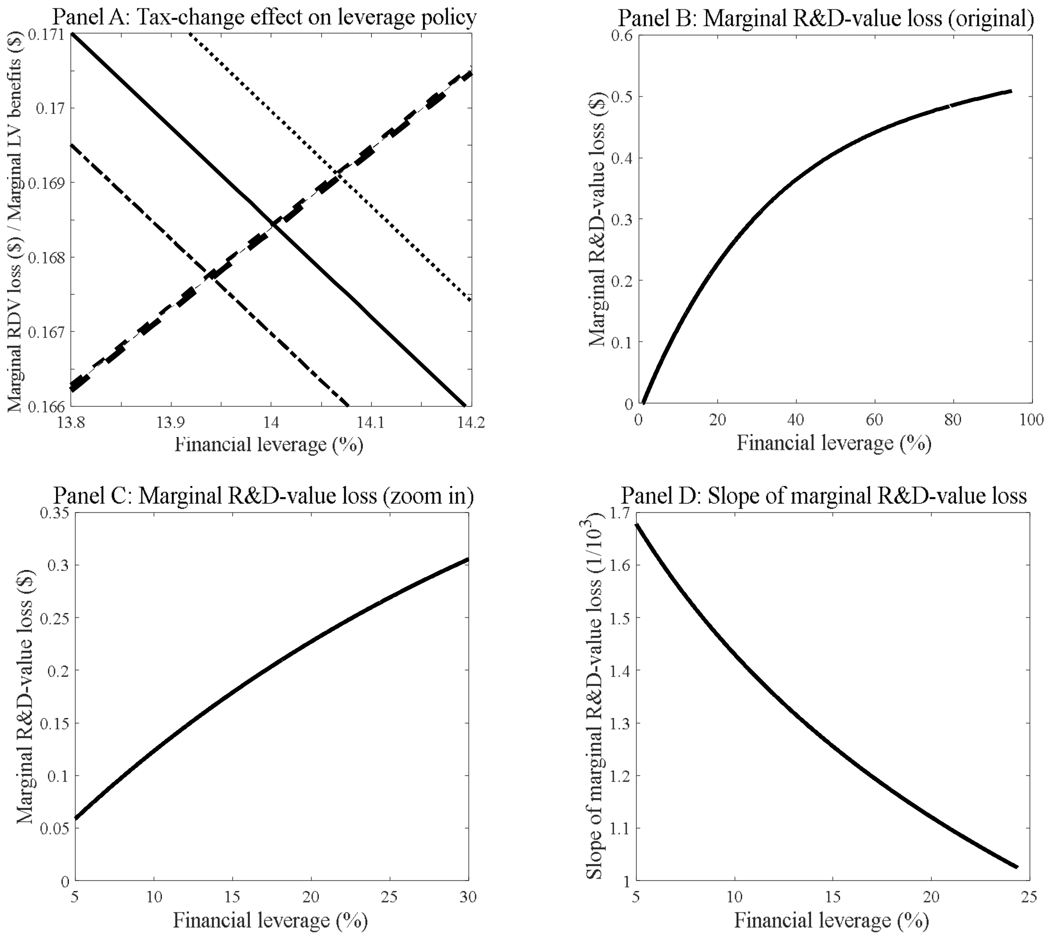

Figure 5: The concavity of marginal R&D-value loss and the tax-change effect on capital structure optimization. In Panel A, the short-dashed, middle-dashed, and long-dashed lines respectively plot marginal R&D-value loss given $\tau = 32\%$, $\tau = 32.2\%$, and $\tau = 31.8\%$ (these three lines almost overlap). The solid, dotted, and dash-dotted lines depict marginal financial leverage value given $\tau = 32\%$, $\tau = 32.2\%$, and $\tau = 31.8\%$, respectively. Panels B-D plot marginal R&D-value loss and its slope given $\tau = 32\%$. The rest of model parameters are chosen at their baseline levels.

against leverage under different tax rates. These patterns help understand how changes in the tax rate influence optimal leverage choice through the mechanism of the tradeoff between leverage value and R&D value. Observe that marginal leverage value reacts more to tax cuts than to tax rises (this causes the tax-cut sensitivity of leverage in the benchmark model to be stronger than the tax-rise sensitivity). The size of the shift from the solid line to the dash-dotted line is greater than that from the solid line to the dotted line. Besides, in contrast to marginal leverage value, marginal R&D-value loss displays a quite weak sensitivity to tax-rate changes. The short-dashed, middle-dashed, and long -dashed lines almost overlap. The key to twist the shape of the leverage-tax sensitivity, hence, lies in the *concavity* of marginal R&D-value loss (see Panels B-D), which makes the sensitivity of this loss to debt decreases higher than that to debt increases.

The occurrence of tax changes leads to the imbalance between marginal leverage value at the current debt level and corresponding marginal R&D-value loss. Such an imbalance makes current leverage deviate from its optimal level (as Proposition 4 says, leverage choice reaches its optimization only when marginal R&D-value loss matches marginal leverage value). In order to regain optimal capital structure, firms will offset this imbalance by adjusting debt use. Because of the concavity of marginal R&D-value loss, firms offset the tax-rise(cut)-induced imbalance by increasing (lowering) debt use in a relatively larger (smaller) size. Hence, the reactions of optimal leverage to tax cuts are weaker than those to tax rises. The shape of the leverage-tax sensitivity predicted by our model is contrary to that by the benchmark model, but consistent with empirical findings in Heider and Ljungqvist (2015).

We have been aware of the robust inverse comovement between optimal leverage and R&D-related quantities (e.g., net R&D value and total expected R&D expenses). A natural question thus arises here —— Is the asymmetric sensitivity to tax changes a common feature of optimal leverage and R&D policy? The answer to this question can be found from Figure 6. In Panels B-F, the solid (dashed) lines plot percent decreases in net R&D value (total expected R&D expenses) due to tax rises minus corresponding percent increases due to tax cuts. The patterns of these lines consistently show that in line with the case of leverage, available R&D benefit and aggregate R&D investment both have stronger reactions to tax rises than to tax cuts. This is because, in the model, these two R&D-related quantities both have a 1-to-1 monotonic relation with debt use. As stated in Section 4B, debt use is negatively associated with the expected duration of inventor employment, so that total expected investment amounts in R&D as well as available R&D benefits for firms issuing less debt are greater. Asymmetries in the tax

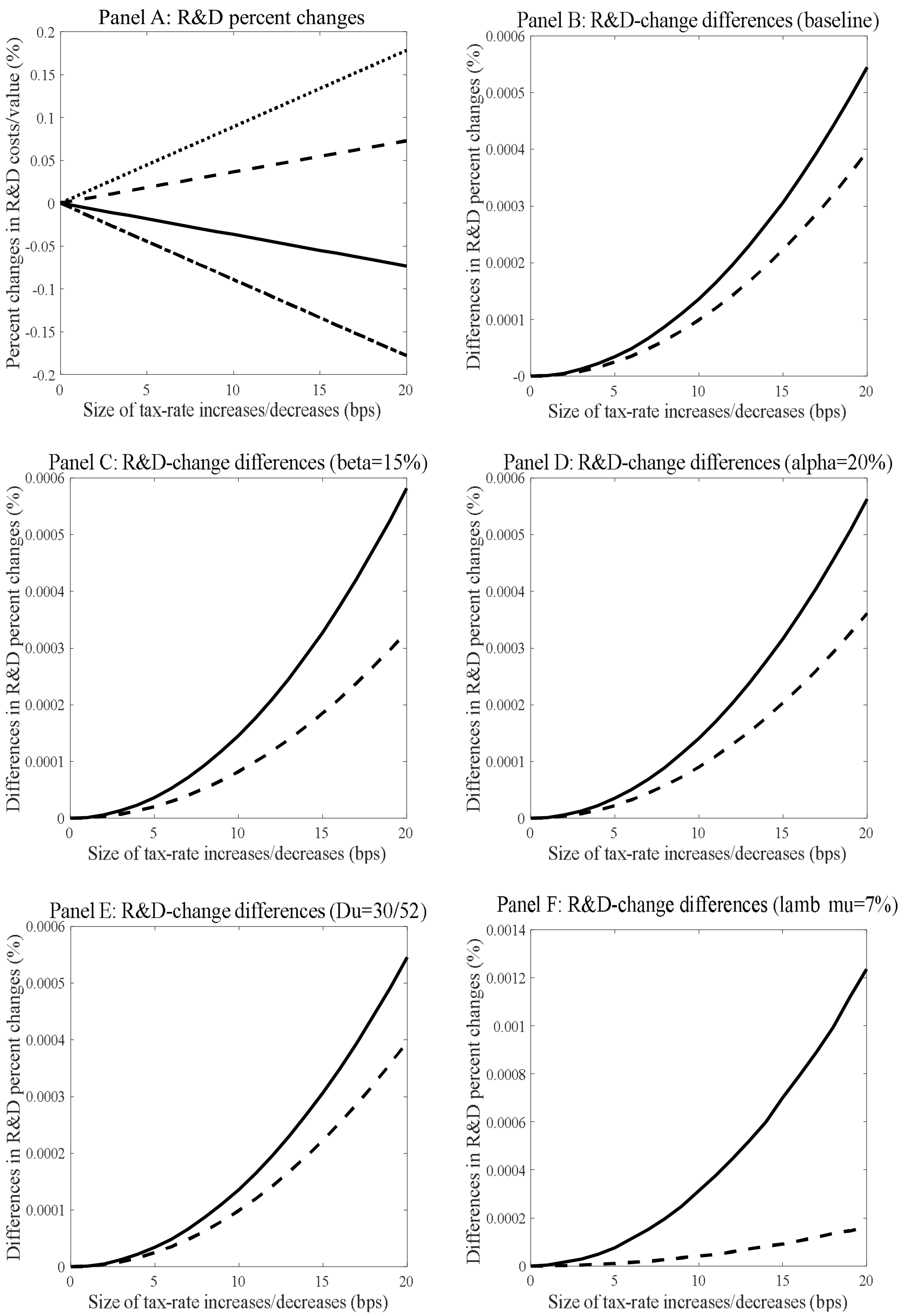

Figure 6: Comparisons of percent changes in R&D policies between tax rises and tax cuts. In Panel A the solid (dotted) and dashed (dash-dotted) lines respectively plot percent changes in net R&D value (total expected R&D expenses) scaled by firm value due to tax rises and tax cuts. In Panels B-F, the solid lines (dashed lines) plot percent decreases in net R&D value (percent increases in total expected R&D expenses) scaled by firm value due to tax rises less corresponding percent increases (percent decreases) due to tax cuts.

sensitivity of R&D policy predicted by our model are consistent with empirical implications in Mukherjee et al. (2017). They document that the tax-rise effect on innovation is significant whereas the tax-cut effect seems little. Using the concavity of marginal R&D-value loss, our model offers a partial explanation for this puzzling stylized fact.

Another finding from Figure 6 is that firms' available R&D benefit is negatively related to the tax rate (see the solid line in Panel A). A rise in the tax rate encourages firms to use more debt by increasing the value of debt's tax benefits. As debt use rises, the likelihood of human capital loss due to financial distress increases and the expected duration of inventor employment shortens. Hence, firms derive less R&D benefit from inventors in place. These implications are in support of evidence from Mukherjee et al. (2017) that tax rises make firms acquire fewer innovation outputs (e.g., patents).

V. Coordination between Innovation Strategy and Pricing

Although successful product and technology innovations both deliver benefits that raise operating earnings, the mechanisms through which firms absorb these two types of innovation benefits are different. Technology progress motivates firms to sell their products at a lower price, which helps them earn a greater product market share. Since improvements in product quality would attract new customers that drive the growth of product demand, firms absorb product innovation benefits by raising the product price (Lin, 2012). The coordination between innovation strategy choice and product pricing is crucial for examining the influence of innovation strategy switches on the interaction among leverage, R&D, and product price competition. To explore the implications of this coordination, Section 5 extends the basic model by allowing for product innovation.

A. The generalized corporate mixed-innovation model

R&D on product innovation helps firms discover new product features or facility continuously. Updating product features might result in product quality improvements (deteriorations) that enhance (lower) customers' willingness to purchase products. The evolution of product features is irreversible. Firms always replace old-version products with new-version products. Under the zero-inventory condition, firms never sell new-version and old-version products simultaneously. The above intuitive notion, similar to Levin and Reiss (1988) and Smolny (1998), inspires us to measure the effect of product innovation on product demand by using the following specification:

$$d\bar{Q}_d(t)\big/\bar{Q}_d(t)=\tilde{\mu}_q(RD)dt+\tilde{\sigma}_q(RD)dB(t)=(\mu_q+\Xi_\mu RD)dt+(\sigma_q+\Xi_\sigma RD)dB(t)$$

where Ξ_μ is the product-innovation-related marginal product demand growth rate and Ξ_σ denotes marginal product innovation risk.

Following Adner and Levinthal (2001), we reformulate technology dynamics as

$$d\bar{A}(t)\big/\bar{A}(t)=\mu_A(RD)dt+\sigma_A(RD)dW(t)+\rho\,\Xi_\sigma RD\,dZ(t)$$

where $\rho\geq 0$ measures the sensitivity of productivity technology aggregate shocks to product innovations, and $dZ(t)$ is a Brownian motion.[19] Note that technology shock components consist of technology-innovation-based shock $\sigma_A(\cdot)dW(t)$ and product-innovation-based shock $\rho\,\Xi_\sigma RD\,dZ(t)$. The product innovation effect on technology shock means that since producing the products with new features always requires new technology, doing product innovation generates additional technology volatility.

The rest of mixed-innovation model setups are identical to the basic model, so that we do not describe them repeatedly. To save space, we show technical derivations and the formulas for corporate securities under mixed innovation in online Appendix B4.

B. Model implications

This subsection performs numerical analysis on the model developed in Section 5A. We consider three types of innovation strategy: technological innovation (given $\Xi_\sigma=\Xi_\mu=0,\ \Lambda_\sigma\Lambda_\mu\neq 0$), product innovation (given $\Lambda_\sigma=\Lambda_\mu=0,\ \Xi_\sigma\Xi_\mu\neq 0$), and mixed

[19] Adner and Levinthal (2001) impose an assumption that doing product innovation generates additional uncertainty over the evolution of productivity technology.

innovation (given $\Lambda_\sigma \Lambda_\mu \Xi_\sigma \Xi_\mu \neq 0$). We calibrate the baseline level of marginal product innovation risk Ξ_σ at 8%, the product-innovation-related marginal product demand growth rate Ξ_μ at 0.2%, and the sensitivity of technology shock to product innovation risk ρ at 50%. Moreover, we respectively reset μ_q and σ_q at 1.17% and 3.82% to ensure that the cash flow growth (volatility) rate in optimization is targeted at roughly 2.5% (25.5%). The baseline values of the rest of parameters remain unchanged.[20]

B.1. Product pricing strategy: Technology innovation versus product innovation

We first make a comparison between two innovations by putting the special focus on product pricing. Recall from Proposition 1 that the optimal product price is strictly increasing in product demand but decreasing in technology. Hence, when experiencing technology progress, firms reduce the product price and earn a greater product market share. In the face of a rise in product demand due to product innovation success, firms raise the product price but earn a smaller market share. Such a view on the coordination between innovation strategy and product pricing is in line with Kogan et al. (2017) and others, and can be validated by the patterns in Panels A and B of Figure 7.[21]

Moreover, it is observable that the evolution processes of expected sales quantities $\hat{Q}_D(p^*(t), Q_d(t))$ under product innovation and technology innovation are dramatically different (Panels C and D). Such results are not beyond our expectation. As mentioned before, firms absorb product (technology) innovation benefits by adopting the strategy that raises (reduces) the product price. Sales quantities are a decreasing function of the product price, so that expected sales quantities under product (technology) innovation fall (grow) over time. We further find that the speeds of the evolution of expected sales quantities in these two innovation cases are quite different as well. The growth of sales

[20] We do not discuss the interaction among optimal leverage, R&D investment, and wages in product-innovation firms, because related results are identical to those in technology-innovation firms.

[21] For example, Lentz and Mortensen (2008) argue that the success of product innovations brings firms market power, and enables firms to set product prices above the marginal cost of production. Adner and Levinthal (2001) find that product price increases are associated with quality development, while price decreases are associated with manufacturing process development.

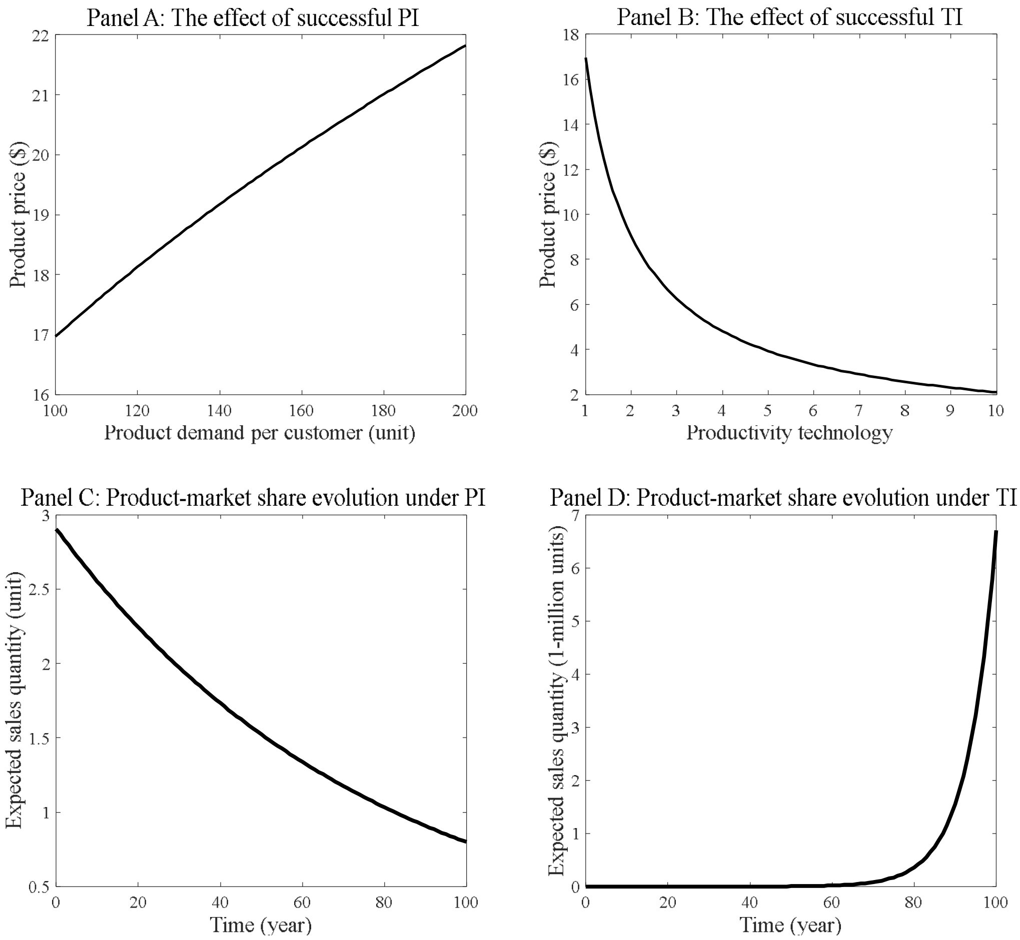

Figure 7: Comparisons of product pricing strategies between product innovation and technology innovation. By considering the growth of product demand as successful product innovation (PI) and technology progress as successful technology innovation (TI), Panels A and B plot the optimal product price against the success of PI and against the success of TI, respectively. Panels C and D plot the expected quantities of product sales as a function of time.

quantities under technology innovation seems fast while the decay of sales quantities under product innovation seems slow. The reasons lie in pricing-strategy inconsistency between two innovation cases and in the asymmetric effect of innovations on product demand. Technology innovation does not affect the individual customer's demand for products, so that it boosts sales quantities only through lowering the product price. The case of product innovation is more complicated. Successful product innovation creates an additional positive effect on product demand growth and makes firms raise the price, simultaneously. The former positive effect on sales quantities partially offsets the latter negative effect, and hence, it slows down the decay of sales quantities.

B.2. Leverage, R&D, and price competition: The role of innovation strategy

We next study how innovation strategy switches influence the reactions of firms' debt and R&D policies to price competition changes via product pricing. By following Hackbarth and Miao (2012), we employ the price elasticity of the customer base as a measure of the price competition intensity in product markets.[22]

Observe from the two figures that switching innovation strategy causes structural changes in the leverage-competition relation. This relation is an inverted-U for a mixed -innovation firm (Panel A of Figure 9), positive for a product-innovation firm (the solid line in Panel A of Figure 8), and negative for a technology-innovation firm (the dashed line in Panel A of Figure 8). The complexity of this relation is attributed to the coordination between innovation strategy and product pricing. In order to absorb innovation benefits and further convert such intangible benefits into tangible operating earnings, technology (product)-innovation firms will adopt a policy of lowering (increasing) the product price. Hence, increasing (decreasing) price competition enhances (dilutes) the technology progress effect on earnings, whereas dilutes (enhances) the effect of product

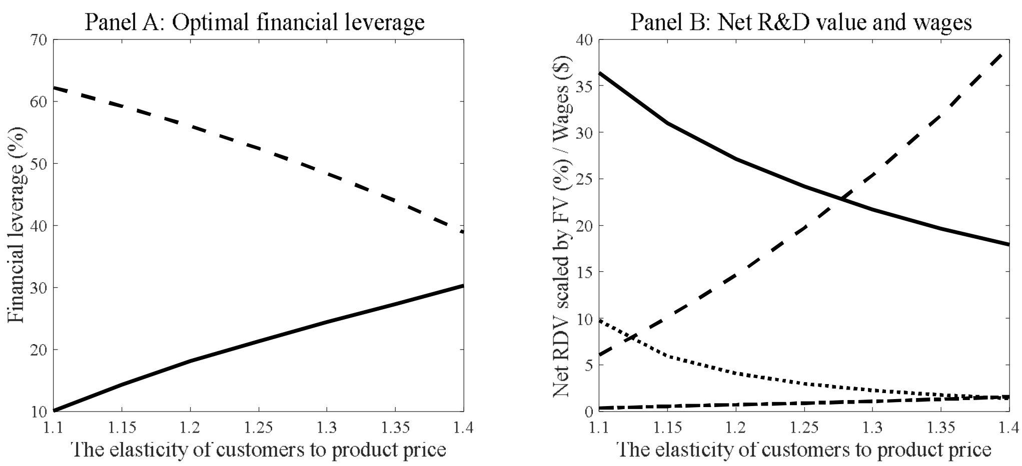

Figure 8: Comparisons between product innovation and technology innovation. In Panel A the dashed (solid) line plots the optimal leverage ratio against price elasticity under technology (product) innovation. In Panel B the solid (dotted) and dashed (dash-dotted) lines respectively plot net R&D value scaled by firm value (endogenous wages) against price elasticity under product innovation and technology innovation.

[22] Hackbarth and Miao (2012) similarly regard the price sensitivity of product demand as a measure of product market competition.

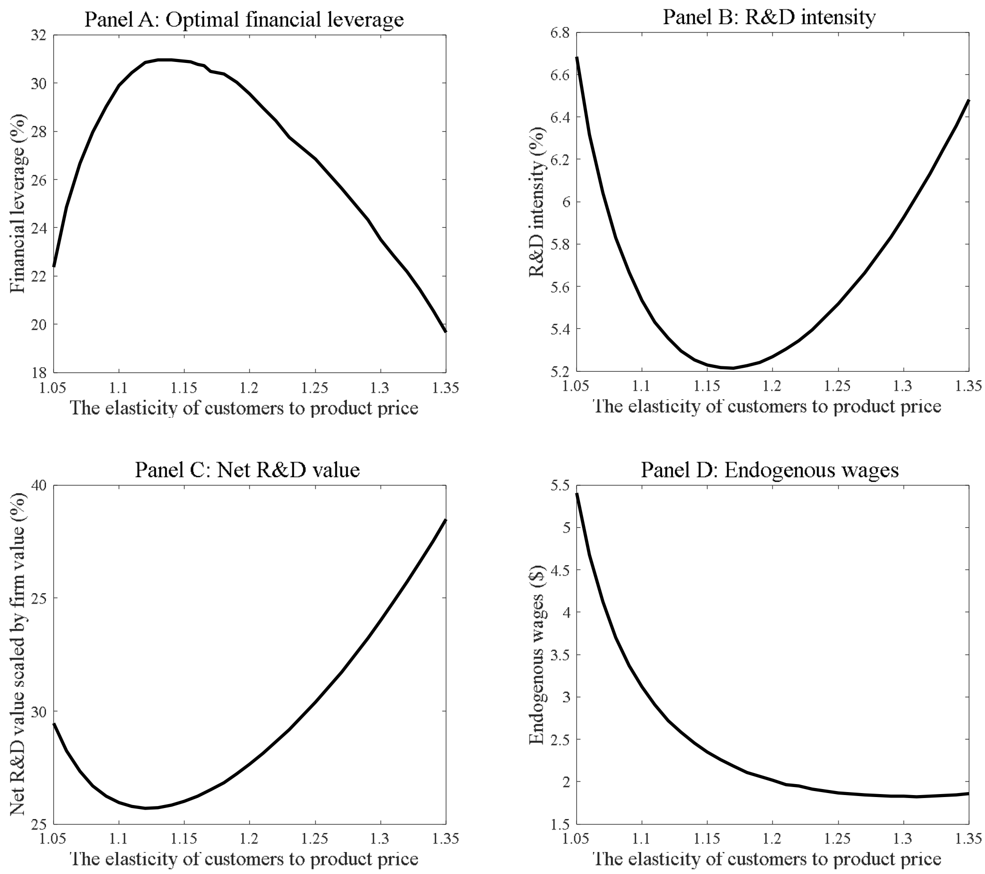

Figure 9: The simultaneous optimization of debt and R&D decisions for a mixed-innovation firm. Panels A-D respectively plot optimal financial leverage, R&D intensity, net R&D value scaled by firm value, and endogenous wages against price elasticity for a mixed-innovation firm.

demand growth driven by product innovation success on earnings. These implications are compatible with empirical findings in Smolny (1998).

The arguments above mean that product price competition kindles (limits) firms' willingness to do R&D on technological (product) innovation. As discussed in Section 4B, an increase (a decrease) in firms' willingness to do R&D crowds out (boosts) their willingness to use debt. Therefore, as price competition intensity increases, technology (product)-innovation firms raise (reduce) R&D investment and reduce (raise) leverage. Mixed-innovation firms' leverage particularly has an inverted-U response to changes in price competition. When competition is moderate (weak or tough), R&D benefits on mixed innovation are relatively small (large), firms' incentives to invest in R&D will be weak (strong), and the corresponding optimal leverage ratio is high (low).

VI. Inventor Mobility and Human Capital Risk Management

In the basic model firms can unilaterally request inventors to abandon outside job options without promising extra compensation. Wages are fixed at the initial time and never change, even if the continuation value of employment contract falls in the future. However, the impact of human capital risk due to labor mobility on firm value has been widely documented (Donangelo, 2014). Labor mobility usually arises from the fact that the continuation value of wage contract is too low or far lower than the value of labors' outside options. Firms could avoid the departures of skilled labors by raising wages or providing additional compensation (e.g., stock options). In view of this fact, we now extend the model with taking inventor mobility into account. We additionally impose a dynamic wage-based compensation scheme on employment contract, which captures the financial effect of hedging human capital risk due to inventor mobility.

A. The model allowing for inventor mobility

We begin with modeling inventor mobility. For brevity, we consider the collective departures of inventors in place as an event of inventor mobility. In order to ensure that inventors have incentives to voluntarily leave the firm for job hopping, we replace the outside-option-loss assumption with a new assumption that managers allow inventors to retain their outside job options. Under this new assumption, inventors can switch job without suffering friction (temporary unemployment). Inventors' collective departures are caused by the exercise of outside job options, rather than by the firm's bankruptcy. Managers do not recruit new inventors after old ones leave. R&D investment will be suspended immediately once inventor mobility occurs.

It is known from expression (7) and Proposition 3 that the total present value of wage flows, which plays a role as inventors' continuation value, increases with product demand. Naturally, the likelihood of inventor mobility rises as inventors' continuation value falls. The timing of inventor mobility, hence, can be specified using a stopping time on inventors' continuation value. Because this value and product demand have a 1-to-1 monotonic relation, we define the random time of inventor mobility as

$$T_M := \inf(\, t > 0 : Q_d(t) \leq Q_d^{\theta}(D))$$

where $Q_d^{\theta}(D) \equiv \theta Q_d(T_d; D)$ is the mobility-triggering threshold and θ is the intensity of mobility subjectively chosen by inventors. Note that $\theta > 1$, otherwise the timing of firm bankruptcy is always earlier than inventor mobility and inventor mobility plays no role in capital structure decision making. θ can be further thought of as the degree of inventors' aversion to the debt issued by the firm (since raising debt use lowers their continuation value). A high debt aversion level leads to a strong positive sensitivity of inventor mobility likelihood to debt increases, suggesting that inventors' intentions to switch job react to debt increases strongly. Therefore, when the degree of debt aversion is greater, debt use is more likely to make firms lose inventive human capital before the occurrence of bankruptcy.

To capture the impact of inventor mobility on R&D valuation, we should re-derive the formula for total expected R&D expense by replacing T_d with T_M. Besides, since $T_M \leq T_d$, indirect bankruptcy costs are replaced with expected losses in intangible asset value due to inventor mobility. To save space, we provide technical derivations and the formulas for corporate securities under inventor mobility in online Appendix B5.

B. The model allowing for human capital risk management

We next construct a model of dynamic upward wage adjustments to describe the firm's behavior for fully hedging inventor mobility. Following He (2011), Ju and Wan (2012), and Cao and Wang (2013), we set the value of inventors' outside job option ***S*** as a constant. In equilibrium this value matches inventors' continuation value. Besides, we consider a process $G_i(t) \equiv V_i^{CON}(Q_d(t); D) \big/ \boldsymbol{S} = \boldsymbol{S}^{-1}\ \mathbb{E}_t \int_t^{T_d} I_{i-1} \mathrm{e}^{-r(s-t)} ds$. This measures the ratio of inventors' continuation value after $i-1$ times of upward wage adjustment to their outside option value. Inventors could exercise outside job options when $G_i < 1$. Because of this job-hopping possibility, firms prevent inventive human capital loss by reconsidering the level of wages.

Denote the *i*th wage adjustment time point by $T_W^i := \inf(t > T_W^{i-1} : G_i(t) \le 1 - \vartheta)$ where $\vartheta \in [0,1]$ is the job-switching cost rate. Note that job-switching costs, which refer to the costs incurred by job hopping (such as household moving costs, relocation fees, etc.), should be distinguished from unemployment cost arising from job-switching frictions. Job-switching costs have important implications for wage adjustment timing. When job-switching costs $\boldsymbol{S}\vartheta$ outweigh job-switching benefits $\boldsymbol{S} - V_i^{CON}(\cdot)$, inventors cannot increase their wealth through the exercise of outside job options. In this case, inventors never quit their current jobs and nothing motivates managers to adjust wages for retaining inventors. Only when job-switching benefits exceed job-switching costs, inventors exercise outside options. Managers can completely avoid inventor departures by choosing wage adjustment timing at an ideal time point at which job-switching costs equal job-switching benefits; i.e., $\boldsymbol{S} - V_i^{CON}(T_W^i) = \boldsymbol{S}\vartheta \Rightarrow G_i(T_W^i) = 1 - \vartheta$. The implications above rationalize the definition of random wage adjustment time.

In the model the role of the job-switching cost rate is to help us determine the size of wage adjustments. At each of wage adjustment time point, managers reset wages in accordance with their competitive level that ensures the match between outside option value and inventors' continuation value. This suggests that at the time point just after wage adjustment, the ratio of continuation value to outside option value equals 1; i.e., $\forall i \in \mathbb{N} : G_i(T_{W+}^{i-1}) = 1$. Besides, it is known that at the moment of wage adjustment, this ratio satisfies the termination condition: $\forall i \in \mathbb{N} : G_i(T_W^i) = 1 - \vartheta$. These two conditions jointly imply $V_i^{CON}(Q_d(T_W^i);D)(1-\vartheta)^{-1} = \boldsymbol{S} = V_{i+1}^{CON}(Q_d(T_{W+}^i);D)$, which helps us derive the endogenous growth rate of wages as $I_i / I_{i-1} = (1-\vartheta)^{-1} \equiv \phi^{-1}$.

We have been aware that G_i and product demand have a 1-to-1 relationship. For convenience in comparing the random time of wage adjustments with that of inventor mobility, we transform the definition of T_W^i into the following:

$$T_W^i := \inf(t > 0 : Q_d(t) \le Q_\phi^i(\phi, D))$$

where $Q_\phi^i(\phi,D) \equiv \left\{1-\phi^i[1-(Q_d(0)/Q_d(T_d;D))^{-x-y}]\right\}^{-1/(x+y)} Q_d(T_d;D)$. Note that since $\lim_{i\uparrow\infty} Q_\phi^i(\phi,D) \to Q_d(T_d;D)$, as the time of wage adjustments approaches infinity, the expected timing of wage adjustment will be close to the time point of bankruptcy. This ensures that (i) the range of employment contract value is bounded, and (ii) firms no longer adjust wages after the occurrence of bankruptcy.

We are ready to define the cost of hedging inventor mobility. Its expression is

$$V^{RDHC}(Q_d(0);D) \equiv \mathbb{E}_{0+} \sum_{i=1}^{\infty} (V_{i+1}^{CON}(Q_d(T_{W+}^i);D) - V_i^{CON}(Q_d(T_W^i);D))\mathrm{e}^{-rT_W^i}$$ [23]

Specifically, it is calculated as the total present value of future spending for retaining inventors. Such spending is quantified using the effect of wage upward adjustment on inventors' continuation value. The formula and technical derivation for hedging costs are available in online Appendix B6. Plugging hedging costs into decision program (8) yields a modified version of capital structure decision program. We solve optimal debt policy using this modified capital structure decision program.

C. Implications of inventor mobility

This subsection quantitatively examines the implications of inventor mobility for firms' debt and R&D policies. For illustration, we plot market leverage, net R&D value, wages, and the mobility threshold against inventor mobility intensity θ in Figure 10.

[23] Our full-hedge model does not allow us to study the optimization of hedge policy. To deal with issues on optimal hedge, a partial-hedge setting (firms do hedge only when net R&D value remains positive) is required. Since the endogenous interaction between optimal hedge and leverage is beyond the scope of our paper, we leave this interesting extension to future research.

C.1. Optimal leverage

Observe that firms lower leverage as inventor mobility intensity increases. In the model, we regard the sensitivity of the mobility-triggering threshold to the bankruptcy threshold as inventor mobility intensity $\frac{\partial Q_d^{\theta}(D)}{\partial Q_d(T_d;D)} = \theta$. When mobility intensity is higher, inventors' intentions to switch job (i.e., inventor mobility likelihood) display a stronger reaction to debt increases. Such inventors' behavior can be thought of as debt aversion (since raising debt hurts their continuation value). Mobility intensity reflects the degree of debt aversion. These mean that in the presence of inventor mobility, debt use is more likely to make firms lose inventive human capital, and hence, the inclusion of inventor

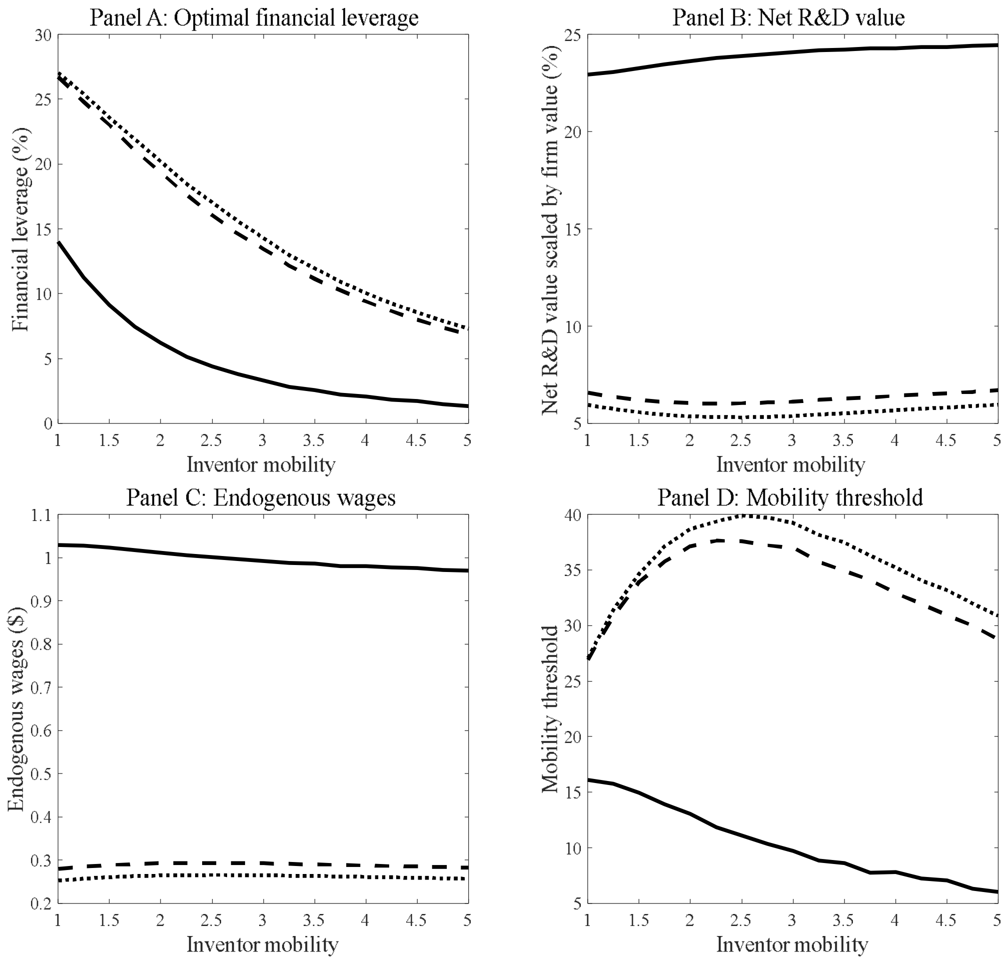

Figure 10: The simultaneous optimization of debt and R&D policies under human capital risk due to inventor mobility. In all panels A, the solid lines are plotted using the baseline parameters. The dashed and dotted lines are plotted using $\Lambda_{\mu} = 3\%$ and $\Lambda_{\sigma} = 30\%$, respectively (the rest of parameters are chosen at their baseline levels).

mobility exacerbates the negative influence of debt use on available R&D benefits. In view of these concerns, firms exposed to human capital risk due to inventor mobility will adopt a relatively more conservative debt policy.

Our results partially capture empirical phenomena related to key human capital. Israelsen and Yonker (2017) identify human capital concentrated in a few irreplaceable employees (e.g., highly-educated inventors) as *key human capital*. They document that firms possessing key human capital bear the risk arising from key employee departures and take less leverage than firms without key human capital. In our model, inventive human capital can be interpreted as one type of key human capital. Therefore, inventor mobility is equivalent to key human capital risk due to inventor departures. Our model implications offer an alternative explanation for the inverse association between firm leverage and key human capital risk. We characterize inventors' (key employees') debt aversion using the mobility intensity parameter (the intensity of key human capital risk). When the degree of debt aversion is grater, investors' intentions to leave the firm have a stronger reaction to debt increases. This means that (i) debt use is more likely to make firms lose innovation benefit attached to key human capital; and (ii) the marginal R&D -related cost of debt use, measured as marginal R&D-value loss due to debt use, will be higher. Firms suffering a higher key human capital risk, hence, tend to use less debt.

C.2. Available R&D benefits and inventor mobility likelihood

Consider next the influence of inventor mobility on available R&D benefits. As Panel B of Figure 10 shows, while inventor mobility intensity has a monotonic relation with leverage, its relation with net R&D value is not always monotonic. When R&D efficiency is chosen at a relatively high level (the solid line in Panel B) and a relatively low level (the dashed and dotted lines in Panel B), this relation has a positive direction and a U shape, respectively. How large expected R&D value earned by a firm is in fact depends on how long the expected duration of inventor employment is. Hence, before explaining the complexity of the relation between inventor mobility and R&D value, we must understand how mobility intensity changes affect inventor mobility likelihood. For convenience in subsequent discussions, we plot the mobility-triggering threshold against mobility intensity in Panel D of Figure 10.

Observe that the patterns of R&D value and the mobility threshold are symmetric. When R&D efficiency is chosen at a relatively high level and a relatively low level, the mobility threshold has a negative relation (the solid line in Panel D) and an inverted-U relation (the dashed and dotted lines in Panel D) with mobility intensity, respectively. In the model, we design this threshold as $Q_d^{\theta}(D^*) \equiv \theta Q_d(T_d;D^*)$. Hence, the influence of mobility intensity changes on this threshold can be decomposed into two parts:

$$\partial Q_d^{\theta}(D^*) \big/ \partial\theta = Q_d(T_d;D^*) + \theta(\partial Q_d(T_d;D^*) \big/ \partial D^*)(\partial D^* \big/ \partial\theta) \tag{10}$$

On the right side of equation (10), the first term represents the direct effect, which is obviously positive. The second term represents the indirect effect, which refers to the case that mobility intensity changes influence the mobility threshold through optimal debt choice. This effect is negative because optimal debt use is decreasing in mobility intensity. The outcomes of the tradeoff between the two effects determine the direction of the influence of mobility intensity changes on inventor mobility likelihood.

It is worth noticing that changes in mobility intensity and R&D efficiency both simultaneously but asymmetrically affect the aforementioned two effects. The direct effect weakens as mobility intensity or R&D efficiency rises. The reason is that when mobility intensity or R&D efficiency is higher, firms use less debt that implies a lower bankruptcy threshold. Increasing mobility intensity enhances the indirect effect, while increasing R&D efficiency dilutes the indirect effect through lowering the sensitivity of optimal debt use to mobility intensity (note that, in Panel A, the solid line given higher R&D efficiency is flatter than the dotted and dashed lines given lower R&D efficiency).

Moreover, the reaction of the indirect effect to R&D efficiency changes is weaker than that of the direct effect.[24] By summarizing the above model implications, we have two following conclusions. The first considers the case of low R&D efficiency. In this case, when mobility intensity is at a relatively lower level, firms use more debt and choose a higher bankruptcy threshold. The direct effect is sufficient to outweigh the indirect effect, so that the mobility threshold and mobility intensity have a positive relation. As mobility intensity increases, the direct (indirect) effect gradually weakens (rises). This twists the direction of their relation, since the indirect effect outweighs the direct effect when mobility intensity is in the high range. The second conclusion refers to the case of high R&D efficiency. Varying R&D efficiency from a low level to a high level will cause the direct effect to be insufficient to outweigh the indirect effect. Such results still hold even if mobility intensity is within the low range. These results are attributed to the fact that the negative reactions of the direct effect to R&D efficiency increases are stronger than those of the indirect effect. In the case of high R&D efficiency, therefore, the indirect effect always outweighs the direct effect. This delivers an inverse relation between the mobility threshold and mobility intensity.

The implications above can help clarify the complexity of the influence of inventor mobility on R&D value. We have known that a higher mobility threshold always causes a larger inventor mobility likelihood as well as a shorter expected duration of inventor employment. Available R&D benefits are negatively related to the mobility threshold. As a result, when R&D efficiency is high, mobility intensity has a positive (negative) relation with R&D value (the mobility threshold). When R&D efficiency is low, it has a U (an inverted-U) relation with R&D value (the mobility threshold).

Our results are partially supported by empirical findings in Liu et al. (2017). They document that firms with a higher inventor mobility intensity enjoy greater innovation

[24] Our tests show that the numerical values of the partial derivative of the indirect effect with respect to R&D efficiency parameters are lower than those of the direct effect. Such results always hold no matter which the level of mobility intensity we choose.

benefits, since inventors in place can contribute more to innovation outputs. Our model predicts that only when inventors in place have high R&D efficiency, available R&D benefits increase with mobility intensity

C.3. Interaction among inventor mobility, leverage, and wages

Consider finally the interaction among inventor mobility, leverage, and wages. It is observable from Panels A and C of Figure 10 that because optimal leverage is strictly decreasing in mobility intensity, optimal leverage and wages will have a nonmonotonic endogenous relation along changes in mobility intensity. Their relation is inverted-U when R&D efficiency is low (the dashed and dotted lines), while that is positive when R&D efficiency is high (the solid lines). Such results are due to the fact that changing mobility intensity simultaneously but asymmetrically affects the RC and HCL effects through leverage decision. A rise in mobility intensity generates a decrease in optimal leverage, and such a leverage decrease simultaneously causes a negative RC effect and a positive HCL effect on wages. When R&D efficiency is high, marginal changes in the RC effect due to leverage decreases outweigh those in the HCL effect, so that leverage and wages simultaneously decrease as mobility intensity rises. When R&D efficiency is low and mobility intensity remains in the low (high) range, marginal changes in the HCL (RC) effect due to leverage decreases will outweigh those in the RC (HCL) effect. These generate an inverted-U relation between mobility intensity and wages as well as an inverted-U wage-leverage endogenous relation.

D. Implications of human capital risk management

We now examine the implications of hedging human capital risk due to inventor mobility for corporate leverage and R&D. In the implementation of hedge analyses, we calibrate mobility intensity by equating the mobility threshold $Q_d^{\theta}(D^*)$ with the first wage-adjustment threshold $Q_{\phi}^{1}(\phi, D^*)$. The purpose of using such a calibration strategy

Table 4: The Effect of Hedging Human Capital Risk on Model Outputs.

This table shows model outputs at the simultaneous optimization of leverage and R&D policies. In each panel the columns (from left to right) report market leverage, net financial leverage value scaled by firm value, net R&D value (minus hedging cost) scaled by firm value, firm value, initial wages, and hedging benefits scaled by firm value. Inventor mobility intensity is calibrated to equate the mobility threshold with the first wage adjustment threshold. The rest of model parameters are set at their baseline levels.

Model type	Major model outputs					
	Market leverage	Net FL value scaled by FV	Net R&D value scaled by FV	Total firm value	Initial wages	Hedging benefits
Panel A: $\phi = 0.2$ (θ is calibrated at 5.873)						
Hedging	4.463%	1.349%	23.656%	$813.424	$0.95872	0.255%
No hedging	1.074%	0.340%	24.473%	$811.352	$0.96541	-----
Panel B: $\phi = 0.15$ (θ is calibrated at 6.28)						
Hedging	4.457%	1.347%	23.724%	$814.141	$0.95871	0.363%
No hedging	0.962%	0.305%	24.494%	$811.194	$0.96348	-----
Panel C: $\phi = 0.1$ (θ is calibrated at 6.64)						
Hedging	4.464%	1.349%	23.791%	$814.895	$0.95879	0.471%
No hedging	0.877%	0.278%	24.510%	$811.076	$0.96191	-----
Panel D: $\phi = 0.05$ (θ is calibrated at 7.08)						
Hedging	4.457%	1.347%	23.896%	$816.010	$0.95879	0.624%
No hedging	0.789%	0.251%	24.526%	$810.952	$0.96023	-----

is to measure hedging benefits, defined as increments in firm value due to hedging. We compile major model outputs as Table 4. Two results immediately stand out.

First, the willingness to hedge human capital risk makes firms raise leverage and derive less R&D benefits from inventors. This is in line with the literature on corporate risk management, which finds that hedging permits greater leverage (e.g., Leland, 1998; Campello et al., 2011; etc.). The existing literature typically considers interest rate risk, foreign exchange risk, climate risk, or credit risk. Because hedging lowers bankruptcy likelihood by smoothing cash flows, hedged firms use more leverage than non-hedged firms. In contrast, we consider human capital risk due to inventor mobility, and regard wage-based compensations for retaining inventors as hedging costs. These costs dilute net R&D benefits enjoyed by shareholders, and thus, marginally alleviate the negative influence of debt use on available R&D benefits. This hedge-induced alleviation effect increases the firm's willingness to use debt via the mechanism of the tradeoff between R&D value and traditional leverage value.

Second, hedging benefits are small, no more than 1% of firm value, and increase with mobility intensity. Hedging is more valuable when human capital risk is higher. We further see that as hedging benefits increase, the positive hedging effect on leverage becomes greater. While hedging benefits seem limited, this effect on the leverage ratio is significant, around 340 bps to 360 bps. Similarly, Leland (1998) shows that hedging raises leverage by about 580 bps even if its benefits are only 1.5% of firm value.

VII. Conclusion

We study how firms' involvement in innovation and leverage decision interact by proposing an integrated model of innovation and capital structure. The model allows us to analyze corporate R&D investment, human capital costs, and leverage in a unified framework. The model goes a long way towards reconciling capital structure tradeoff theories with puzzling leverage cross-sectional features. The model also delivers novel capital structure empirical predictions about the coordination between product pricing and innovation strategy choice and about human capital risk due to inventor mobility. The model is more generalized than existing R&D/innovation models, and has a rich set of attractive features. It can be further applied to research in asset pricing, corporate finance, endogenous economic growth, and innovation management.

References

Abel, A. "Optimal Debt and Profitability in the Trade-off Theory." *Journal of Finance*, 73 (2018), 95-143.

Adner, R. and D. Levinthal. "Demand Heterogeneity and Technology Evolution: Implications for Product and Process Innovation." *Management Science*, 47 (2001), 611-628.

Agrawal, A. and D. A. Matsa. "Labor Unemployment Risk and Corporate Financing Decisions." *Journal of Financial Economics*, 108 (2013), 449-470.

Akyol, A. and P. Verwijmeren. "Human Capital Costs, Firm Leverage, and Unemployment Rates." *Journal of Financial Intermediation*, 22 (2013), 464-481.

Andrade, G. and S. Kaplan. "How Costly is Financial (Not Economic) Distress? Evidence from Highly Leveraged Transactions that Became Distressed." *Journal of Finance*, 53 (1998), 1443-1493.

Antill, S. and S. Grenadier. "Optimal Capital Structure and Bankruptcy Choice: Dynamic Bargaining versus Liquidation." *Journal of Financial Economics* 133 (2019), 198-224.

Atanassov, J. and X. Liu. "Can Corporate Income Tax Cuts Stimulate Innovation?" *Journal of Financial and Quantitative Analysis* 55 (2020), 1415-1465.

Bena, J. and L. Garlappi. "Corporate Innovation and Return." *Review of Corporate Finance Studies*, (2019), forthcoming.

Berk, J., R. Stanton, and J. Zechner. "Human Capital, Bankruptcy, and Capital Structure." *Journal of Finance*, 65 (2010), 891-926.

Bessler, W., W. Drobetz, R. Haller, and I. Meier. "The International Zero-Leverage Phenomenon." *Journal of Corporate Financ*e, 23 (2013), 196-221.

Black, F. and J. Cox. "Valuing Corporate Securities: Some Effects of Bond Indenture Provisions." *Journal of Finance*, 31 (1976), 351-367.

Caggese, A. "Entrepreneurial Risk, Investment, and Innovation." *Journal of Financial Economics*, 106 (2012), 287–307.

Campello, M., C. Lin, Y. Ma, and H. Zou. "The Real and Financial Implications of Corporate Hedging." *Journal of Finance*, 66 (2011), 1615-1647.

Cao, M. and R. Wang. "Optimal CEO Compensation with Search: Theory and Empirical Evidence." *Journal of Finance*, 68 (2013), 2001-2058.

Carlson, M. and A. Lazrak. "Leverage Choice and Credit Spreads when Managers Risk Shift." *Journal of Finance*, 65 (2010), 2323-2362.

Cazier, R. "Measuring R&D Curtailment among Short-Horizon CEOs." *Journal of Corporate Finance*, 17 (2011), 584-594.

Chemmanur, T., Y. Cheng, and T. Zhang. "Human Capital, Capital Structure, and Employee Pay: An Empirical Analysis." *Journal of Financial Economics*, 110 (2013), 478-502.

Chen, H. "Macroeconomic Conditions and the Puzzles of Credit Spreads and Capital Structure." *Journal of Finance*, 65 (2010), 2171-2212.

Chu, Y. "Optimal Capital Structure, Bargaining, and the Supplier Market Structure." *Journal of Financial Economics*, 106 (2012), 411-426.

Cohen, L., K. Diether, and C. Malloy. "Misvaluing Innovation." *Review of Financial Studies*, 26 (2013), 635-666.

Davydenko, S., I. Strebulaev, and X. Zhao. "A Market-based Study of the Cost of Default." *Review of Financial Studies,* 25 (2012), 2959-2999.

Donangelo, A. "Labor Mobility: Implications for Asset Pricing." *Journal of Finance*, 69 (2014), 1321-1346.

Foster, L., J. Haltiwanger, and C. Syverson. "Reallocation, Firm Turnover, and Efficiency: Selection on Productivity or Profitability?" *American Economic Review*, 98 (2008), 394–425.

Ghoul, S., O. Guedhami, C. Kwok, and X. Zheng. "Zero-Leverage Puzzle: An International Comparison." *Review of Finance,* 22 (2018), 1063-1120.

Goldstein, R., N. Ju, and H. Leland. "An EBIT-Based Model of Dynamic Capital Structure." *Journal of Business*, 74 (2001), 483–512.
Graham, J. "How Big Are the Tax Benefits of Debt?" *Journal of Finance*, 55 (2000), 1901-1941.
Graham, J. and M. Leary. "A Review of Empirical Capital Structure Research and Directions for the Future." *Annual Review of Financial Economics,* 3 (2011), 309 -345.
Gu, L. "Product Market Competition, R&D Investment, and Stock Returns." *Journal of Financial Economics*, 119 (2016), 441–455.
Hackbarth, D. and J. Miao. "The Dynamics of Mergers and Acquisitions in Oligopolistic Industries." *Journal of Economic Dynamics and Control*, 36 (2012), 585-609.
Hall, B. and J. Lerner. Handbook of the Economics of Innovation, Elsevier-North-Holland, chap. The Financing of R&D and Innovation, (2010).
Hanka, G. "Debt and the Terms of Employment." *Journal of Financial Economics*, 48 (1998), 245-282.
He, Z. "A Model of Dynamic Compensation and Capital Structure." *Journal of Financial Economics*, 100 (2011), 351-366.
Heider, F. and A. Ljungqvist. "As Certain as Debt and Taxes: Estimating the Tax Sensitivity of Leverage from Exogenous State Tax Changes." *Journal of Financial Economics*, 118 (2015), 684-712.
Hoch, S., B. Kim, A. Montgomery, and P. Rossi. "Determinants of Store-Level Price Elasticity." *Journal of Marketing Research*, 32 (1995), 17-29.
Islam, E. and J. Zein. "Inventor CEOs." *Journal of Financial Economics,* 135 (2020), 505-527.
Israelsen, R. and S. Yonker. "Key Human Capital." *Journal of Financial and Quantitative Analysis,* 52 (2017), 175-214.
Ju, N., R. Parrino, A. Poteshman, and M. Weisbach. "Horses and Rabbits? Trade-Off Theory and Optimal Capital Structure." *Journal of Financial and Quantitative Analysis,* 40 (2005), 259-281.
Ju, N. and X. Wan. "Optimal Compensation and Pay-Performance Sensitivity in a Continuous-Time Principal-Agent Model." *Management Science,* 58 (2012), 641 -657.
Klette, T. and S. Kortum. "Innovating Firms and Aggregate Innovation." *Journal of Political Economy,* 112 (2004), 986-1018.
Kogan, L., D. Papanikolaou, A. Seru, and N. Stoffman. "Technological Innovation, Resource Allocation, and Growth." *Quarterly Journal of Economics,* 132 (2017), 665-712.
Korteweg, A. "The Net Benefits to Leverage." *Journal of Finance*, 65 (2010), 2137-2170.
Kumar, P. and V. Yerramilli. "Optimal Capital Structure and Investment with Real Options and Endogenous Debt Costs." *Review of Financial Studies,* 31 (2018), 3452-3490.
Kusnadi, Y. and K. C. Wei. "The Equity-Financing Channel, the Catering Channel, and Corporate Investment: International Evidence." *Journal of Corporate Finance,* 47 (2017), 236-252.
Leland, H. "Corporate Debt Value, Bond Covenants, and Optimal Capital Structure." *Journal of Finance*, 49 (1994), 1213-1252.

Leland, H. "Agency Costs, Risk Management, and Capital Structure." *Journal of Finance*, 53 (1998), 1213-1243.

Lentz, R. and D. Mortensen. "An Empirical Model of Growth through Product Innovation." *Econometrica,* 76 (2008), 1317–1373.

Levin, R. and P. Reiss. "Cost-Reducing and Demand-Creating R&D with Spillovers." *RAND Journal of Economics*, 19 (1988), 538–556.

Li, D. "Financial Constraints, R&D Investment, and Stock Returns." *Review of Financial Studies*, 24 (2011), 2974–3007.

Lin, X. "Endogenous Technological Progress and the Cross Section of Stock Return." *Journal of Financial Economics*, 103 (2012), 411-427.

Liu, T., Y. Mao, and X. Tian. "The Role of Human Capital: Evidence from Patent Generation." working paper, University of Pennsylvania, Cornell University, and Tsinghua University (2017).

Lustig, H., C. Syverson, and S. Nieuwerburgh. "Technological Change and Growing Inequality in Managerial Compensation." *Journal of Financial Economics*, 99 (2011), 601–627.

Malamud, S. and F. Zucchi. "Liquidity, Innovation and Endogenous Growth." *Journal of Financial Economics,* 132 (2019), 519-541.

Matsa, D. "Capital Structure as a Strategic Variable: Evidence from Collective Bargaining." *Journal of Finance*, 49 (2010), 1197-1232.

Miao, J. "Optimal Capital Structure and Industry Dynamics." *Journal of Finance,* 60 (2005), 2621-2659.

Michaels, R., T. Beau Page, and T. Whited. "Labor and Capital Dynamics under Financing Frictions." *Review of Finance,* 23 (2019), 279-323.

Miller, M. "Debt and Taxes." *Journal of Finance*, 32 (1977), 261-275.

Morellec, E. "Asset Liquidity, Capital Structure, and Secured Debt." *Journal of Financial Economics,* 61 (2001), 173-206.

Mukherjee, A., M. Singh, and A. Zaldokas. "Do Corporate Taxes Hinder Innovation?" *Journal of Financial Economics,* 124 (2017), 195-221.

Pennetier, C., K. Girotra, and J. Mihm. "R&D Spending: Dynamic or Persistent?" *Manufacturing and Service Operations Management,* 21 (2019), 636-657.

Pichler, P., A. Stomper, and C. Zulehner. "Why Leverage Affects Pricing?" *Review of Financial Studies*, 21 (2008), 1733-1765.

Simintzi, E., V. Vig, and P. Volpin. "Labor Protection and Leverage." *Review of Financial Studies*, 28 (2015), 561-591.

Smolny, W. "Innovations, Prices, and Employment: A Theoretical Model and an Empirical Application for Western German Manufacturing Firms" *Journal of Industrial Economics*, 46 (1998), 359-381.

Stigliz, J. "Credit Market and Capital Control." *Journal of Money, Credit, and Banking*, 17 (1985), 133-152.

Strebulaev, I. "Do Tests of Capital Structure Theory Mean What They Say?" *Journal of Finance*, 62 (2007), 1747-1787.

Strebulaev, I. A. and B. Yang. "The Mystery of Zero-Leverage Firms." *Journal of Financial Economics,* 109 (2013), 1-23.

Van Binsbergen, J., J. Graham, and J. Yang. "The Cost of Debt." *Journal of Finance*, 65 (2010), 2089-2136.