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Los Angeles

**Human Capital Investment, Cash Flow Risk and  
Capital Structure Dynamics**

A dissertation submitted in partial satisfaction  
of the requirements for the degree  
Doctor of Philosophy in Management

by

**Xiaolan Zhang**

2014

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ABSTRACT OF THE DISSERTATION

**Human Capital Investment, Cash Flow Risk and  
Capital Structure Dynamics**

by

**Xiaolan Zhang**

Doctor of Philosophy in Management

University of California, Los Angeles, 2014

Professor Hanno Lustig, Chair

My dissertation explores the financial effects of firms growing reliance on intangible capital in their production technology. I examine the fundamental link between the cash flow risk, financial decision-making and the accumulation of firm-level intangible capital both in theory and in empirics.

In chapter one, I document that public firms in the United States that provide better insurance against productivity shocks to their workers experience higher cash flow volatility. Difference in intra-firm risk sharing between workers and capital owners accounts for more than 50% of the variation in firm-level cash flow volatility. I develop a theory in which wages can act either as a hedge or as leverage, depending on the history of the productivity shocks the firm has faced. Heterogeneous roles of workers in the firm are derived by analyzing the dynamic equilibrium wage contracts between risk-neutral owners and risk-averse workers who can leave with a fraction of the accumulated human capital. Owners of the firm will optimally bear more risk when the current value of the firm's human capital is lower than the peak value it has reached. The model successfully explains the joint distribution of cash flow volatility and the wage-output sensitivity. Also, the model produces predictions for the dynamics of cash flow volatility that are consistent with the time series properties of the firm-level data.

In chapter two, we provide the theoretical and empirical analysis on firms dynamic capital structure decision with the presence of intangible capital accumulation. In the US publicly traded firm sample, the intangible capital investment is financed mainly through employee-initiated equity issuance. We propose a theory in which firms issue self-enforcing debt contracts to external investors and also offer long-term wage contracts to the employees with limited commitment. We show that the long-term wage contract optimally serves as financing instrument for the shareholders. Firms dynamically trade off between financial debt and employee financing until their intertemporal marginal rates of substitution are equal. The accumulation of intangible capital in the production imposes two effects on the financial structure: precautionary effect and intangible capital overhang effect. The structural estimation indicates the dominating effect of intangible capital overhang. Identifying the different financing channels provide a new solution to the contrasting secular trend in corporate net debt ratio and the firms' increasing importance on intangible capital in the production.

The dissertation of Xiaolan Zhang is approved.

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# CHAPTER 1

## Who Bears Firm-Level Risk?

### Implications for Cash Flow Volatility

#### 1.1 Introduction

Cash flow risk has long been a topical and challenging question for finance academia. Firm-level cash flow volatility of U.S. public firms has increased over the past five decades (Comin and Philippon (2005), Irvine and Pontiff (2009a), Kelly et al. (2012), etc.). In particular, the fraction of the firm's final output accrued to its capital owners has also become more volatile. Figure 1.2 presents the time series of firm-level volatility of the cash flow-to-sales ratio. This measure of cash flow volatility has doubled<sup>1</sup> over the period 1960-2010. Moreover, it exhibits very different growth patterns cross-sectionally over the same time. Firms in the information, computer and technology industry experienced the largest cash flow volatility increase of more than 100%, while firms in the consumer goods industry experienced a relatively mild 20% increase. This cross-industry heterogeneity in growth patterns indicates that the intra-firm risk allocation between its claimholders must be changing in different ways for each industry. As the most senior output claimholder of the firm, workers should have first order importance in understanding the capital owners' cash flow risk.

In this paper, I develop a theory in which labor can act either as a leverage or

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<sup>1</sup>The result is robust when using the corporate earnings as the measure of cash flows, and the percentage change of earnings' growth volatility is more than 200% since 1950 (Irvine and Pontiff (2009a)).

hedge to the cash flow risk, depending on the history of the productivity shocks the firm has faced. Risk neutral capital owners invest in the firm-level human capital of the workers. To retain the risk averse workers, who are embedded with human capital but cannot commit to the wage contract. This limited commitment on the labor side leads to the contract derived by Harris and Holstrom (1982): the owners offer the optimal wage contract with the downward-rigid property. Depending on the history of the productivity shocks, the downward-rigid wage contracts either provide perfect insurance to the workers or meet their outside options. When perfect insurance is achieved, wage contracts, just as debt contracts, lever the cash flow risk. When capital owners have to offer higher compensation to meet the outside option, wage contracts hedge productivity risk for the owners since wage contracts comove with firms' output. The different ways in which optimal wage contracts respond to productivity shocks drive the dynamics of risk allocation between the owners and the workers within the firm.

The dynamics of optimal wage contract is completely captured by two state variables: the current human capital level and the historical maximum level of the human capital. Unlike Harris and Holstrom (1982), due to the partial portability of firm-level human capital, the history of productivity shocks affects the worker's outside option through the accumulation path of firm-level human capital. The equilibrium "effective" outside option is determined by the firm's historical maximum of human capital. Firms optimally offer the downward-rigid wage contract to trade off between incentives and insurance. When the worker's current human capital level is higher than the historical maximum, causing a positive change in her outside option, the owner benefits from retaining the current worker and raising her wage by the smallest possible amount. With a positive wage-output sensitivity, the wage contract acts as a "hedging" device to the owner's cash flow risk. On the other hand, the current human capital level can be lower than the historical maximum level, and the outside option is lower than what the current

wage contract is offering, the optimal wage contract provides perfect insurance to the worker. With a zero wage-output sensitivity, wage contracts act as a rigorous “debt” contract and transfer total output into a volatile cash flow. Moreover, the competitive equilibrium determines a concave outside option as a function of accumulated firm-level human capital. The concavity leads to heterogeneous degrees of risk allocation whenever a firm achieves a new historical maximum of human capital.

In the competitive equilibrium with firm dynamics, the joint distribution of wage-output sensitivity and cash flow risk is determined by the joint distribution of current and historical firm-level human capital accumulation. Cash flow volatility is low and wage-output sensitivity is high when current human capital level exceeds the historical maximum. Cash flow volatility is high and wage-output sensitivity is low when the worker’s current human capital level is below the historical maximum. When wage contracts hedge the cash flow risk, firms with a higher historical maximum of human capital have lower wage-output sensitivity and higher cash flow volatility.

Quantitatively, the model produces predictions that are consistent with the cross-sectional and time-series evidence on the joint distribution of cash flow volatility and wage-output sensitivity. Cross-sectionally, the wage-output sensitivity explain a significant fraction of the cross sections of the firm-level cash flow volatility. More than 50% of firm-level cash flow volatility is explained by the changing risk sharing patterns within the firm. The calibrated model produces the same scale of cash flow volatility variation and also matches the joint distribution of firm-level cash flow volatility and wage-output sensitivity with the data. I further evaluate the model’s implications on the driving force of the intra-firm risk sharing dynamics. I find that the higher historical maximum of firm-level human capital predicts (conditionally) lower wage growth and lower wage-output sensitivity, but higher cash flow volatility. The joint distribution of the historical



maximum of firm-level human capital and cash flow volatility in the data lines up with the model prediction through the link of the wage-output sensitivity.

In time series, the time-varying intra-firm risk allocation provides a novel explanation of the increasing firm-level cash flow volatility. The average wage-output sensitivity decreases 38% over the period from 1960 to 2010, which suggests that workers were getting better insurance in U.S. public firms over time. On average, the estimated historical maximum firm-level human capital is growing over the same period. The historical human capital accumulation path explains the incremental cash flow volatility through the channel of intra-firm risk allocation. The historical maximum firm-level human capital increases most dramatically in information, computer and technology industry, as does its average cash flow volatility at the firm level. This industry also experiences the largest decline (more than 60%) in wage-output sensitivity. However, in consumer goods and manufacturing industries, I didn't find a significant positive trend either in the historical maximum firm-level human capital or in the average wage-output sensitivity at the industry level.

Finally, I conduct the panel analysis and confirm model's implications in the data. I generate the following three main empirical implications: 1) a positive relationship between the historical maximum of firm-level human capital and wage contracts; 2) a negative relationship between compensation sensitivity and the maximal firm-level human capital conditionally; 3) a positive relationship between cash flow volatility and maximum firm-level human capital. The history dependence of the cross-sectional pattern of risk allocation between workers and capital owners is sizable and significant in the data. Unconditionally, one standard deviation increase in the historical maximum human capital level leads to a 30% change in cash flow volatility.

**Literature Review** This paper contributes to the literature on firm-level volatility dynamics (e.g., Malkiel et al. (2001), Comin and Philippon (2005), Comin and Mulani (2006), Irvine and Pontiff (2009b), Kelly et al. (2012), etc.). Robust evidence is found (Comin and Philippon (2005)) on the increase in firm-level volatility using different real measures and financial data, while my paper explores and documents the increasing trend in firm-level cash flow (accrued to its capital owners). Comin and Mulani (2009) explain the dynamics of productivity volatility with an endogenous growth model that predicts an endogenous increase in the share of resources spent on innovation. Kelly et al. (2013) propose a model of firm volatility based on customer-supplier networks. My paper takes a novel intra-firm perspective and is the first that links wage contract dynamics to cash flow volatility both theoretically and empirically. Empirical effort has also been made to understand the firm-level labor income risk in the literature. Guiso et al. (2005) evaluates the allocation of risk between firms and their workers using matched employer-employee panel data. Comin et al. (2009) relates firm-level volatility to wage volatility using both firm-level and worker-level dataset. Also, Lagakos and Ordonez (2011) are among the few to examine which workers get insurance within the firm using industry-level data, but my paper proposes the leverage effect of wage contracts which few have yet emphasized in the literature on firm-level volatility.

This paper combines the organizational capital theory (Atkeson and Kehoe (2005), Jovanovic and Rousseau (2008), etc.) with dynamic implicit wage contract in a production-based framework. Theoretically, the optimal wage contract in my paper shares the downward-rigid property as in the seminal papers (Harris and Holstrom (1982), Thomas and Worrall (1988), etc) in which, however, cash flow is exogenous and does not interact with the optimal contracting decision. Lustig et al. (2011) is the first study to relate production to implicit labor contracts to shed light on CEO compensation inequality. Eisfeldt and Papanikolaou (2013) model

the effect of the outside option of key talents on the systematic cash flow risk that shareholders face. Ai et al. (2013) model the equilibrium mechanism design with limited commitment to explain the inequality in CEO compensation. In contrast, I explore the endogenous relationship between organization capital accumulation and the wage contract stickiness. My paper also contributes to the empirical literature on wage structure at the firm level. Baker et al. (1994) use an employee-employer matched database for a single firm and find that employees are partly shielded against changes in external market conditions. Wachter and Bender (2007) find the persistent cohort effect on wages within the firm. Beaudry and DiNardo (1991) show that there is a time-varying degree of risk sharing between workers and firms at the time of entry. My model implications are consistent with the empirical evidence on wage structure in the existing literature, and provides additional insights into the second moment of wage structure.

This paper is related to both the empirical and theoretical corporate finance literature that focuses on the optimal compensation scheme and the interaction between financial decisions and agency frictions (e.g., He (2011), Demarzo et al. (2012)). I study dynamic wage contracts with limited commitment, similar to Berk et al. (2010), to generate the labor-induced operating leverage effect. Different from Berk et al. (2010), where the amount of risk sharing between investors and employees depends on the debt level, the degree of risk sharing in my paper depends on the high-water mark of human capital reached in the firm's entire history. Michelacci and Quadrini (2009) study the long-term wage contract in the financially constraint firms and find a positive relationship between firm size and wages. My model produce predictions consistent with Michelacci and Quadrini (2009) but with emphasis on implications for wage-output sensitivity and cash flow volatility. There is rising attention on labor in empirical corporate finance. Garmaise (2008) and Benmelech et al. (2011) among others, study the interaction between firms' employment decisions and financial frictions. Tate and Yang

(2013) estimate the labor market consequences of corporate diversification using worker-firm matched data. My paper suggests implications concerning the inefficiency of human capital investment at the firm level and provides a novel link between corporate investment and labor compensation. Related to the empirical work starting with Jensen and Murphy (1990), my model produces a stickier performance-pay wage contract that survives the empirical tests.

This paper also incorporates several successful themes from the emerging literature that examines the relation between labor market frictions and asset returns. Berk and Walden (2013) examines the interplay between labor income risk and equity market risk. In their study, owners of the firm offer labor contracts to insure workers' human capital risk, and hence the limited capital market participation arises as an equilibrium outcome. My paper assumes exogenous nonparticipation in the capital markets and focuses on the implications for intra-firm risk sharing. The leverage effect of wage stickiness has been shown by Danthine and Donaldson (2002), Favilukis and Lin (2012) and Favilukis and Lin (2013), who document the importance of labor leverage in explaining equity premium. In a competitive labor market setting, Gourio (2008) shows the empirical implications of sticky wages for the cross-sectional differences in return as well. Donangelo (2013) studies that labor mobility amplifies the firms' existing exposure to systematic risk. In my paper, I emphasize the heterogeneity in the corporate rent-splitting and endogenize the elasticity of wage to output by the implicit wage contracts. Eisfeldt and Papanikolaou (2013) also explore the division of surplus between key talent and shareholders with the accumulation of organizational capital. In their paper, the dynamics of the rent splitting depend on the current level of frontier technology, but not on the historical accumulation path of organization capital. The unmeasured capital is also modeled in Jovanovic and Rousseau (2008) with an emphasis on the managerial function of assembling heterogeneous assets. The specificity of human capital creates rents in the assembly in Jovanovic and Rousseau (2008),

but their model does not imply the division of rents between different claimholders of the firm.

## 1.2 The Model

I construct an competitive industry equilibrium model in the tradition of Hopenhayn (1992) and Gomes (2001), augmented with human capital and implicit labor contract. I start with a simple version of the model that features only human capital accumulation and production to illustrate the key dynamics of cash flows and wage contracts.

### 1.2.1 The Environment

The production economy consists of two sectors: capital owners and workers. A continuum of firms is owned by risk neutral capital owners who have limited liability, while a continuum of workers is risk averse and cannot participate in the financial market<sup>2</sup> and have no access to a storage technology. Both the owners and the workers have the same discount factor  $\beta$ . The labor contract is the only source of consumption smoothing for the risk averse agent.

**Firm Behavior** Production requires two inputs, capital  $h_t$  and labor  $l_t$ , and is subject to an idiosyncratic technology shock,  $z_t \sim Q(z_t|z_{t-1})$ :

$$y_t = e^{z_t} f(h_t, l_t). \tag{1.1}$$

---

<sup>2</sup>Berk and Walden (2013) studies the limited participation in the capital markets as an optimal equilibrium outcome in a production economy.

The production function  $f(\cdot)$  is well-defined<sup>3</sup> and displays decreasing return to scale. The output is homogeneous. Assumption 1 and 2 concern the nature of the productivity shock.

**Assumption 1** (a) *The stochastic process for the idiosyncratic shock  $z$  has bounded support  $\mathcal{Z} = [\underline{z}, \bar{z}]$ ,  $-\infty < \underline{z} < \bar{z} < \infty$ ; (b) the idiosyncratic shocks follow a common stationary and increasing Markov transition function  $Q(z_t|z_{t-1})$  that satisfies the Feller property; (c) the productivity shock  $z_t$  is independent across firms.*

For the sake of simplicity, I normalize the overall labor force of the firm equal to one ( $l_t = 1$ ); hence human capital  $h_t$  can be interpreted as the productivity per worker. An active firm is equivalent to a match of capital  $h_t$  and one worker. The space of capital input is a subset of the non-negative bounded real numbers,  $\mathcal{H} \in [h_{\min}, \infty)$ , and  $h_{\min} \in \mathcal{R}$  is the general human capital (e.g., education) embodied in the worker at the beginning of the match. The match-level human capital is  $h_t \in \mathcal{H}$ . The accumulation law of capital  $h_{t+1}$  for the next period follows the traditional investment function  $I_t$ :

$$I_t = h_{t+1} - (1 - \delta_h)h_t, \quad \delta_h \in (0, 1), \quad (1.2)$$

where  $\delta_h$  is the depreciation rate of human capital.

The match-level human capital accumulation is not completely exclusive to the worker.<sup>4</sup> Unlike the standard neoclassical investment model, this paper emphasizes the sharing property of match-level human capital.

**Assumption 2 (*Portability*)** *The fraction of match-level human capital  $\phi h_t$  is portable with the worker when the separation of capital and labor happens,  $0 < \phi < 1$ .*

---

<sup>3</sup>Production is carried out under the well-defined space, which is strictly increasing, strictly concave, twice continuously differentiable, homogeneous, and constant return to scale, and satisfies Inada conditions.

<sup>4</sup>For example, the “skill-weights” view suggested by Lazear (2009).

Due to the partial *portability* of human capital, the capital is most efficient in the match where it was accumulated, although it can also be partially adopted by other firms ( $\phi < 1$ ).

I summarize the firm's decision by first writing down the cash flow process:

$$CF_t = e^{z_t} f(h_t) - w_t - I_t^h - s, \quad (1.3)$$

where  $s$  is the fixed production cost for each period. Each firm maximizes the discounted cash flow stream over its life cycle:  $E_0[\sum_{s=t}^{\infty} \beta^{s-t} CF_s | z_0]$ .

**Labor Market** A continuum of workers are risk averse and infinitely-lived. Each period, workers consume their wages, but they have *limited commitment* to the wage contracts. Workers can always walk away whenever an outside option is higher than the contract provided by the match. The owners have full commitment to the wage contracts, but with limited liability. Owners commit to a complete contingent optimal contract at the start of the match  $\{w_t(z^t), \eta_t(z^t)\}_{t=0}^{\tau}$ , where  $z^t$  denotes the history of shocks,  $z^t = \{z_t, z_{t-1}, \dots\}$ ,  $\eta_t$  is an indicator function that governs the optimal decision of dissolving the match, and  $\tau$  is the optimal time of termination. Here, for tractability, I assume that the contingent optimal contract cannot be negotiated ex post.<sup>5</sup>

Subject to Assumption 2, the labor mobility cost between firms is captured by  $1 - \phi$ , where  $\phi$  is an exogenous parameter and may vary across industries, so the optimal wage contract must be self-enforcing. I provide a simple characterization of the optimal contract following Thomas and Worrall (1988), but with an endogenous equilibrium outside option.

The optimal contract maximizes the total expected payoff of the owner, subject

---

<sup>5</sup>In some states where the match is terminated, the contract does leave room for renegotiation as long as the turnover is also costly for the worker ( $\phi < 1$ ).

to delivering initial utility  $\varphi_0$  to the workers:

$$\varphi_0(z^0) = E_0\left[\sum_0^{\infty} \beta^t u(w_t(z^t))\right].$$

To make the problem recursive, the worker's promised expected utility is treated as a new state variable. The optimal contract delivers  $\varphi_t$  today by delivering current wage  $w_t$  and a state-contingent promised expected utility  $\varphi_{t+1}$  tomorrow. The owners commit to deliver  $\{w_t, \varphi_{t+1}(z_{t+1}, h_{t+1}, \eta_{t+1})\}$  each period, where  $\varphi_{t+1}(z_{t+1}, h_{t+1}, \eta_{t+1})$  is defined as:

$$\varphi_t(z_t, h_t, \eta_t) = E_t\left[\sum_{s=t}^{\infty} \beta^{s-t} u(w_s(z^s, h^s, \eta^s))\right]. \quad (1.4)$$

The domain of feasible promised utility  $\Phi = [\underline{\varphi}, \bar{\varphi}]$  is defined in Appendix 1.7.1. The capital owners have to keep their promises by setting up the following promise-keeping constraint:

$$\varphi_t = u(w_t) + \beta \int \eta_{t+1} \varphi_{t+1} Q(dz_{t+1}|z) + \beta \int (1 - \eta_{t+1}) \varphi_{res,t+1} Q(dz_{t+1}|z). \quad (1.5)$$

Given workers' limited commitment and the partial portability of match-level human capital, the optimal contract should provide retention incentives. Let  $\varphi_{res,t+1}$  denote the workers' reservation utility, which is defined as the outside option of the workers; thus, the contingent promised utility has to be higher than  $\varphi_{res,t+1}$  for any realized state at  $t + 1$ . The participation constraint of the workers is given by:

$$\varphi_{t+1} \geq \varphi_{res,t+1}(\phi h_{t+1}, z_{t+1}, \eta_{t+1}), \quad \forall z_{t+1} \in \mathcal{Z}, \quad \forall h_{t+1} \in \mathcal{H}. \quad (1.6)$$

The contract offers as high as the worker's outside option, which is an equilibrium outcome from firm dynamics.



**Exit, Entry and Firm Dynamics** The entry and exit of the firm is defined as the formation and termination of the capital-labor match respectively. The timing of firms' entry and exit decision is shown in Figure 1.1.

In any given period, the owner of each incumbent firm decides whether to exit or stay *before* the shock ( $z_{t+1}$ ) is observed (see Gomes (2001)). Hence, incumbents know in advance whether or not to exit in the next period, and the exit is completely determined by the current productivity shock  $z_t$ . The indicator variable  $\eta_{t+1}$  is one if continuation is optimal and zero otherwise:

$$\eta_{t+1} = \begin{cases} 1, & \text{if } z_t \geq \max[z_t^*, \underline{z}] \\ 0, & \text{otherwise,} \end{cases} \quad (1.7)$$

where  $z^*$  is the threshold value that satisfies  $E_t[\sum_{s=t}^{\infty} \beta^{s-t} CF_s(z_s, h_s, \eta_s) | z_t] = 0$ . If  $\eta_{t+1} = 0$ , the match is terminated, and the owner earns zero profit and will stay out of the market forever. If  $\eta_{t+1} = 1$ , the owner chooses the investment decision and the wage contract by maximizing the discounted cash flows over the life cycle.

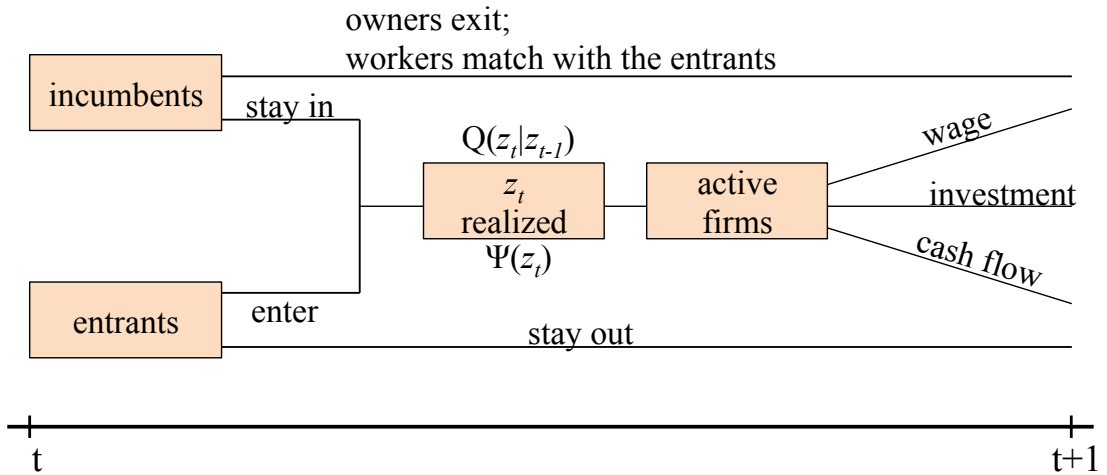


Figure 1.1: Timing of Exit and Entry

At the same time, there is a continuum of potential entrants (capital owners) who determine whether or not to enter the economy at the beginning of each

period. They make their entry decisions *before* the idiosyncratic shocks are realized. Each period, the entrants draw their initial level of  $z$  independently from a common distribution  $\Psi(z)$ . The initial level of  $z_0$  is drawn from  $\Psi(z)$  to ensure substantial heterogeneity in productivity across all new entrants. Upon entry, owners incur a fixed sunk cost  $F$ .<sup>6</sup>

The turnover of workers happens when the incumbent firm exits. Workers from the dissolved matches will be employed by the potential entrants before  $z_t$  is realized with an initial human capital level  $h_t = \max[\phi h_{t-1}, h_{\min}]$ . The competitive entry condition determines the outside option  $\varphi_{res,t}$ .

### 1.2.1.1 The Firm's Optimization Problem

If the capital-labor match dissolves, the owner realizes zero value forever. Hence, the interesting case that remains is the optimal compensation and investment decision of the incumbent firms.

The dynamic formulation of each incumbent firm's problem can be written in a recursive form in which the state variables are  $\{h, \varphi, z\} \in \mathcal{H} \times \Phi \times \mathcal{Z}$  and subject to constraints from capital accumulation and labor market friction. Define  $V(h, \varphi; z)$  as the value of a firm that has a capital stock of  $h$ , promised utility to the worker  $\varphi$ , and productivity  $z$ . Both owners and workers discount the future by a common factor  $\beta$ . Given  $\eta_{t+1} = 1$ , the dynamic problem  $\mathcal{P}$  facing the owner of each incumbent is:

$$V(h, \varphi; z) = \max_{h_{t+1}, \varphi_{t+1}, w; z_{t+1}|z} \left( CF_t + \beta \int V(h_{t+1}, \varphi_{t+1}; z_{t+1}) Q(dz_{t+1}|z) \right) \quad (1.8)$$

---

<sup>6</sup>For entrants, the workers they hire are the ones from last period's dissolved matches, or any other laid-off workers from other matches in the previous periods. The supply of labor is inelastic in the model.

subject to:

$$CF_t = \exp(z_t)f(h_t) - w_t - I_t, \quad (1.9)$$

$$I_t = h_{t+1} - (1 - \delta_h)h_t, \quad \delta_h \in (0, 1), \quad (1.10)$$

$$\varphi_t = u(w_t) + \beta \int \varphi_{t+1} Q(dz_{t+1}|z), \quad (1.11)$$

$$\varphi_{t+1} \geq \varphi_{res,t+1}(\phi h_{t+1}, z_{t+1}), \quad \forall h_{t+1} \in \mathcal{H}, \quad \forall z_{t+1} \in \mathcal{Z}. \quad (1.12)$$

Constraint (1.9) is the budget constraint for the capital owner; constraint (1.10) is the law of motion of human capital; and constraint (1.11) is the promise-keeping constraint. Since the incumbent has made the decision regarding  $\eta_{t+1}$  before solving  $\mathcal{P}$ , constraint (1.11) is the version of equation (1.5) with  $\eta_{t+1} = 1$ . The participation constraint (1.12) is contingent on the endogenous state  $h_{t+1}$ . This is the main difference from the literature on the risk-sharing contract with one-sided commitment. The model allows for dynamic contracting to interact with the firm's investment behavior. The more the firm invests, the higher the worker's outside option as the firm grows.

The limited commitment on the part of workers and the endogenous exit decision complicate the dynamic programming considerably. However, I show that there exists a unique solution to problem  $\mathcal{P}$  characterized in the Lemma 1 and 2.

**Lemma 1** *Given the outside option  $\varphi_{res}(\phi h) \in [\underline{\varphi}, \bar{\varphi}]$ , the solution  $V(h, \varphi, z)$  to the Bellman equation  $\mathcal{P}$  exists. The value function is strictly monotone, concave, continuous and differentiable in  $\varphi$  and  $h$ .*

**Proof.** See Appendix 1.7.2. ■

**Lemma 2** *Given the initial  $\varphi_0$ , the optimal contract  $\{w_t, \varphi_{t+1}\}$  and policy function of  $h$  is unique and continuous.*

**Proof.** See Appendix 1.7.2. ■ The risk averse worker is willing to accept a lower

expected wage in exchange for a smoother income stream. The capital owner can make a profit by paying a wage lower than the competitive wage when the productivity shock is positive and vice versa. This is an implicit leverage effect generated by the self-enforcing wage contract. The leverage effect consists of two parts. (1) Since the contract wage will be lower than the competitive spot market wage, more room for profit is left to the capital owners; (2) the wage will be stickier than the competitive market wage, and the stickiness is history-dependent. The intra-firm risk allocation is governed by the strength of the implicit leverage effect.

### 1.2.1.2 Aggregation and Equilibrium

In the competitive equilibrium, free entry stipulates that the equilibrium value of a new match of labor and capital is equal to the entry cost:

$$\int V_t(\phi h_t, \varphi_{res}(\phi h_t), z) \Psi(dz) \leq F. \quad (1.13)$$

This equilibrium condition indicates that the total utility assigned to the new worker with  $\phi h$  is the value that makes the new firm zero expected profit. Therefore, this equilibrium condition determines the outside option  $\varphi_{res}$  in equilibrium. Since the entry decision at time  $t$  is made before the realization of productivity  $z_t$ , the equilibrium outside option is independent of  $z$ , but is only a function of capital level  $\varphi_{res}(\phi h)$ . The timing simplifies the optimal decision-making process as the dimension of participation constraints in  $\mathcal{P}$  is equal to that of the state space  $\mathcal{H}$ .

I characterize the aggregate variables for this economy as follows. Let  $\mu(h, \varphi, z)$  denote the measure of the mass of firms in the state  $(h, \varphi, z)$ . Let  $\Gamma_t$  denote the aggregate law of motion for the measure  $\mu$  and the state variables at time  $t$ . In the invariant industry equilibrium, the mass of new entry equals the mass of the exit in that same period. See Appendix 1.7.1 for the details. The stationary industry

equilibrium is defined as follows.

**Definition 1 *Stationary Industry Equilibrium*** *A stationary recursive equilibrium is a value function  $V(h, \varphi, z)$ , policy function  $h'$  and  $\varphi'$ , outside option  $\varphi_{res} : \mathcal{H} \rightarrow [\underline{\varphi}, \bar{\varphi}]$ , a positive measure of the law of motion of state variables  $\Upsilon$ , and the measure of firms  $\mu$  on the Borel sets of  $\mathcal{H} \times \Phi \times \mathcal{Z}$ :*

1. (Agent Optimality)

(a) (Continuing Firms): *Given  $\varphi_{res,t+1}$  for all  $h' \in \mathcal{H}$ ,  $V$  solves the dynamic programming problem  $\mathcal{P}$ , and  $h'$  and  $\varphi'$  are the associated policy functions.*

(b) (Exiting Firms): *The exit decision is summarized by condition (1.27).*

2. (Outside Option): *For all  $h' \in \mathcal{H}$ :*

$$\varphi_{res} \in \arg \max_{\varphi} \left\{ \varphi \int V(\max[\phi h, h_{\min}], \varphi) \Psi(dz) \leq F \right\}. \quad (1.14)$$

3. (Stationary Distribution) *Define the measure  $\mu$  such that  $\forall (h, \varphi, z)$ ,  $\mu(h, \varphi, z)$  denotes the mass of firms in state  $(h, \varphi, z)$ , and define  $\Upsilon$  following equation (1.24). In equilibrium,*

$$(\Upsilon, \mu) = H(\Upsilon, \mu).$$

The following proposition summarize the equilibrium properties.

**Proposition 1** *The stationary equilibrium exists and the equilibrium outside option is strictly increasing and concave in  $h$ .*

**Proof.** See Appendix 1.7.4. ■

The nonlinearity of the outside option gives a very distinct impulse response to the productivity shocks, given different human capital accumulation paths. The

heterogeneous degree of risk sharing between workers and capital owners arises endogenously across firms.

### 1.3 Equilibrium Risk Allocation

Perfect consumption-smoothing breaks with limited commitment and firm dynamics. In this section, I describe the heterogeneous degree of stickiness of the wage contracts in the equilibrium. Two state variables summarize all necessary information for risk sharing in equilibrium: the current level of human capital  $h_t$  and the historical maximal level of human capital:  $h_{\max,t-1} = \max\{h_{s-1}, s = 1 \dots t\}$ .

#### 1.3.1 Optimal Wage Contract

Given the existence of the equilibrium, I first characterize the dynamics of the wage contract in Proposition 2.

**Proposition 2 (Downward-Rigidity)** *Given the initial wage contract  $\{w_0, \varphi_0\}$  and  $z_t \geq \max[z^*, \underline{z}]$ , the maximum of human capital  $h_{\max,t} = \max\{h_s, s \leq t\}$  is the sufficient statistic of the equilibrium wage.*

**Proof.** See Appendix 1.7.4. ■

As in Harris and Holstrom (1982), proposition 2 implies that only the maximum level of  $h_t$  impacts the wage level as long as the firm stays in the economy.  $h_{\max,t}$  governs how much the capital owner needs to transfer to the worker in the optimal contract, and the wage contract is reset whenever  $h_{\max,t} > h_{\max,t-1}$ .

The perfect risk sharing wage contract provides smooth consumption over time ( $\frac{1}{u'(w_t)} = \frac{1}{u'(w_{t+1})}$ ), and the lagged inverse marginal utility (LIMU),  $\frac{1}{u'(w_t)}$ , contains the only relevant information in forecasting next period's wage level,  $w_{t+1}$ . When perfect consumption-smoothing is constrained by limited commitment, LIMU is no longer sufficient to determine the next period's wage. The Euler equation is

obtained under limited commitment:

$$\frac{1}{u'(w_{t+1})} = \frac{1}{u'(w_t)} - \theta_t(h_{t+1}), \quad (1.15)$$

where  $\theta_t(\cdot)$  is the Lagrangian multiplier of the participation constraint (1.12). Conditional only on  $\theta_t(\cdot)$ , the shadow price of the promised utility at time  $t + 1$ , LIMU is sufficient for predicting the next period's wage level. The wage contract is reset to the higher level whenever the participation constraint is binding; it remains at the same level when the participation constraint is not binding. The shadow price of the promised utility  $\theta_t(\cdot)$  becomes positive only when workers' outside option rises. Given that the outside option is an increasing function of  $h$  from Proposition 1, the maximum level of human capital  $h_{\max,t}$  contains all the information relevant for forecasting the wage contract in the next period.

With limited commitment on the labor side, the optimal contract should move as little as possible to trade off between the marginal value of retention incentives and the marginal benefit of consumption smoothing. Figure 1.7(a) illustrates the equilibrium wage contract. Whenever the productivity shock  $z_{t+1}$  induces a positive increase in  $h_{\max,t+1}$ , the participation constraint binds and the marginal value of increasing  $\varphi_{t+1}$  rises and dominates the marginal value of insurance. The firm increases the promised value  $\varphi_{t+1}$  to retain the worker in the match. The optimal contract depends only on the current state of the firm. Although it is costly for the firm to increase  $\varphi_{t+1}$ , it benefits the firm from the marginal productivity of the worker. However, when the productivity shock  $z_{t+1}$  leads to disinvestment at  $t + 1$  and  $h_{t+1} < h_{\max,t+1}$ , the worker's participation constraint is loosened and the optimal wage contract stays constant. As long as  $h_{t+1} < h_{\max,t+1}$ , the marginal value of smoothing the worker's consumption dominates, and perfect insurance is achieved. The wage contract is completely captured by the maximum level of the human capital stock in the firm's history  $h_{\max,t}$ . The dynamics of wage

contract can be concluded using the following corollary.

**Corollary 1** *Given that the capital owners and workers are equally patient, equilibrium wage is nondecreasing over time when  $z_t \geq \max[z^*, \underline{z}]$ .*

**Proof.** See Appendix 1.7.4. ■

Corollary 1 follows from Proposition 2 since  $h_{\max,t}$  is non-decreasing as long as  $z_t > \max[z^*, \underline{z}]$ . The efficient allocation is to increase the compensation and make the worker indifferent between staying or leaving the firm whenever the firm faces a positive productivity shock, and to smooth the worker's consumption when the productivity shock is negative. The downward-rigid wage contract is valid only when the productivity shock of this period is not lower than the threshold  $\max[z^*, \underline{z}]$ .

When  $z_t < \max[z^*, \underline{z}]$ , the workers from the dissolved match are reallocated to the entrants. Upon the termination of the match, the worker leave the firm with a proportion of human capital,  $\phi h_{t-1}$ . In Figure 1.7(b), the initial wage of the worker and  $\varphi_0$  are set to make the entrant profitable enough to continue production. The wage contract is not downward-rigid at the point of reallocation since workers lose the fraction  $1 - \phi$  of human capital when they move to a new entrant.

### 1.3.1.1 History-Dependent Risk Allocation in Equilibrium

In equilibrium, the outside option drives the optimal rent-splitting rule between workers and capital owners, and the sensitivity of the outside option to the productivity shocks differs across firms. The important question before moving on to cash flow volatility is the relative risk-sharing magnitude in equilibrium and its cross-sectional distribution. The equilibrium property of workers' outside option directly implies the following corollary:



**Corollary 2** *Given  $\varphi_0$ ,  $z_t < \max[z^*, \underline{z}]$ , and the concavity of  $\varphi_{res}(h)$  from Proposition 1,  $\frac{\partial \varphi_t}{\partial h_t^1} \geq \frac{\partial \varphi_t}{\partial h_t^2}$  if  $h_t^1 \leq h_t^2$ .*

Concavity of the outside option in the human capital level implies a difference in sensitivity of the promised utility on the maximum level of the human capital accumulation. As the maximum of the human capital level gets higher, the promised utility becomes less responsive to the productivity shock and, hence, the consumption. However, when the historical maximum of human capital level is low, the worker gets better insured from the productivity shock, and the wage contract is less responsive. The equilibrium distribution of wage to output sensitivity is consistent with the equilibrium distribution of  $h_{\max}$ .

Figure 1.6 shows the impulse response function of cash flows and wage contracts subject to a one-standard deviation shock. Consider two firms with the same starting level of  $\varphi_0$  and human capital  $h_t$  level, but with a different history of human capital accumulation  $h_{\max,t}$ . With high  $h_{\max,t}$ , the firm offers a wage contract that is less responsive to productivity shocks (both positive and negative), while with low  $h_{\max,t}$ , the firm offers a wage contract that is more sensitive to productivity shocks. When the wage contract is less sensitive, compensation to the worker is relatively smooth and acts as leverage to the owner's cash flow and firm value. When the wage contract fluctuates with respect to the productivity shocks, the cash flow and the firm value become smoother since the compensation hedges against the productivity risk for the capital owner.

### 1.3.1.2 Labor as Hedge or Leverage?

Allowing the endogenous outside option produces the equilibrium joint distribution of wage contract dynamics and cash flow volatility. The wage contract can act either as a hedge against productivity shocks or as leverage for the owner's cash flow. Also, the leverage and hedge effect differs across firms, depending on

the historical maximum level of human capital and the current human capital level. I define  $\frac{h_t}{h_{\max,t-1}}$  as the distance between the current capital level and the running maximum level of the human capital,  $h_{\max,t-1}$ .

**Proposition 3** *Given  $\varphi_0$  and  $w_0$ ,  $h_{\max,t}$  and  $\frac{h_t}{h_{\max,t-1}}$  are the only relevant state variables that impact wage contract dynamics.*

**Proof.** The dynamics are captured by the tightness of the participation constraint. Given the monotonicity of  $\varphi_{res}(h)$  in equilibrium, the Proposition is straightforward. ■

The role of labor in the firm is governed by  $\frac{h_t}{h_{\max,t-1}}$ . I first define the wage-output sensitivity  $\beta_{w,y} = \beta_{\Delta w, \Delta y}$  of wage growth on output growth as a measure of the degree of risk sharing in equilibrium. When  $\frac{h_t}{h_{\max,t-1}}$  is greater than one, investment responds to the significant positive productivity shock, and firms optimize the total value by taking advantage of the better investment opportunity and committing to higher labor costs. Both the wage-output sensitivity is then positive,  $\beta_{w,y} > 0$ . The wage contract acts as a hedge to the cash flow risk. Labor acts as leverage to the cash flow and  $\beta_{w,y} = 0$  when  $\frac{h_t}{h_{\max,t-1}} \leq 1$ , since the wage contract is downward-rigid. The productivity risk is allocated optimally between the capital owner and the worker conditional on  $\frac{h_t}{h_{\max,t-1}}$ . The wage contract provides insurance to the worker for small positive and negative shocks, but not for large positive shocks. The state variable  $\frac{h_t}{h_{\max,t-1}}$  has the same feature as all the dynamic contracts with limited commitment, e.g., Thomas and Worrall (1988), Kocherlakota (1996), Krueger and Uhlig (2006), except that, here, the state variable  $\frac{h_t}{h_{\max,t-1}}$  is from an endogenous decision.

A nice intuition behind the state variable  $\frac{h_t}{h_{\max,t-1}}$  is the average Q value of the firm (as in Lustig et al. (2011)). The market-to-book ratio is defined as  $q = \frac{M}{B} = \frac{V(h,\varphi,z)}{h}$ . When  $\frac{h_t}{h_{\max,t-1}}$  is low, for a given level  $h_t$ , a higher  $h_{\max,t-1}$  indicates that the worker is compensated with higher rent according to the optimal

wage contract, so  $V(h, \varphi, z)$  is lower and, hence,  $\frac{V(h, \varphi, z)}{h}$  is low. Low market-to-book ratio firms are low  $\frac{h_t}{h_{\max, t-1}}$  firms. On the one hand, firms with a low market-to-book ratio are firms that have a higher historical maximum capital level,  $h_{\max, t-1}$ , and tend to provide better insurance to their workers. On the other hand, high market-to-book ratio firms have a relatively lower running maximum level of historical human capital, so they share less rent with workers, and the owners of the firms bear less productivity risk. Workers act more like leverage in the low market-to-book ratio firms, but act more like a hedge in the high market-to-book ratio firms.

	$\frac{h_t}{h_{\max, t-1}} \leq 1$	$\frac{h_t}{h_{\max, t-1}} > 1$
High $h_{\max, t}$	$\beta_{\Delta w, \Delta y} = 0$ High Leverage High $\sigma(\Delta CF)$	Low $\beta_{\Delta w, \Delta y}$ Hedge Median $\sigma(\Delta CF)$
Low $h_{\max, t}$	$\beta_{\Delta w, \Delta y} = 0$ Low Leverage Median $\sigma(\Delta CF)$	High $\beta_{\Delta w, \Delta y}$ Hedge Low $\sigma(\Delta CF)$

Table 1.1: Equilibrium Joint Distribution of  $\beta_{w, y}$  and  $\sigma(\Delta CF)$

The historical running maximum of human capital,  $h_{\max}$ , determines how the corporate rent created by the match of capital and labor is split between these two claimholders. When labor acts as leverage to the cash flow risk,  $h_{\max}$  governs the difference in the leverage ratio. When labor acts as a hedge on productivity risk for the owners,  $h_{\max}$  controls the difference in the magnitude of risk that the wage contract helps offset.

The dynamics of the wage contracts are characterized jointly by  $\frac{h_t}{h_{\max, t-1}}$  and  $h_{\max, t}$ . The joint distribution of sensitivity of wage growth on output growth,  $\beta_{w, y}$ , and cash flow volatility in equilibrium lines up with the joint distribution of  $\frac{h_t}{h_{\max, t-1}}$  and  $h_{\max, t}$  in equilibrium (Table 1.1).

Figure 1.9 shows the dynamics of sensitivity and volatility with respect to the change of  $\frac{h_t}{h_{\max, t-1}}$  and  $h_{\max, t}$  before the match dissolves. The wage-output

sensitivity is increasing in  $\frac{h_t}{h_{\max,t-1}}$  and decreasing in  $h_{\max,t}$ . When  $\frac{h_t}{h_{\max,t-1}} \leq 1$ , wage growth responds little to output growth and wage-output sensitivity stays close to zero. When  $\frac{h_t}{h_{\max,t-1}} \geq 1$ , wage gets less sensitive and less responsive to output as  $h_{\max,t}$  gets higher. The dynamic risk allocation is consistent with the cash flow volatility dynamics: the better the consumption smoothing provided to the worker, the more risk the capital owner bears.

The policy function of a numerical exercise in Figure 1.5 shows wage-output sensitivity and cash flow volatility as the function of  $h$  and  $\varphi$  implied by the model. To facilitate the quantitative analysis, Figure 1.5 shows the policy for the volatility of cash flows scaled by output ( $\frac{CF}{y}$ ). The result is preserved when cash flow is scaled by output. Since  $h_{\max}$  is the sufficient statistic for the worker's promised utility  $\varphi$ , the policy function illustrates the dynamics of wage-output sensitivity and cash flow volatility with respect to  $h$  and  $h_{\max}$ . The volatility of cash flow increases in  $h_{\max}$  because of the leverage effect, but decreases in  $h$ . The reason why cash flow volatility decreases in  $h$  in the policy function is as follows. When  $h$  exceeds  $h_{\max}$ , wage contracts comove with the human capital level  $h$  and act as hedges, so cash flow volatility remains at a low level; when  $h$  is lower than  $h_{\max}$ , the implicit wage contract becomes effective leverage, hence cash flow volatility is high. The wage-output sensitivity increases with respect to  $h$ , but decreases with respect to  $h_{\max}$ . In the bottom panel (left picture), wherever wage-output sensitivity hits zero, the value of promised utility  $\varphi$  implies the value of  $h_{\max}$  equal to  $h$ , and as  $h_{\max}(\varphi)$  increases, the sensitivity is equal to zero. Higher wage-output sensitivity is obtained when  $h$  is higher than  $h_{\max}$ .

## 1.4 Quantitative Results

This section presents the quantitative results of the stationary industry equilibrium. Computing the equilibrium requires the specification of the functional forms

and determination of the parameter values. Because the exact analytical solution is impossible to obtain under this framework, the computational procedure is provided in Appendix 1.7.5.

#### 1.4.1 Measurement and Data Construction

One of the key features of the model is that it generates the distribution of firm-level human capital and the evolution of firm-level human capital accumulation. Measuring human capital or intangible capital has a long history in the economics literature. The conceptual and measurement approach depends on my theoretical predictions as well as the availability of firm-level data.

**Defining and Measuring Firm-Level Human Capital** The key variable  $h$  that governs the risk allocation dynamics is firm-level human capital: human capital that is accumulated along with production. Different from the standard definition of human capital (general skill of labor), firm-level human capital has more overlap with the intangible assets of the firm in both accounting terms and qualitative properties. Borrowing from the definition of intangible assets in Brynjolfsson et al. (2002), I focus on a firm's intellectual assets and innovation, as well as its organizational structure (including information technology and computer expenses).

According to the existing literature (Corrado et al. (2004), Lev and Radhakrishnan (2005), Hulten and Hao (2008), Eisfeldt and Papanikolaou (2013), Falato et al. (2013), etc.), in the Compustat database, the computerized information (including organizational structure, etc.) and the economic competencies (knowledge embedded in firm-specific human and structural resources, including brand names) are recognized as a fraction of *Selling, General and Administrative* (SG&A) expenses, and the corresponding line for innovative property is R&D expenses. I

attribute 30% of SG&A outlays<sup>7</sup> plus R&D expenses to labor-related intangible spending. All the investment spending is deflated by the production price index from NIPA.

To obtain the firm-level human capital stock, I start with the estimates of real investment spending and apply the perpetual inventory method  $h_{t+1} = (1 - \delta_h)h_t + I_h$ . I need two further elements to implement the capital accumulation method: a depreciation rate  $\delta_h$  and the capital benchmark  $h_0$ . Relatively little is known about depreciation rates for human capital. I borrow the depreciation rate estimated by Corrado et al. (2006) for all three categories of intangible assets. The initial capital stock,  $h_0$ , for each category is set to the same amount of capital spending as that of the first year available in the Compustat database divided by depreciation rate. The assumption of the initial stock value and depreciation rate is not crucial for the result since I am more interested in the relative position of firm-level human capital stock than in its quantitative value. For a robustness check, I use the total SG&A expenses as labor-related investment at the firm level, and I also exclude R&D expenses from our firm-level human capital investment estimates. The quantitative result remains robust in general.

## 1.4.2 Variables Construction

### State Variable Construction

Given the calculation of firm-level human capital stock  $h_{i,t}$ , the measure of  $h_{\max,it}$  is constructed in two ways.

First, I measure  $h_{\max,it}$  by taking the maximum of the whole history (available in the data). Although there are missing data before IPO, I assume that the first available observation captures that history.

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<sup>7</sup>The labor-related items account for 10% to 70% of the SG&A expenses (from 10-K filings of public firms). In Hulten and Hao (2008), 30% is applied to capture the investment in organizational development and worker training. I use 30% here to follow the general guidance of Corrado et al. (2006)'s macro research.

Second, I construct  $h_{\max,it}$  by computing the value-weighted average of the past  $N$ -year firm-level human capital stock,  $h_{t-N+1}, \dots, h_t$ . Also for robustness, I define a dummy variable  $d_{h,t} = 1$  if  $h_{t-i} > h_{t-i+1}$ , and impose the weight in that year,  $w_{i,t} = 0$ . This measure helps to smooth out the noise by taking a moving weighted average of the historical capital stock, but it also rules out the data points where the depreciation of human capital is dominant. I drop the estimates whenever there is a missing observation in the  $N$ -year horizon.  $h$  is scaled by the physical capital level given by gross property, plant, and equipment (PPEGT) item from Compustat.

### **Other Variables**

The firm-level wage-output sensitivity  $\beta_{w,y}$  is computed by running a ten-year rolling window regression of the per capita wage growth on the growth of per capita value-added. The regression is conducted for each firm, and I record the panel of the regression coefficients  $\beta_{w,y,it}$ .

The sample includes all the U.S. public firms in CRSP-Compustat merge file from 1960-2010. For consistency, I include firms with fiscal year ending month in December ( $\text{fyr}=12$ ), firms with non-missing SIC codes, firms with non-negative value of sales and firms with non-missing SG&A expenses. The details in the data sources, as well as the definition and construction of other variables can be found in Appendix 1.8. All the firm characteristics and target moments for parameter choices are summarized in Table 1.2.

### **1.4.3 Benchmark Parameter Choices**

Given the availability of firm-level public firm accounting data, I calibrate all the parameters of the model at an annual frequency to match the standard macroeconomic moments and firm dynamics.

**Preference** For convenience, I assume that employees are endowed with CRRA utility with a constant risk-aversion coefficient equal to 2 ( $\gamma = 2$ ). The time preference parameter  $\beta$  is set to 0.96, which implies an annual risk-free rate of 4%. I calibrate the model to match interest rate at a relatively higher level since the model does not have implications for the risk premium; 4% is the average of long-term risk premium and the 30-day U.S. Treasury bill return.

**Technology** Assume that production takes place in each firm according to a decreasing returns-to-scale Cobb-Douglas production function,  $y_t = e^{z_t} h_t^\alpha$ . The parameter  $\alpha$  is drawn randomly from  $[0.78, 0.86]$ . The range of human capital intensity is set to match the average labor share jointly with  $\phi$ . The output  $y$  and firm-level human capital  $h$  are both scaled by physical capital  $k$ .

The idiosyncratic productivity shocks are uncorrelated across firms and have a common stationary and monotonic Markov transition function, denoted by  $Q_z(z_t|z_{t-1})$  as  $z_t = \rho_z z_{t-1} + \sigma_z \epsilon_t$ . The parameters  $\rho_z$  and  $\sigma_z$  are calibrated to match the unconditional second moments and first-order autocorrelation of firm-level TFP shocks.  $\rho_z$  and  $\sigma_z$  are also chosen to match the degree of persistence and the dispersion in the equilibrium distribution of firms, so I restrict their value to  $\rho_z = 0.7$  and  $\sigma_z = 0.3$ . The new entrants draw the initial productivity level  $z_0$  from a uniform distribution over the same finite support  $\mathcal{Z}$  as the incumbents. See Appendix 1.7.5.3 for details.

The rate of depreciation in human capital is set to equal 0.2.<sup>8</sup> I also assume it is costly to adjust firm-level human capital in the calibration with the convex adjustment cost  $g(h, I) = \frac{1}{2} \xi_h (\frac{I}{h})^2 h$ . The convexity parameter  $\xi_h$  is set to 3.2 assuming a similar adjustment time of human capital from the empirical evidence (See Appendix 1.7.5.3).

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<sup>8</sup>A six-year write-off of human capital is suggested by Corrado et al. (2004).



**Labor Market** There is little suggested evidence of  $\phi$  in the data, and it's reasonable to believe that  $\phi$  should vary across firms and over time. The parameters  $\phi$  and  $\alpha$  are calibrated to determine the labor share. In the benchmark calibration, I set  $\phi = 0.5$  to match the labor share 0.43 in U.S. public firms, since the major focus in this paper is on equilibrium distribution of human capital accumulation.

**Entry and Exit** The choice of fixed sunk cost  $s$  and entry cost  $F$  should be calibrated to match the entry and exit rate, respectively. The Compustat dataset provides an unbalanced panel with significant firm turnover. In the model, the match turnover dynamics are essentially skilled labor turnover at the micro level, so I calibrate the values to match the the plant-level exit and entry rate 6.2% found in the literature (e.g., Clementi and Palazzo (2010)).

Table 1.4 summarizes the key parameter values used in solving and simulating the baseline model.

#### 1.4.4 Calibration Results

The model is solved numerically with all the details of solving the firm's optimization problem and the outside option in the industrial equilibrium in the Appendix 1.7.5. I then simulate the economy with  $N$  firms over  $T$  periods using the optimal decision rule and value function. Set  $N = 3000$  and  $T = 300$  and repeat the simulation in a large number of times. The first 100 periods is discarded to make sure the convergence of the "simulated economy".

Panel A, B and C in Table 1.5 contain the key moments that the model is calibrated to match under benchmark parameterization. The parameters are chosen to match the distribution of firm-level human capital and TFP shocks. Table 1.6 provides the results of matching the data moments at the aggregate level. The model produces lower wage growth (log) volatility  $-1.48$  than cash flows growth volatility  $-0.09$ , which is close to the cash flow growth volatility

in the data. The cash flow-output sensitivity is greater than one since the labor cost of firms is sticky. The model produces a lower wage-output sensitivity than what is found in the typical neoclassical production-based model. The model generates a lower wage-output sensitivity than the data. The per capita wage from the Compustat sample is the average wage among both administrative and manufacturing workers, so I expect to see a lower wage-output sensitivity once we are able to measure the wages of the skilled workers at the firm level.<sup>9</sup>

### **Joint Distribution of Wage-Output Sensitivity and Cash Flow Volatility**

Figure 1.3 shows the time series of the average cash flow volatility within different wage-output sensitivity groups. The highest  $\beta_{w,y}$  group on average is 70% lower than the lowest  $\beta_{w,y}$  group in cash flow volatility. This magnitude is more than half of the unconditional standard deviation (1.30) of cash flow volatility in the whole sample. In fact, in the highest  $\beta_{w,y}$  quantile, the cash flow volatility trends downward over time.

Table 1.7 shows the cash flow volatility of different wage-output sensitivity groups. The wage-output sensitivity  $\beta_{w,y}$  is estimated using the regression coefficient of wage growth and output growth over a ten-period<sup>10</sup> rolling window for each firm in the simulated economy. I also obtain estimates of firm-level cash flow volatility over the same window. All the firms are sorted into three groups based on  $\beta_{w,y}$ . The simulation is repeated 100 times. Table 1.7 reports the cross-simulation averages for each group.

Table 1.7 Panel B shows that there is a spread of 70% in cash flow volatility (among different wage-output sensitivity groups). The model also produces about

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<sup>9</sup>Lagakos and Ordóñez (2011) estimate the industry-level wage-productivity elasticity and find that high-skilled industries have the most wage smoothing, with elasticity close to zero. Jensen and Murphy (1990) show a very weak relationship between the top-management compensation and shareholders' performance.

<sup>10</sup>I apply both five-period and fifteen-period window to estimate the wage-output sensitivity, the result is robust in general.

60% difference in cash flow volatility between highest  $\beta_{w,y}$  group and the lowest  $\beta_{w,y}$  group. The change in degree of insurance provided to the workers within the firm is correlated with the change in the firm-level cash flow volatility and hence the return volatility.

The model captures the joint distribution of wage dynamics and cash flow volatility in the data. Panel B of Table 1.7 shows a strong positive relationship between  $\beta_{w,y}$  and cash flow volatility and a positive relationship between  $\beta_{w,y}$  and firm-level stock return volatility. The fact that the cash flow volatility spread between the highest  $\beta$  group and the lowest is the same as the wage volatility spread indicates that the variation in cash flow volatility is due to the variation in wage contract sensitivity. The wage leverage is more effective and stickier in the low  $\beta_{w,y}$  group, where firm-level cash flow growth is more volatile. One exception is that the model does not generate the same magnitude of stock return volatility, since the risk premium and stochastic discount factor are not modeled here. However, the stock return volatility across  $\beta_{w,y}$  groups decreases with respect to  $\beta_{w,y}$ , and the difference in volatility between the highest and the lowest  $\beta_{w,y}$  groups is about 15% in the data.

**Joint Distribution of State Variables and Cash Flow Volatility** I now show the empirical results that support the model mechanism and the consistent transitory dynamics of the state variables with cash flow volatility and the wage-output sensitivity. Two main predictions are obtained regarding the joint distribution of state variables and key second moments from both Corollary 2 and Proposition 3. First, the higher the maximal level of human capital, the lower is the wage sensitivity conditional on  $\frac{h_t}{h_{\max,t-1}} > 1$ ; second, the higher the maximal level of human capital, the higher is the cash flow volatility unconditionally.

Table 1.8 shows the portfolio cash flow volatility and portfolio wage-output sensitivity for different  $h_{\max}$  groups conditional on  $\frac{h_t}{h_{\max}}$  from the data. In Panel

A, cash flow volatility increases with  $h_{\max}$  unconditionally, with a 90% difference between high  $h_{\max}$  group and low  $h_{\max}$  group. In Panel B, there is also consistent evidence that  $\beta_{w,y}$  is lower when  $h_{\max}$  gets higher. In terms of predicting cash flow growth volatility,  $\frac{h_t}{h_{\max}}$  does not play a significant role. Conditional on  $\frac{h_t}{h_{\max}} > 1$ , cash flow growth volatility is on average higher, while the model predicts less risk allocated to the owners because part of the volatility is absorbed by the wage contract. The data do not show a strong effect of  $\frac{h_t}{h_{\max}}$ , mainly because over time there is a positive trend in  $h_t$ . In most of the sample period,  $\frac{h_t}{h_{\max}}$  is a number slightly above 1. In terms of model evaluation, the simulated economy also generate a reasonable distribution of cash flow growth volatility (see Table 1.9). The average cash flow volatility in the highest  $h_{\max}$  group is 47% higher than the lowest  $h_{\max}$  group. The group with  $\frac{h}{h_{\max}} > 1$  does not produce a much lower cash flow volatility than the group with  $\frac{h}{h_{\max}} \leq 1$  due to the way I estimate the second moments. Cash flow volatility and wage-output sensitivity are both estimated over a ten-period rolling window, so  $\frac{h}{h_{\max}} > 1$  at period  $t$  does not guarantee that  $\frac{h}{h_{\max}} > 1$  in the following nine periods within the window. Wage-output sensitivity is higher on average in the group with  $\frac{h}{h_{\max}} > 1$ , and there is a 0.21 spread between high  $h_{\max}$  group and the low  $h_{\max}$  group. In the high  $\beta_{w,y}$  group, the negative  $\beta_{w,y}$  comes from workers 's turnover and the negative growth of output when the firm has a high-water mark of human capital. For the same reason as I match the aggregate moments, the model produces a relatively lower wage-output sensitivity than the data.

#### 1.4.5 Increasing Cash Flow Volatility 1960-2010

Knowing how risk is allocated between capital and labor within the firm not only helps us to understand the cross sections of cash flow volatility, but also provides a novel explanation for the time-varying firm-level cash flow volatility. Capital owners of U.S. public firms bear more and more risk over the past few decades

(Comin and Philippon (2005), Comin et al. (2009) and Kelly et al. (2012), etc.). Table 1.3 provides the key measure of intra-firm risk-sharing dynamics over different periods. On average,  $h_{\max}$ , cash flow growth volatility and wage growth volatility (i.e., firm-level volatility) all increase at the firm level, but within the firm, the wage-output sensitivity decreases 41% (Figure 1.12). The average U.S. public firms have become more and more human capital intensive and have provided better insurance to their workers over time (Figure 1.12).

As shown in Figure 1.12, risk allocation between labor and capital owners presents different patterns across industries. The industries with high  $h_{\max}$  in equilibrium have lower wage sensitivity to output growth. Even industries that are currently experiencing positive productivity shocks have little flexibility in adjusting compensation since their production technologies rely heavily on human capital. If we look at the intra-firm risk allocation dynamics of different industries, the average wage-output sensitivity trends downward (Figure 1.12(b)), with information, computer and technology industry declining the most. In manufacturing and consumer goods, where cash flow volatility increased mildly before the 1980s, the firm-level human capital accumulation is relatively stable.

The secular rise in intangible capital is well-documented in macroeconomics and finance literature<sup>11</sup>. Since  $h_{\max}$  has increased over time, I conduct a comparative-static exercise to see whether the model converges to a different equilibrium cash flow volatility by varying the human capital intensity parameter in the production function. Figure 1.13(a) shows that equilibrium  $h$  distribution with different  $\alpha$  values leads to heterogeneous cash flow volatility and wage-output sensitivity, which is highly consistent with the time series moments in Figure. 1.13(b).

As shown in Figure 1.11(b), the fraction of firms with  $\frac{h_t}{h_{\max,t-1}}$  lower than one

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<sup>11</sup>Jovanovic and Rousseau (2008) emphasize the rise in firm specificity of human capital as a result of the growth of product variety. Falato et al. (2013) explores the rise in intangible assets as a fundamental driver of the secular trend in U.S. corporate cash holdings over the past few decades.

increases over time, while  $\frac{h_t}{h_{\max,t-1}}$  decreases over time, but on average is above one. The average firm in the market exhibits growth in firm-level human capital, implying that there is improvement in risk sharing at the firm-level. The ratio of the current human capital level to the historical maximal human capital level is relevant for this explanation. The ratio tends to be above one, on average, before 1980, and then decreases after 1980. The maturity indicates a high inflexibility in the labor sector of a firm, which creates a strong leverage effect on the firm's cash flow.

## 1.5 Empirical Evidence From Panel Analysis

As additional empirical examination of my theory, I conduct the panel analysis and confirm the model's implications using actual data. There are three key implications from the theory: 1) a positive relationship between the historical maximum of firm-level human capital and wage contracts; 2) a negative relationship between compensation sensitivity and the maximal firm-level human capital conditional on  $\frac{h_t}{h_{\max,t-1}} > 1$ ; 3) a positive relationship between cash flow volatility and maximal firm-level human capital unconditionally.

### 1.5.1 Wage Contract and $h_{\max}$

First, wage level is predicted by  $h_{\max,t}$  controlling for current productivity shocks and other firm characteristics. The prediction is tested as follows:

$$wage_{it} = \alpha + \eta_i + \lambda_t + \beta_1 h_{\max,it} + \beta_2 TFP_{it} + \Gamma X_{it} + \epsilon_{it}, \quad (1.16)$$

where  $X_{it}$  is a vector of control variables, including market-to-book ratio, net sales, and market capitalization. The results are shown in Table 1.10 and Table 1.11 as the robustness check. Wage is measured using per capita labor expenses from

Compustat dataset (wage I) or using per capita labor expenses with the missing total labor expenses replaced by per capita SG&A (wage II). See Appendix 1.8 for details. Table 1.10 shows the regression results using the direct measure of  $h_{\max}$ . The dependent variable is  $\log(\text{wage I})$  in the columns (1) and (2) and is  $\log(\text{wage II})$  in the columns (3) and (4). Controlling for the current TFP level,  $h_{\max}$  is positively correlated with wage level ( $\beta_1 > 0$ ). The result also holds when the historical maximum TFP level is used as the measure of the historical maximum of firm-level human capital accumulation. Table 1.11 reports the regression results using the value-weighted measure of  $h_{\max, vw}$  (see Appendix 1.8).

The effect of the historical maximum of firm-level human capital on the average real wage is statistically significant and sizeable. Controlling for the current productivity level, a one standard deviation<sup>12</sup> change in  $h_{\max}$  accounts for a 22% increase in the firm-level average real wage. Workers are compensated by firms' historical investment in human capital. Over the period from 1960 to 2010, the maximum of accumulated human capital has increased 267% (about one standard deviation, see Table 1.3), while the average real wage at the firm level has increased by an average of 85%. The historical maximum of firm-level human capital indicates an increase of greater than 25% in the average real wage in the sample.

### 1.5.2 Risk Allocation and Firm-Level Human Capital Investment

The model has direct implications for how wage contracts respond to output growth, conditional on the history of firm-level human capital. Wage-output sensitivity is positive when the firm hits a new running maximum of human capital,  $h_{\max}$ , but wage-output sensitivity is negatively correlated with maximal firm-level human capital conditional on  $\frac{h_t}{h_{\max, t-1}} > 1$ .

I first conduct a regression of wage growth on dummy  $D(h_{\max, it} > h_{\max, it-1}) =$

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<sup>12</sup>The standard deviation of  $\log(h_{\max})$  is 1.35.

1 if  $h_{\max,it} > h_{\max,it-1}$ , controlling for output growth, and adding the interaction term of  $D(h_{\max,it} > h_{\max,it-1})$  and output growth:

$$\Delta wage_{it} = \alpha + \eta_i + \lambda_t + \beta_1 D(h_{\max,it} > h_{\max,it-1}) \quad (1.17)$$

$$+ \beta_2 \Delta y + \beta_3 (Dummy \times \Delta y) + \Gamma X_{it} + \epsilon_{it}. \quad (1.18)$$

Wage growth is the difference in the log average real wage of each firm. As shown in the regression results in Table 1.12, the output growth is proxied by using labor productivity growth (column (1)-(2)) and value-added growth (column (3)-(4)). Robust results are obtained by changing the measures for output. The wage growth is positive when firms invest in their firm-level human capital ( $\beta_1 > 0$ ), and is significantly positively correlated to output growth. With a one standard deviation increase in labor productivity growth, wage growth increases (on average) 11.5%, contributing to 55% of the wage growth standard deviation. This result is consistent with the average labor share in U.S. public firms. The regression coefficient is negative in the interaction term, which is also aligned with the model's predictions. When firms increase their human capital accumulation, the sensitivity of wage growth to labor productivity growth declines. The following regression is needed to help explain the magnitude of this finding:

$$\Delta wage_{it} = \alpha + \eta_i + \lambda_t + \beta_1 h_{\max,it} + \beta_2 \Delta y + \beta_3 (h_{\max,it} \times \Delta y) + \Gamma X_{it} + \epsilon_{it}. \quad (1.19)$$

A negative regression coefficient  $\beta_3$  means that  $h_{\max}$  increases, the wage-output sensitivity declines. In the subsample  $\frac{h_t}{h_{\max,t-1}} > 1$ ,  $\beta_3$  is significantly negative (Table 1.14, column (2)). A one standard deviation increase in  $h_{\max}$  absorbs 8% of the wage-output sensitivity, which is 13% of a standard deviation of  $\beta_{w,y}$ . The negativity of  $\beta_3$  is robust to the change of measure of  $\Delta y$  (Table 1.14, column (4)). In the subsample where  $\frac{h_t}{h_{\max,t-1}} \leq 1$ ,  $\beta_3$  is either non-negative or insignificant. Table 1.13 reports the results using wage (I) as the dependent variables. All



results remain robust, except for the significant negative  $\beta_3$  when using  $\Delta tfp$  as the measure of  $\Delta y$ .

### 1.5.3 Cash Flow Volatility and Human Capital Accumulation

Finally, I examine whether the model’s implication for cash flow volatility is also confirmed in the data. I test the positive correlation between cash flow volatility and historical human capital accumulation in the subsample where  $\frac{h_t}{h_{\max,t-1}} \leq 1$ , and then compare the results with the results where  $\frac{h_t}{h_{\max,t-1}} > 1$ .

$$\sigma(\Delta CF) = \alpha + \eta_i + \lambda_t + \beta_1 h_{\max,it} + \Gamma X_{it} + \epsilon_{it}. \quad (1.20)$$

Regression results are shown in Table 1.15. Cash flow volatility is significantly negatively correlated with  $h_{\max}$ . In column (3) when  $\frac{h_t}{h_{\max,t-1}} \leq 1$ ,  $h_{\max}$  predicts a higher cash flow volatility than when  $\frac{h_t}{h_{\max,t-1}} > 1$ . Unconditionally, a one standard deviation increase in  $h_{\max}$  leads to a 30% change in cash flow volatility. When  $\frac{h_t}{h_{\max,t-1}} \leq 1$ , the leverage effect of human capital is amplified and leads to 50% increase in cash flow volatility. Over the sample period from 1960 to 2010, firm-level  $h_{\max}$  has increased by about one standard deviation, which predicts a 30% change in cash flow volatility on average. This result seems to underestimate the incremental size of cash flow volatility, but the intra-firm channel dominates other firm characteristics in predicting change in cash flow risk. I also check equity return volatility as a measure of firm-level cash flow risk. I find that equity return volatility is positively correlated with  $h_{\max}$ , but this significant positive correlation is found only in the sample where  $\frac{h_t}{h_{\max,t-1}} \leq 1$ . The labor “leverage” effect is stronger than the size effect from column (1).

## 1.6 Conclusion

Who bears more risk within the firm? It depends on the current and historical human capital of the firm. On the one hand, wage contracts can serve as a hedging device to the capital owner's cash flow risk when the firm has a higher current level of human capital than its historical maximum. On the other hand, wage contracts can behave like debt and leverage the cash flow risk when the historical level of human capital is higher than the current level.

To understand the heterogeneous roles of labor in the firm, I develop a theory in which the optimal wage contract and the optimal investment decision are both endogenously determined in equilibrium. This paper is the first to generate the joint distribution of cash flow volatility and wage-output sensitivity. Empirically, my predictions from the model line up with the cross-sectional and time series evidence in the data. The intra-firm risk allocation channel explains more than 50% of the cash flow volatility variation in the data. Over time, the decline in wage-output sensitivity coincides with the increase in firm-level cash flow volatility.

The intra-firm labor frictions bring a novel perspective to understanding the firm-level risk. Firms have invested more and more in the workers over the past few decades. This paper shows that investing in human capital can be potentially more costly than investing in physical capital. Better understanding of the endogenous investment cost on human capital and its implications for asset returns is an important part of the future research.

## 1.7 Technical Appendix

### 1.7.1 Aggregation

#### Technical Assumptions

(a) The space of input is a subset of the (non-negative) bounded real numbers,  $\mathcal{H} \in [h_{\min}, \infty)$  and  $h_{\min} \in \mathcal{R}$ . The stochastic process for the idiosyncratic shock  $z$  has bounded support  $\mathcal{Z} = [\underline{z}, \bar{z}]$ ,  $-\infty < \underline{z} < \bar{z} < \infty$ ; (b) the idiosyncratic shock follows a common stationary and increasing Markov transition function  $Q(z_t|z_{t-1})$  that satisfies the Feller property; (c) the productivity shock  $z_t$  is independent across firms; (d) each period, the entrants draw their initial level of  $z$  independently from a common distribution  $\Psi(z)$ ; (e) the domain of feasible promised utility,  $\Phi = [\underline{\varphi}, \bar{\varphi}]$ .

Naturally,  $\bar{\varphi}$  is the lifetime discounted utility of a worker in the firm with the highest human capital accumulation.<sup>13</sup>

$$\bar{\varphi} = \max_{\{w_t\}_0^\infty} \sum_{t=0}^{\infty} \beta^t u(w_t), \quad (1.21)$$

subject to:

$$\sum_{t=0}^{\infty} \beta^t w_t \leq W(\bar{h}),$$

where  $W(h) = \frac{y(\bar{h}, z)}{1-\beta} + \beta \sum_{z'} \pi(z'|z) y(\bar{h}, z')$  is the present discounted social output.

Symmetrically, I can define the lower bound of promised utility to the worker by picking an arbitrary small positive  $\underline{w} > 0$  (smaller than the marginal product of  $l$  at  $h_{\min}$ , and define  $\underline{\varphi} = u(\underline{w})$  as the lifetime utility from consuming the lowest possible income forever. Note that the boundary is loose enough that the equilibrium  $\varphi$  might not hit either the lower or the upper bound.

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<sup>13</sup> $\bar{h}$ , the existence of  $\bar{h} < h^*$  is guaranteed by the decreasing return to scale production function.

## Aggregation

Define the measure  $\mu$  such that  $\forall (h, \varphi, z) \in \mathcal{H} \times \Phi \times \mathcal{Z}$ ,  $\mu(h, \varphi, z)$  denotes the mass of firms in the state  $(h, \varphi, z)$  and  $\Theta = \mathcal{H} \times \Phi \times \mathcal{Z}$ . The law of motion of the state variable depends on the transition function from agents' optimality, but the invariant distribution of mass of the firm  $\mu$  is determined by the exit-entry decision.

Let  $\kappa$  be an indicator function defined by the policy function for the promised utility and human capital:

$$\kappa(h', \varphi', z'; h, \varphi, z) = \begin{cases} 1, & \text{if } \varphi'(h', \varphi', z'; h, \varphi, z) = \varphi' \ \& \ h'(h', \varphi', z'; h, \varphi, z) = h', \\ 0, & \text{elsewhere.} \end{cases} \quad (1.22)$$

I can then define the transition function  $\Lambda$  for  $\Theta$ :

$$\Lambda((h', \varphi', z'), (h, \varphi, z)) = Q(z'|z)\kappa(h', \varphi', z'; h, \varphi, z). \quad (1.23)$$

I use  $\Upsilon_t$  to denote a positive measure of the law of motion of state variables at time  $t$ . Its law of motion is implied by the transition function  $\Lambda$ :

$$\Upsilon_{t+1}(h', \varphi', z') = \int_{h_{\min}}^{\infty} \int_{\underline{\varphi}}^{\bar{\varphi}} \int_{\underline{z}}^{\bar{z}} \Lambda((h', \varphi', z'), (h, \varphi, z)) \mu_t(h, \varphi, z) d\Theta_t, \quad (1.24)$$

where  $\mu_t(h, \varphi, z)$  is the measure of surviving firms in period  $t$ :

$$\mu_t(h, \varphi, z) = \int_{h_{\min}}^{\infty} \int_{\underline{\varphi}}^{\bar{\varphi}} \int_{\underline{z}}^{\bar{z}} \eta(k, \nu, a) d\Lambda(k, \nu, a). \quad (1.25)$$

In the invariant industry equilibrium, the mass of new entry equals the mass of the exit in that same period:

$$\mu'(h', \varphi', z') = \begin{cases} \Lambda((h', \varphi', z'), (h, \varphi, z))\mu(h, \varphi, z), & \text{if } \varphi \leq \varphi^* \\ \Lambda((h', \varphi', z'), (h, \varphi_{res}(h), z))\mu(h, \varphi_{res}(h), z), & \text{if } \varphi > \varphi^*. \end{cases} \quad (1.26)$$

### 1.7.2 Proof of Lemma 1 and Lemma 2

This is the standard proof following Stokey, Lucas and Prescott (1989).

**Proof of Lemma 1.** (Existence.) First, I show that the constraint set is non-empty. The value function is a mapping from a set of bounded and continuous functions  $C(\mathcal{H} \times \Phi \times \mathcal{Z})$  to  $C(\mathcal{H} \times \Phi \times \mathcal{Z})$ . Second, I show that value function is a contraction in  $C(\mathcal{H} \times \Phi \times \mathcal{Z})$ . A standard contraction mapping theorem implies that there is a unique fixed point in  $C(\mathcal{H} \times \Phi \times \mathcal{Z})$ , and ensures the existence, strict monotonicity, and concavity of  $V$ .

(*Monotonicity.*) From Lemma 9.5 and Corollary 1 of Theorem 3.2 in Stokey, Lucas and Prescott (1989), it is straightforward that  $V(h, \varphi, z)$  is strictly increasing in  $h$  and  $z$ , and strictly decreasing in  $\varphi$ .

(*Concavity.*) To prove that  $V(h, \cdot, z)$  is strictly concave, I first consider some  $h$  and  $\varphi_1 \neq \varphi_2$  and, for each  $\varphi_i$ , consider a stochastic sequence of optimal choice  $(y_{t,i}, \varphi_{t,i}, z_{t,i}, w_{t,i})|_{t=0}^{\infty}$  from iterating the solution to the dynamic programming problem forward, starting with  $h_{0,i} = h$  and  $\varphi_{0,i} = \varphi_i$ . Given the boundedness, per iteration gives:

$$\varphi_i = (1 - \beta)E\left[\sum_0^{\infty} \beta^t u(w_{t,i})\right].$$

A similar iteration for  $V(h, \varphi)$  yields:

$$V(h, \varphi_i) = E\left[\sum_0^{\infty} \beta^t d_{t,i}\right].$$

Consider now the convex combination  $\varphi_\lambda = \lambda\varphi_1 + (1 - \lambda)\varphi_2$ . A feasible plan is given by the convex combination of  $(\varphi_{t,i}, w_{t,i})_{t=0}^\infty$ , with the concave utility:

$$V_\lambda = E\left[\sum_0^\infty \beta^t d_{t,\lambda}\right] > \lambda V(h, \varphi_1) + (1 - \lambda)V(h, \varphi_2),$$

where  $d_\lambda = \lambda d_1 + \lambda d_2$ , and the inequality is from the strict concavity of the utility function. Obviously,  $V(h, \varphi_\lambda) \geq V_\lambda > \lambda V(h, \varphi_1) + (1 - \lambda)V(h, \varphi_2)$ . ■

**Proof of Lemma 2.** The uniqueness follows from the strict concavity of  $V$ , and the continuity follows from the maximum theorem. ■

### 1.7.3 Proof of Proposition 1: Existence of Equilibrium

**Proof of Proposition 1.** (1)  $Q(z'|z)$ ,  $h' = h'(\varphi, h; \varphi')$  and  $\varphi' = \varphi'(\varphi, h; h')$  together induce a well-defined Markov transition function that satisfies the Feller property. The continuous policy function ensures this. According to Theorem 12.10 in Stokey, Lucas, and Prescott (1989), the existence of a stationary measure  $\Psi$  is guaranteed.

(2) I show the unique existence of  $\varphi_{res}$  from (1.14) and Lemma 1 that value function  $V(\cdot)$  is continuous, and strictly increasing in  $h$  and strictly decreasing in  $\varphi$ . Value function is concave in  $h$  and  $\varphi$ ; hence, from the zero profit condition (1.14) and the implicit function theorem,  $\varphi_{res}$  is concave in  $h$  too.

$$\frac{\partial \varphi_{res}}{\partial h} = -\frac{\partial V}{\partial h} / \frac{\partial V}{\partial \varphi} > 0$$

$$\frac{\partial^2 \varphi_{res}}{\partial h^2} = -\frac{\partial^2 V}{\partial h^2} / \frac{\partial V}{\partial \varphi} + \frac{\partial V}{\partial h} / \frac{\partial^2 V}{\partial \varphi^2} < 0.$$

■

#### 1.7.4 Proof of Proposition 2

**Proof.** Since the exit takes place before the productivity shock is observed, firms know in advance whether or not they choose to exit in the next period. Exit decision is therefore completely determined by the current state and can be summarized by a threshold value for the idiosyncratic productivity level. The exit decision can be described by the cutoff  $z^*$  as:

$$\eta_{t+1} = \begin{cases} 1, & \text{if } z_t \geq \max[z_t^*, \underline{z}] \\ 0, & \text{otherwise,} \end{cases} \quad (1.27)$$

where  $z_t^*$  is the cutoff value that satisfies  $E_t[V_{t+1}(h_{t+1}, \varphi_{t+1}, z_{t+1})|z_t^*] = 0$ .

Limited commitment imposes further constraints on problem  $\mathcal{P}$ . Firms solve the optimal investment and exit decisions by maximizing the expected dividend flows subject to the promise-keeping constraint (with multiplier  $\omega_t$ ), the investment budget constraint (with multiplier  $q_t$ ), and the participation constraints (with multiplier  $\beta\theta_t(h', z')$ ). Maximizing value function

$$V(h, \varphi; z) = \max_{h', \varphi', w} \left( d_t + \beta \int V(h', \varphi'; z') Q(dz'|z) \right),$$

subject to constraint (1.9) - (1.12) yields the Lagrangian equation:

$$\begin{aligned} L &= e^{z_t} f(h_t) - w_t - I_t - s + \beta \int V(h', \varphi'; z') Q(dz'|z) \\ &+ q_t(I_t - h_{t+1} + (1 - \delta_h)h_t) \\ &+ \omega_t[u(w_t) + \beta \int \varphi_{t+1} Q(dz'|z) - \varphi_t] \\ &+ \beta \int \int \theta_t(h', z') [\varphi_{t+1} - \varphi_{res,t+1}(\phi h_{t+1})] H(dh|h) Q(dz'|z) \end{aligned}$$

where  $\theta_t(h, z)$  is the multipliers of a series of constraints (1.12) for any feasible  $z_{t+1} \in \mathcal{Z}$  and  $h_{t+1} \in \mathcal{H}$ .

The first-order conditions for  $\{w_t, I_t, h_{t+1}, \varphi_{t+1}\}$  are:

$$-1 + \omega_t u'(w_t) = 0 \quad (1.28)$$

$$-1 + q_t = 0 \quad (1.29)$$

$$\beta \int V_{h,t+1} Q(dz'|z) - q_t = \beta \int \theta_t(h', z') \varphi'_{res,t+1}(h) Q(dz'|z) \quad (1.30)$$

$$V_{\varphi,t+1} + \omega_t + \theta_t(h', z') = 0, \quad \forall z' > \max[z^*, \underline{z}], \quad \forall h' \in \mathcal{H}, \quad (1.31)$$

and the envelope conditions for the current capital level and promised utility are:

$$V_{h,t} = e^{z_t} f'(h_t) + q_t(1 - \delta_h) \quad (1.32)$$

$$V_{\varphi,t} = -\omega_t. \quad (1.33)$$

Substituting (1.32) into (1.30), I obtain the investment Euler equation in  $h$ :

$$\begin{aligned} 1 &= \beta \int [e^{z_{t+1}} f'(h_{t+1}) + (1 - \delta_h)] Q(dz'|z) \\ &\quad - \beta \int \theta_t(h) \varphi'_{res,t+1}(h_{t+1}) Q(dz'|z). \end{aligned} \quad (1.34)$$

Substituting (1.33) into (1.31), we obtain the investment Euler equation in promised utility  $\varphi$ :

$$V_{\varphi,t+1} = V_{\varphi,t} - \theta_t(h', z'), \quad \forall z' > \max[z^*, \underline{z}], \quad \forall h' \in \mathcal{H}. \quad (1.35)$$

Combining with (1.28), I obtain the law of motion of the lagged inverse marginal utility:

$$\frac{-1}{u'(w_{t+1})} = -\frac{1}{u'(w_t)} - \theta_t(h', z'), \quad \forall z' > \max[z^*, \underline{z}], \quad \forall h' \in \mathcal{H}. \quad (1.36)$$



From equation (1.36), it can be shown that wage is increasing over time, and strictly increasing when the participation constraint is binding (positive  $\theta_t$ ).

Given  $h_{t+1}$  and  $z_t > \max[z^*, \underline{z}]$ , when  $\theta_t(h', z') = 0$ , the participation constraint is not binding; thus  $-\frac{1}{u'(w_{t+1})} = \frac{\partial V_{t+1}}{\partial \varphi_{t+1}} = \frac{\partial V_t}{\partial \varphi_t} = -\frac{1}{u'(w_t)}$ . Hence,  $w_t = w_{t+1}$  from the non-binding participation constraint for given  $h_{t+1}$ .

Given  $h_{t+1}$  and  $z_t > \max[z^*, \underline{z}]$ , when  $\theta_t(h', z') > 0$ , the participation constraint is binding; thus  $-\frac{1}{u'(w_{t+1})} = \frac{\partial V_{t+1}}{\partial \varphi_{t+1}} < \frac{\partial V_t}{\partial \varphi_t} = -\frac{1}{u'(w_t)}$ . Due to the concavity of  $u(\cdot)$ ,  $w_{t+1} \geq w_t$ .

If  $z_t < \max[z^*, \underline{z}]$ ,  $\varphi_{t+1} = \varphi_{res,t+1}$ , and  $w_{t+1} = w_0$ .

The wage contract dynamics are governed by the tightness of the participation constraints (governed by  $\theta_t(h, z)$ ). Since the equilibrium outside option  $\varphi_{res}$  is independent of  $z$ , the relevant state variable is the human capital level  $h$  if  $z_t > \max[z^*, \underline{z}]$ . Define an optimal wage function  $W(h, \varphi)$  such that  $W(h, \varphi) = (u')^{-1}(1/\omega_t)$ . Also, define the running maximum of  $h_t$ :  $h_{\max,t} = \max\{h_s, s \leq t\}$ . Conditional on  $z_t > \max[z^*, \underline{z}]$  and the initial wage level  $w_0$ , the wage is determined by  $h_{\max,t}$ :

$$w_t = \max\{w_0, W(h_{\max,t}, \varphi_{\max,t})\}. \quad (1.37)$$

**Corollary 1:** Corollary 1 is a direct implication from Proposition 2 since  $h_{\max,t}$  is non-decreasing as long as  $z_t > \max[z^*, \underline{z}]$ . ■

### 1.7.5 Computation Algorithm

**General Steps** Solving this model includes three general steps: 1) Given the worker's outside option, solve the owner's optimization problem by iterating the value function. The value function and the optimal decision rule are solved on a grid in a discrete state space by iterating value function. 2) After solving the value

function given worker's outside option, check the equilibrium free-entry condition and obtain an updated outside option. 3) Parameterize the outside option as a concave function of the human capital stock, and iterate steps 1) and 2) until the parameters converge.

#### 1.7.5.1 Choice of Grids

- I specify a grid with 100 points for  $h$  with upper bound  $\bar{h}^S$  (large enough to be nonbinding at all times). The grids for human capital are constructed recursively, following McGrattan (1999), which is,  $h_i = h_{i-1} + c_{h1} \exp(c_{h2}(i - 2))$ , where  $i = 1, 2, \dots, 100$  is the index of grid points, and  $c_{h1}$  and  $c_{h2}$  are two constants chosen to provide a desirable upper bound  $\bar{h}^S$ . The method will generate more grids around the lower bound  $h_{\min}$ , where the value function has most of its curvature.
- The grid for the promised utility to the worker  $\varphi$  is constructed linearly by specifying the lower and upper bound of  $\varphi$ . The upper bound of  $\varphi$  is chosen to be close to zero, and the lower bound is defined as the discounted worker's utility given that the wage is the lowest possible.

#### 1.7.5.2 Algorithm

##### 1. Initialization $t = 0$ .

- Initialize the outside option  $\varphi_{res,t=0}$ .  $\varphi_{res,t=0,i} = \frac{u(MPL(h_i))}{1-\beta}$ .
- Initialize the step for updating the outside option. Set  $s_0 = \lfloor \min(\varphi)/100 \rfloor$ .
- Iterate to generate initial value function. Given the specification of the parameter and state variable grids, and find the optimal next period state variables  $\{h', \varphi'\}_i$ . Iterate until the value function converges.
- Save the value function  $v_{t=0}$ .

## 2. Outer Loop $t > 0$ .

- While equilibrium condition is violated,  $\max |err2| > 1e - 6$ .
  - **Inner loop**
  - Interpolate  $\varphi_{res}(h)$  from  $V_t(\underline{h}, h, \varphi) = 0$ .
  - Estimate parameters  $\mathcal{A}_t$  of the concave function  $\tilde{\varphi}(h, \mathcal{A})$ .
  - Compute  $err_p = \max |\mathcal{A}_t - \mathcal{A}_{t-1}|$ , which is the violation of the equilibrium condition.
  - Set  $\varphi_{res,t} = \tilde{\varphi}(h, \mathcal{A}_t)$ .
- End.

### 1.7.5.3 Calibration and Simulation

**Other Calibration Details** Convexity of Adjustment Cost: Assume the adjustment cost is quadratic  $g(h, I) = \frac{1}{2}\xi_h(\frac{I}{h})^2h$ . Set  $\xi_h = 3.2$  to match the the level and dispersion of Tobin's Q. Eisfeldt and Papanikolaou (2013) applied the same adjustment cost for organization capital. The convexity of adjustment cost also has implications on the adjustment time of human capital, but since there is little evidence on the adjustment time of human (intangible) capital in the literature, I take  $\xi_h = 3.2$  (implying more than three years adjustment time) to match the investment-capital ratio in the data. For physical capital, the adjustment cost is usually set within the range of adjustment period, which is from 6 to 24 months in the literature (e.g., Whited (1992), Hall (2001), Shapiro (1986)). The result is robust to the variation from 1.5 to 3.5.

**Running Simulation** The stochastic process for the level of technology for incumbents is assumed to follow a common stationary and monotonic Markovian process with a finite support. I proximate the finite support using  $\mathcal{Z} =$

$[-\sigma\sqrt{\frac{n-1}{1-\rho^2}}, \sigma\sqrt{\frac{n-1}{1-\rho^2}}]$ , where  $n$  is the number of grids for  $z$  in the computation. The initial level of  $z_0$  is drawn from the uniform distribution with the same support. When firms overshoot over boundaries, I replace that  $z_t$  to its closest boundary value.

I simulate 3,000 firms for 300 periods. Whenever one firm exits, it will be replaced by an entrant with the starting productivity level drawn from the uniform distribution. The parameter  $\alpha$  for each firm is also drawn randomly from  $[\underline{\alpha}, \bar{\alpha}]$  at the point of the entry. To minimize the impact of the initial value, I drop the first 100 periods to make sure that firms in this simulated economy are in their steady states. I repeat the simulation 1,000 times.

## 1.8 Data Appendix

### 1.8.1 Data Sources

The sample includes all the U.S. firms in CRSP-Compustat merge file from 1960-2010. For consistency, I include firms with fiscal year ending month in December (fyr=12), firms with non-missing SIC codes, firms with non-negative value of sales (SALE), and firms with non-missing human capital investment (selling, general and administrative expenses). All variables are winsorized to ensure that results are not driven by outliers. The firm-level TFP is from Imrohoroglu and Tuzel (2011),<sup>14</sup> where they apply the method in Olley and Pakes (1996) to estimate firm-level TFP using Compustat data.

### 1.8.2 Definition and Measurement

**Definition: Firm-Level Human Capital** Different from the standard definition of general human capital ( for example, education and other individual characteristics), firm-level human capital is the capital accumulated in the process of production in the firm. The human capital that workers gain from production is defined as firm-level human capital. Firm-level human capital can be general human capital (completely portable) or firm-specific human capital (nonportable), as long as it contributes to the value of the firm. Measuring human capital by directly constructing proxies using *individual-level* data in the U.S. or by exploiting wage differences across groups defined by different *individual* characteristics (see Abowd et al. (2005) for a detailed survey) is not helpful for measuring *firm-level* human capital.

Firm-level human capital has more overlap with the intangible assets of the firm than with individual human capital. The definition of intangible assets varies

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<sup>14</sup>Thanks to Selale Tuzel for kindly sharing their TFP estimate with me.

from a firm's intellectual assets and innovation (R&D expenses), to human capital, intellectual property (marketing and reputation), and to organizational structure (including IT and computer expenses (Brynjolfsson et al. (2002))). I focus on the firm-level intangible assets that have portability with the workers (the portable part of intangible assets).<sup>15</sup>

Industry classification is not precise enough to differentiate firm-level human capital because it can either substitute for or complement individual human capital (or skilled labor). Depending on the technology, there exists large spread of firm-level human capital intensity within an industry. Based on the reasons above, a new measure of firm-level human capital is needed.

### 1.8.3 Industry Definition

I examine four main industries in this paper: consumer goods, manufacturing, health product and information, computer and technology industry. The classification of consumer goods, manufacturing and health product industries are taken from Fama-French 5-industry classification. The information, computer and technology industry classification (defined according to NAICS) is from BEA Industry Economic Accounts, which consists of computer and electronic products; publishing industries (includes software); information and data processing services; and computer systems design and related services. I classified all the rest of the firms (including the finance industry) into other Industries.

### Variable Construction

- $h$ : 30% of SG&A expenses plus R&D expenses. Investment spending is de-

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<sup>15</sup>The theory emphasizes the stickiness of intangible leverage from the portability assumption, so the direct measurement of firm-level human capital should be restricted to the portability property. Although the historical investment of other intangible assets, such as marketing and advertising, will also creates a similar effect to that of the portable human capital, but through a different channel, which is not my focus here.

flated by the production price index from NIPA. Apply perpetual inventory method to obtain the stock.  $h$  is scaled by the level of physical capital given by gross property, plant, and equipment (PPEGT) from Compustat.

- $h_{\max}$ : The maximum of the whole history (available in the data)
- $h_{\max,vw}$ : The value weighted average of the past five-year firm level human capital stock  $h_{t-4}, \dots, h_t$ .
- wage (I): Replace the missing XLR observations by SG&A expenses.<sup>16</sup> Accordingly, we get the per capita labor cost by deviding EMP. XSGA is deflated by the Consumer Price Index from NIPA.
- wage (II): Total labor expenses (XLR) from Compustat and scaled by number of employees (EMP). XLR is scaled by the Consumer Price Index from NIPA.
- Cash Flow (CF): Operating Income before Depreciation and Amortization (OIBDP), deflated by the consumer price index from NIPA.
- Cash Flow Volatility: Cash flow growth is computed by  $\Delta \frac{CF}{y} = \frac{CF_t - CF_{t-1}}{0.5Sales_t + 0.5Sales_{t-1}}$ . Cash Flow Volatility at year  $t$ :  $\sigma_t(\Delta CF/y) = \left[ \frac{1}{N} \sum_{\tau=t}^{\tau=t+N-1} (\Delta \frac{CF}{y}_{\tau} - \Delta \frac{CF}{y}_t) \right]$ .
- Value Added: Sales - Materials, deflated by the GDP price deator from NIPA. Sales is net sales from Compustat (SALE). Materials is measured as Total expenses minus Labor expenses. Total expenses is approximated as [Sales - Operating Income Before Depreciation and Amortization (Compustat (OIBDP))]. Labor expenses is the Total Staff Expenses (XLR). When XLR is missing, labor expenses is calculated by multiplying the number of

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<sup>16</sup>For the firms in the Compustat dataset, firms who miss reporting labor cost expenses (XLR) usually include the managerial compensation in SG&A and include the manufacturing labor expenses in Cost of Goods Sold.

employees from Compustat (EMP) by average wages from the Social Security Administration). These steps follow those in Imrohoroglu and Tuzel (2011).

- Labor Productivity (LP): Value Added divided by EMP, i.e., per capita value added.
- Laborshare: Real total labor expenses (XLR) with missing observation replaced by real SG&A expenses, divided by value added.



## 1.9 Tables

Table 1.2: Summary Statistics

Variables	Mean	$\sigma$	5%	95%	Median	$N$
$h$	2.04	2.59	0.09	6.97	1.15	62,982
$h_{\max,vw}$	2.06	2.67	0.08	6.97	1.15	64,822
$h_{\max}$	2.62	3.62	0.10	8.91	1.40	73,804
$\frac{h}{h_{\max,vw}}$	1.2	0.40	0.59	1.79	1.09	55,060
$\frac{h}{h_{\max}}$	0.95	0.42	0.31	1.68	0.94	52,045
$\beta_{w,y}$	0.18	0.65	-0.51	1.31	0.05	58,129
$\log(\sigma(\Delta \frac{CF}{y}))$	-3.31	1.30	-5.84	-1.27	-3.24	139,085
$\log(\sigma(ret))$	-3.58	0.62	-4.59	-2.54	-3.59	226,272
$\log(wageI)$	9.67	1.16	7.74	11.31	9.70	187,224
$\Delta wageI$	0.02	0.28	-0.38	0.44	0.016	166,851
$\log(wageII)$	10.61	0.67	9.43	11.58	10.71	40,323
$\Delta wageII$	0.02	0.15	-0.20	0.25	0.017	35,496
$\Delta Value\_Added$	0.03	0.83	-1.01	0.98	0.05	181,328
$\Delta Labor\_Productivity(LP)$	0.003	0.45	-0.72	0.69	0.01	152,912
$\log(TFP)$	-0.63	0.43	-1.27	0.027	-0.64	104,883
$\Delta TFP$	-0.02	0.27	-0.44	0.41	-0.01	91,901

The table reports the key moments of the variables used in the quantitative analysis. The details of data construction can be found in Appendix 1.8. TFP is the total factor productivity at the firm level. TFP is the residual from estimating a log linear Cobb-Douglas production function for each firm and year. The estimates are provided by Imrohoroglu and Tuzel (2011). Data Source: Compustat Fundamental Annual: 1960-2010.

Table 1.3: Data: State Variables and Volatility: Time Series

Year	$h_{\max}$	$\frac{h}{h_{\max}}$	$\log(\sigma\Delta wage)$	$\log(\sigma\Delta\frac{CF}{y})$	$\beta(\Delta CF, \Delta y)$	$\beta(\Delta w, \Delta y)$
1960-1970	0.71	1.30	-2.06	-3.75	1.24	0.54
1970-1980	1.45	1.32	-1.92	-3.41	1.29	0.40
1980-1990	1.85	1.14	-1.88	-3.19	1.27	0.38
1990-2000	2.20	1.12	-1.82	-3.22	1.25	0.43
2000-2010	3.27	1.11	-1.93	-3.20	1.40	0.39

The table presents the time series of the cash flow moments and average state variables within each time period. The standard deviation is computed within a ten-year rolling window and average across firms within the horizon. The volatility is the annualized log standard deviation.  $CF$  stands for cash flow, measured using operating income (OIBDP).  $y$  stands for output measured by value added. Data Source: Compustat Fundamental Annual: 1960-2010.

Table 1.4: Benchmark Calibration

Parameter	Symbol	Value
Human capital intensity	$\alpha$	0.78-0.86
Human capital depreciation rate	$\delta_h$	0.2
Symmetric investment adjustment cost	$\xi_h$	3.2
Persistent coefficient of idiosyncratic productivity	$\rho_z$	0.7
Conditional volatility of idiosyncratic productivity	$\sigma_z$	0.3
Time preference	$\beta$	0.96
Constant risk-aversion coefficient (CRRA utility)	$\gamma$	2
Portability of human capital	$\phi$	0.5
Production cost	$s$	0.08

The table presents the calibration parameter choice for the benchmark model. The parameters are either estimates from empirical studies or calibrated to match a set of key moments in the model to the U.S. data at an annual frequency. See Appendix 1.7.5.3.

Table 1.5: Key Moments Under Baseline Parameterization

Target Moments	Model	Data
Panel A: <i>Technology</i>		
TFP persistency AR(1)	0.7	0.7
$\sigma(TFP)$	0.43	0.42
Panel B: <i>Human Capital (h)</i>		
Standard Deviation	2.55	2.59
Skewness	1.70	2.82
Investment to Capital (h) Ratio	0.21	0.23
Investment to Revenue Ratio	0.28	0.18
Panel C: <i>Labor Share</i>		
$\frac{wage}{output}$	0.49	0.43

The table presents key moments generated by the model baseline parameterization compared to the data moments. All the second moments reported above are unconditional. The investment to revenue ratio is the ratio of investment in organizational capital divided by net sales. The data source of firm-level cash flow and investment characteristics is from Compustat fundamental annual: 1960-2010 and Eisfeldt and Papanikolaou (2013). The data source of firm-level TFP is from Imrohoroglu and Tuzel (2011).

Table 1.6: Aggregate Results Under Baseline Parameterization

Moments	Model	Data
Panel A: Wages and Cash Flows		
$corr(\Delta wage, \Delta y)$	0.22	0.22
$corr(\Delta \frac{CF}{y}, \Delta y)$	0.68	0.48
$\beta(\Delta wage, \Delta y)$	0.09	0.25
$\beta(\Delta \frac{CF}{y}, \Delta y)$	0.46	0.21
$log(\sigma(\Delta wage))$	-1.48	-1.83
$log(\sigma(\Delta CF))$	-0.09	-0.04
$log(\sigma(\Delta \frac{CF}{y}))$	-1.56	-3.31
Panel B: Other Firm Characteristics		
Market-to-Book Ratio	1.68	1.8
Exit Rate	7.7%	6.2%

The table presents aggregate results generated by the model's baseline parameterization compared to the moments from the data. The cash flow volatility  $\sigma(\Delta CF)$  is the standard deviation of the simple first-order difference in firm-level cash flow over a ten-year rolling window. All the second moments are unconditional averages. The sensitivity estimates  $\beta(\Delta wage, \Delta y)$  and  $\beta(\Delta CF, \Delta y)$  are from the pooled OLS regressions. The firm-level cash flow and investment characteristics data are from Compustat Fundamental Annual: 1960-2010.

Table 1.7: Volatility of Portfolios Sorted on  $\beta(\Delta w, \Delta y)$ 

Panel A: Model Portfolio Volatility

Group ( $\beta\Delta w, \Delta y$ )	$\log(\sigma\Delta wage)$	$\log(\sigma ret)$	$\log(\sigma\Delta \frac{CF}{y})$	$\log(\sigma\Delta CF)$
low	-3.37	-0.85	-1.17	0.51
median	-2.66	-0.97	-1.38	0.19
high	-2.46	-1.11	-1.77	-0.23

Panel B: Data Portfolio Volatility

Group( $\beta\Delta w, \Delta y$ )	$\log(\sigma\Delta wage)$	$\log(\sigma ret)$	$\log(\sigma\Delta \frac{CF}{y})$	$\log(\sigma\Delta CF)$
low	-2.30	-3.69	-3.38	0.31
median	-2.26	-3.72	-3.55	-0.19
high	-1.81	-3.84	-4.08	-0.52

This table presents the volatility of wages and cash flows for the  $\beta(\Delta w, \Delta y)$  sorted portfolios.  $\frac{CF}{y}$  is the operating income scaled by sales. The volatility is in terms of log and is annualized. The volatility is computed within a ten-year rolling window and average across firms within the group. The cash flow volatility  $\sigma(\Delta CF)$  is the standard deviation of the simple first-order difference in firm-level cash flow over a ten-year rolling window. The stock return volatility is computed using CRSP daily stock returns, and I derive the stock return volatility using observations within each year and then annualize the volatility estimates. Panel A reports the results from the simulation based on the benchmark choice of parameters. Panel B reports the results from the historical data (1960-2010).

Table 1.8: 3 Portfolios Sorted by State Variables (Data)

	Panel A: $\log(\sigma(\frac{CF}{y}))$			Panel B: $\beta(\Delta w, \Delta y)$			
		$\frac{h_t}{h_{\max, t-1}} \leq 1$	$\frac{h_t}{h_{\max, t-1}} > 1$	Total	$\frac{h_t}{h_{\max, t-1}} \leq 1$	$\frac{h_t}{h_{\max, t-1}} > 1$	Total
Group( $h_{\max}$ )							
low		-3.47	-3.37	-3.44	0.30	0.32	0.30
median		-3.06	-3.00	-3.04	0.12	0.11	0.12
high		-2.55	-2.58	-2.56	0.09	0.10	0.09

This table presents the cash flows ( $\frac{CF}{y}$ ) growth volatility and wage-output sensitivity for the  $h_{\max}$ -sorted and  $\frac{h_t}{h_{\max, t-1}}$ -sorted portfolios. Both the standard deviation and the sensitivity are computed within a ten-year rolling window and averaged across firms within the group. The volatility is the log of the standard deviation and is annualized. Data Source: Compustat Fundamental Annual: 1960-2010.

Table 1.9: 3 Portfolios Sorted by State Variables (Model)

	Panel A: $\log(\sigma(\frac{CF}{y}))$			Panel B: $\beta(\Delta w, \Delta y)$			
		$\frac{h_t}{h_{\max, t-1}} \leq 1$	$\frac{h_t}{h_{\max, t-1}} > 1$	Total	$\frac{h_t}{h_{\max, t-1}} \leq 1$	$\frac{h_t}{h_{\max, t-1}} > 1$	Total
Group( $h_{\max}$ )							
low		-1.62	-1.66	-1.65	0.03	0.06	0.03
median		-1.22	-1.21	-1.21	0.008	0.01	0.01
high		-1.13	-1.19	-1.18	-0.15	-0.25	-0.16

This table presents the cash flow ( $\frac{CF}{y}$ ) growth volatility and wage-output sensitivity estimated from the simulated economy using the benchmark calibration. The exact same procedure of estimation is conducted in the simulated economy. The standard deviation and sensitivity  $\beta$  are computed within a ten-period rolling window and averaged across firms within the group. The volatility is in terms of log.

Table 1.10: Wage Contract and Firm-Level Human Capital Accumulation History

	wage(I)		wage(II)	
	(1)	(2)	(3)	(4)
$\log(h_{\max,t})$	0.363*** (0.085)		0.628 (0.940)	
$\log(TFP_{\max,t})$		0.281*** (0.030)		0.195*** (0.072)
$\log(TFP_t)$	-0.089*** (0.012)	-0.119*** (0.011)	0.016 (0.046)	0.032 (0.060)
MB	-0.062*** (0.020)	-0.082*** (0.012)	0.006 (0.011)	-0.033*** (0.011)
Market Cap	0.156*** (0.049)	0.138*** (0.028)	-0.058* (0.032)	0.004 (0.032)
$\log(\text{Sales})$	0.213*** (0.031)	0.281*** (0.023)	0.197*** (0.064)	0.305*** (0.035)
Constant	8.463*** (0.310)	9.417*** (0.104)	7.537** (3.156)	9.984*** (0.133)
Year FE	y	y	y	y
Firm FE	y	y	y	y
$N$	43,322	106,353	2,913	13,988
R-squared	0.062	0.046	0.122	0.136
Firm ID	5,034	10,883	433	1,628

This table reports the coefficients of the following regression:

$$wage_{it} = \alpha + \eta_i + \lambda_t + \beta_1 h_{\max,it} + \beta_2 TFP_{it} + \Gamma X_{it} + \epsilon_{it},$$

Wage is log average real wage of each firm. TFP is the total factor productivity at the firm level. TFP is the residual from estimating a log linear Cobb-Douglas production function for each firm and year. The estimates are provided by Imrohoroglu and Tuzel (2011).  $\log(h_{\max})$  is the log maximum firm-level human capital level before year  $t$ . Market Cap is the log of market capitalization, which is equal to total asset + market value of equity – common equity.  $\log(\text{Sales})$  is the log deflated net sales. The details of measurement and construction of all variables are included in Appendix 1.8. Data Source: Compustat Fundamental Annual 1960-2010. Standard errors in parentheses are clustered, \*\*\*  $p < 0.01$ , \*\*  $p < 0.05$ , \*  $p < 0.1$ .



Table 1.11: Wage Contract and Firm-Level Human Capital Accumulation History (Value-Weighted)

	wage(I)		wage(II)	
	(1)	(2)	(3)	(4)
$\log(h_{\max,vw,t})$	0.367*** (0.026)		0.088*** (0.034)	
$\log(TFP_{\max,vw,t})$		0.167*** (0.022)		0.036 (0.039)
$\log(TFP_t)$	-0.085*** (0.010)	-0.130*** (0.009)	-0.010 (0.052)	0.059 (0.056)
MB	-0.044*** (0.014)	-0.081*** (0.012)	0.002 (0.012)	-0.031*** (0.011)
Market Cap	0.109*** (0.0347)	0.127*** (0.029)	-0.051 (0.036)	-0.002 (0.032)
$\log(\text{Sales})$	0.170*** (0.026)	0.296*** (0.023)	0.180*** (0.057)	0.311*** (0.036)
Constant	9.244*** (0.205)	9.267*** (0.103)	9.692*** (0.169)	9.843*** (0.138)
Year FE	y	y	y	y
Firm FE	y	y	y	y
$N$	37,952	106,353	2,510	13,988
R-squared	0.160	0.043	0.151	0.130
Firm ID	4,908	10,883	414	1,628

This table reports the coefficients of the following regression:

$$wage_{it} = \alpha + \eta_i + \lambda_t + \beta_1 h_{\max,it} + \beta_2 TFP_{it} + \Gamma X_{it} + \epsilon_{it}.$$

Wage is log average real wage of each firm. TFP is the total factor productivity at the firm level. TFP is the residual from estimating a log linear Cobb-Douglas production function for each firm and year. The estimates are provided by Imrohoroglu and Tuzel (2011).  $\log(h_{\max,vw})$  is the log maximum value-weighted firm-level human capital level over the past five years. Market Cap is the log of market capitalization, which is equal to total asset + market value of equity – common equity.  $\log(\text{Sales})$  is the log deflated net sales. The details of measurement and construction of all variables are included in Appendix 1.8. Data Source: Compustat Fundamental Annual 1960-2010. Standard errors in parentheses are clustered, \*\*\*  $p < 0.01$ , \*\*  $p < 0.05$ , \*  $p < 0.1$ .

Table 1.12: Wage Contract Sensitivity and Human Capital Investment

	$\Delta wage(I)$ (1)	$\Delta wage(II)$ (2)	$\Delta wage(I)$ (3)	$\Delta wage(II)$ (4)
Dummy	0.056*** -0.003	0.014 (0.008)	0.060*** (0.003)	0.015 (0.011)
$\Delta(LP)$	0.209*** (0.004)	0.275*** (0.009)		
Dummy $\times$ $\Delta(LP)$	-0.085*** (0.009)	0.054 (0.058)		
$\Delta(Value\_Added)$			0.036*** (0.004)	0.086*** (0.007)
Dummy $\times$ $\Delta(Value\_Added)$			-0.034*** (0.007)	0.042 (0.052)
MB	-0.007*** (0.001)	-0.003** (0.001)	0.003*** (0.001)	-0.001 (0.002)
Sales	0.048*** (0.003)	0.026*** (0.004)	0.069*** (0.003)	0.041*** (0.004)
Market Cap	-0.033*** (0.003)	-0.013*** (0.003)	-0.050*** (0.003)	-0.028*** (0.004)
Constant	-0.581*** (0.007)	-0.042*** (0.014)	-0.654*** (0.008)	-0.049*** (0.016)
Year FE	y	y	y	y
Firm FE	y	y	y	y
$N$	146,218	32,226	146,218	32,226
R-squared	0.135	0.272	0.017	0.041
Firm ID	15,515	3,672	15,515	3,672

This table reports the coefficients of the following regression:

$$\Delta wage = \alpha + \eta_i + \lambda_t + \beta_1 D(h_{\max,it} > h_{\max,it-1}) + \beta_2 \Delta y + \beta_3 (Dummy \times \Delta y) + \Gamma X_{it} + \epsilon_{it}.$$

Wage growth is the difference in the log average real wage of each firm.  $\Delta y$  is proxied using firm-level labor productivity growth and firm-level value added growth. Dummy  $D(h_{\max,it} > h_{\max,it-1}) = 1$  if  $h_{\max,it} > h_{\max,it-1}$ .  $h_{\max}$  is the log maximum value-weighted firm-level human capital level over the past five years. Market Cap is the log of market capitalization, which is equal to total asset + market value of equity – common equity.  $\log(Sales)$  is the log deflated net sales. The details of measurement and construction of all variables are included in Appendix 1.8. Data Source: Compustat Fundamental Annual 1960-2010. Robust standard errors in parentheses, \*\*\*  $p < 0.01$ , \*\*  $p < 0.05$ , \*  $p < 0.1$ .

Table 1.13: Wage Contract Sensitivity and State Variables (I)

	$\frac{h}{h_{\max}} \leq 1$ (1)	$\frac{h}{h_{\max}} > 1$ (2)	$\frac{h}{h_{\max}} \leq 1$ (3)	$\frac{h}{h_{\max}} > 1$ (4)
$\log(h_{\max,vw,t})$	-0.048*** (0.008)	-0.021*** (0.007)	-0.047*** (0.008)	-0.035*** (0.008)
$\Delta(ValueAdded)$	-0.009** (0.005)	-0.001 (0.004)		
$\log(h_{\max,vw,t}) \times \Delta(ValueAdded)$	-0.002 (0.003)	-0.006** (0.003)		
$\Delta \log(TFP)$			-0.094*** (0.012)	-0.104*** (0.009)
$\log(h_{\max,vw,t}) \times \Delta \log(TFP)$			-0.021** (0.009)	-0.002 (0.007)
MB	-0.003 (0.004)	0.009** (0.004)	-0.007* (0.004)	0.009** (0.004)
Market Cap	-0.039*** (0.012)	-0.067*** (0.010)	-0.003 (0.011)	-0.032*** (0.011)
$\log(Sales)$	0.125*** (0.013)	0.042*** (0.009)	0.165*** (0.015)	0.132*** (0.013)
Constant	-0.089** (0.041)	-0.296 (0.291)	-0.106 (0.100)	-0.190*** (0.053)
Year FE	y	y	y	y
Firm FE	y	y	y	y
$N$	20,252	35,478	12,563	19,739
R-squared	0.030	0.017	0.044	0.040
Firm ID	4,107	6,460	2,494	3,877

This table reports the coefficients of the following regression:

$$\Delta wage = \alpha + \eta_i + \lambda_t + \beta_1 h_{\max,it} + \beta_2 \Delta y + \beta_3 (h_{\max,it} \times \Delta y) + \Gamma X_{it} + \epsilon_{it}.$$

Wage growth is the difference in the log average real wage of each firm, where the average real wage is wage (I). TFP is the total factor productivity at the firm level. TFP is the residual from estimating a log linear Cobb-Douglas production function for each firm and year. The estimates are provided by Imrohorglu and Tuzel (2011).  $\log(h_{\max,vw})$  is the log maximum value-weighted firm-level human capital level over the past five years. Market Cap is the log of market capitalization, which is equal to total asset + market value of equity – common equity.  $\log(Sales)$  is the log deflated net sales. The details of measurement and construction of all variables are included in Appendix 1.8. Data Source: Compustat Fundamental Annual 1960-2010. Robust standard errors in parentheses, \*\*\*  $p < 0.01$ , \*\*  $p < 0.05$ , \*  $p < 0.1$ .

Table 1.14: Wage Contract Sensitivity and State Variables (II)

	$\frac{h}{h_{\max}} \leq 1$ (1)	$\frac{h}{h_{\max}} > 1$ (2)	$\frac{h}{h_{\max}} \leq 1$ (3)	$\frac{h}{h_{\max}} > 1$ (4)
$\log(h_{\max,vw,t})$	0.048* (0.026)	0.008 (0.031)	0.055* (0.030)	-0.001 (0.026)
$\Delta(ValueAdded)$	0.082*** (0.031)	0.041* (0.022)		
$\log(h_{\max,vw,t}) * \Delta(ValueAdded)$	0.003 (0.025)	-0.060*** (0.012)		
$\Delta \log(TFP)$			0.079 (0.067)	-0.024 (0.059)
$\log(h_{\max,vw,t}) \times \Delta \log(TFP)$			-0.003 (0.044)	-0.076*** (0.025)
MB	-0.017* (0.010)	0.002 (0.0093)	-0.005 (0.009)	-0.005 (0.011)
Market Cap	-0.002 (0.024)	-0.066*** (0.024)	-0.007 (0.027)	-0.006 (0.028)
$\log(Sales)$	0.074 (0.089)	0.069* (0.040)	0.106 (0.071)	0.189*** (0.069)
Constant	-0.031 (0.112)	-0.222* (0.116)	-0.168 (0.143)	-0.289* (0.160)
Year FE	y	y	y	y
Firm FE	y	y	y	y
$N$	1,102	2,306	676	1,364
R-squared	0.114	0.101	0.132	0.104
Firm ID	296	519	155	296

This table reports the coefficients of the following regression:

$$\Delta wage = \alpha + \eta_i + \lambda_t + \beta_1 h_{\max,it} + \beta_2 \Delta y + \beta_3 (h_{\max,it} \times \Delta y) + \Gamma X_{it} + \epsilon_{it}.$$

Wage growth is the difference in the log average real wage of each firm, where the average real wage is wage (II). TFP is the total factor productivity at the firm level. TFP is the residual from estimating a log linear Cobb-Douglas production function for each firm and year. The estimates are provided by Imrohorglu and Tuzel (2011).  $\log(h_{\max,vw})$  is the log maximum value-weighted firm-level human capital level over the past five years. Market Cap is the log of market capitalization, which is equal to total asset + market value of equity – common equity.  $\log(Sales)$  is the log deflated net sales. The details of measurement and construction of all variables are included in Appendix 1.8. Data Source: Compustat Fundamental Annual 1960-2010. Robust standard errors in parentheses, \*\*\*  $p < 0.01$ , \*\*  $p < 0.05$ , \*  $p < 0.1$ .

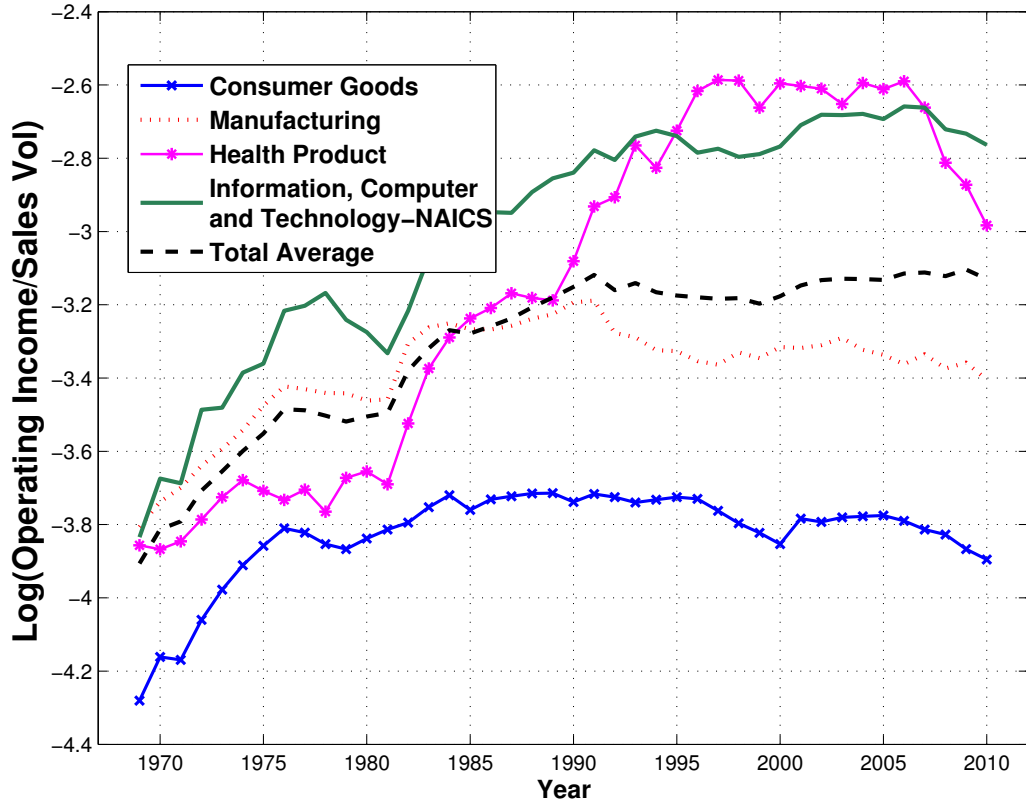
Table 1.15: Volatility and Firm-Level Human Capital Accumulation

Dependent Variables	$\frac{h}{h_{\max}} \leq 1$	$\frac{h}{h_{\max}} > 1$	$\frac{h}{h_{\max}} \leq 1$	$\frac{h}{h_{\max}} > 1$	$\frac{h}{h_{\max}} \leq 1$	$\frac{h}{h_{\max}} > 1$
	(1)	(2)	(3)	(4)	(5)	(6)
	$\sigma(\text{ret})$	$\sigma(\text{ret})$	$\sigma(\Delta CF/y)$	$\sigma(\Delta CF/y)$	$\sigma(\Delta \text{wage}II)$	$\sigma(\Delta \text{wage}II)$
$\log(h_{\max, vw})$	1.891*** (0.149)	-0.053 (0.036)	0.374*** (0.063)	0.069** (0.036)	-0.044* (0.025)	-0.066** (0.027)
Market Cap	-1.727*** (0.228)	-0.076 (0.064)	0.100*** (0.038)	0.076*** (0.024)	0.001 (0.035)	-0.046 (0.031)
$\log(\text{Sales})$	0.533*** (0.182)	-0.0002 (0.047)	-0.088* (0.049)	-0.001 (0.034)	-0.105*** (0.026)	-0.058** (0.026)
MB	0.149** (0.074)	0.011 (0.019)	0.027* (0.015)	0.009 (0.009)	0.017 (0.012)	0.025** (0.010)
Emp	0.736*** (0.190)	0.009 (0.051)	-0.157*** (0.041)	0.182*** (0.032)	-0.055* (0.029)	-0.056* (0.029)
Constant	-7.720*** (2.203)	-2.335*** (0.294)	-3.696*** (0.213)	-3.033*** (0.248)	-2.164*** (0.394)	-1.393*** (0.282)
Year FE	y	y	y	y	y	y
Firm FE	y	y	y	y	y	y
$N$	25,679	34,357	12,727	18,048	16,253	20,170
R-squared	0.080	0.013	0.331	0.328	0.052	0.027
Firm ID	6,599	6,193	2,899	4,031	4,319	3,625

This table reports the coefficients of the following regression:  $\sigma = \alpha + \eta_i + \lambda_t + \beta_1 h_{\max, it} + \Gamma X_{it} + \epsilon_{it}$ .  $\sigma(\text{ret})$  is estimated using the CRSP daily stock return within each ear and annualize the volatility estimates to obtain annual stock return volatility.  $\sigma(\Delta CF/y)$  is the standard deviation of cash flow growth  $\Delta \frac{CF}{y} = \frac{CF_t - CF_{t-1}}{0.55 \text{ sales}_t + 0.55 \text{ sales}_{t-1}}$  over a ten-year rolling window.  $h_{\max, vw}$  is the log maximum value-weighted firm-level human capital level over the past five years scaled by Property, Plant and Equipment-Total(Gross). The details of measurement and construction of all variables are included in Appendix 1.8. Data Source: Compustat Fundamental Annual 1960-2010. Robust standard errors in parentheses, \*\*\*  $p < 0.01$ , \*\*  $p < 0.05$ , \*  $p < 0.1$ .

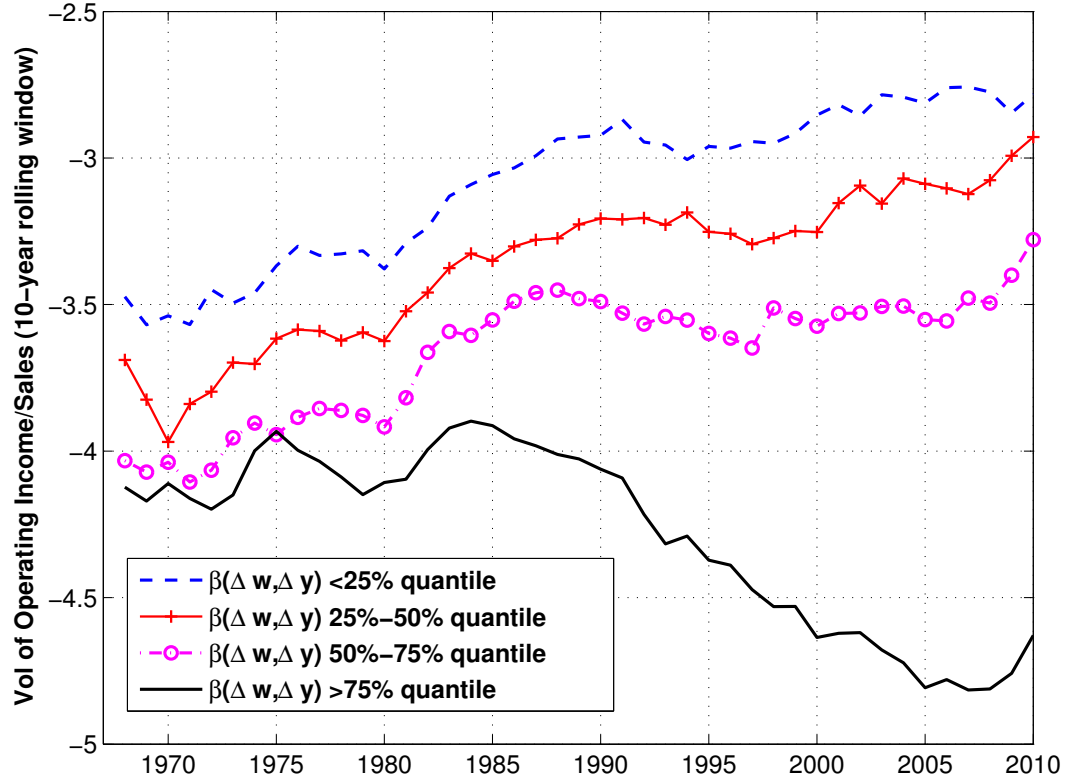
## 1.10 Figures

Figure 1.2: Firm-Level Cash Flow Volatility



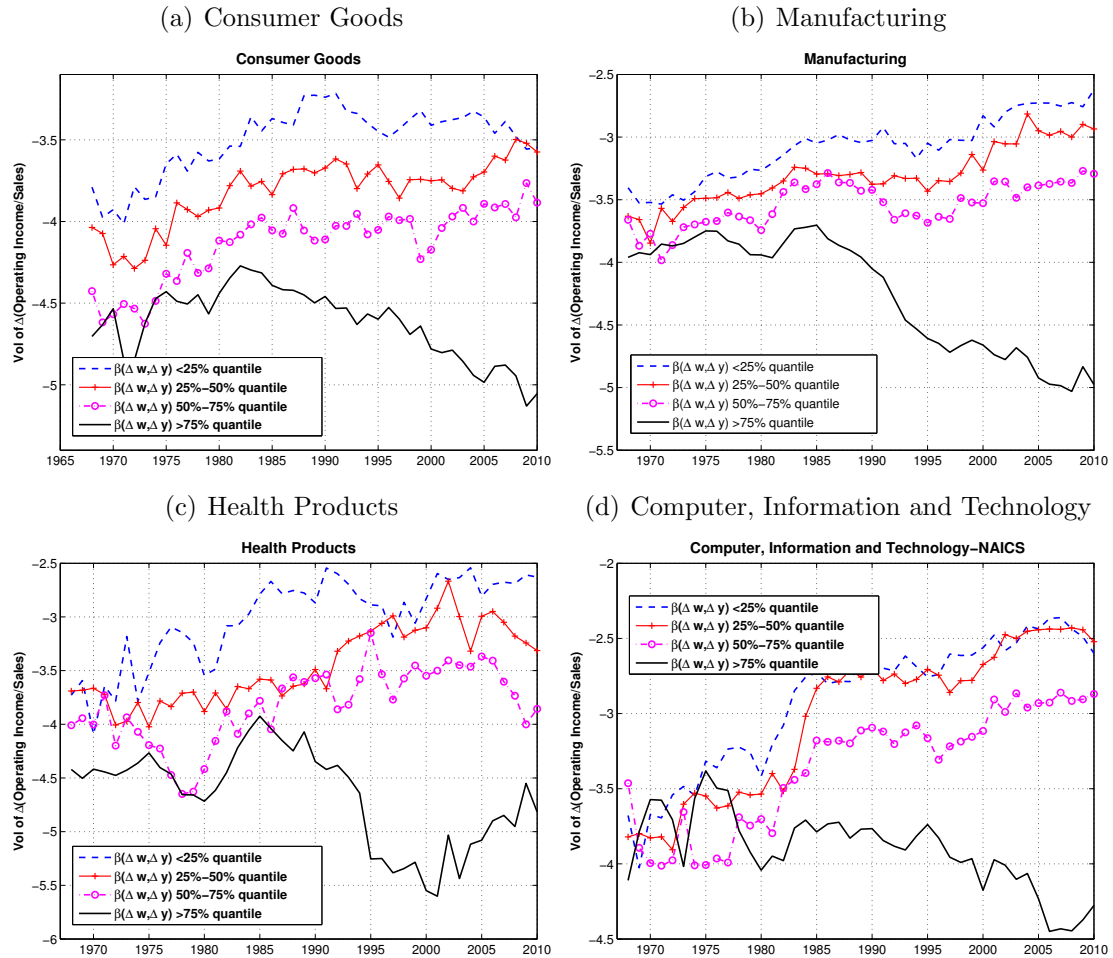
The figure reports the cash flow growth volatility at the firm level over 1960-2010. Cash flow growth is measured by  $\frac{CF_t - CF_{t-1}}{0.5 * Sales_t + 0.5 * Sales_{t-1}}$  (Bloom (2009), Jurado et al. (2013)), and cash flow is measured by operating income (OIBDP). The standard deviation of cash flow growth is estimated over a ten-year rolling window. The firm-level volatility is the log of the standard deviation. The figure plots the cross-firm average of volatility within an industry. Data Source: Compustat Fundamental Annual 1960-2010.

Figure 1.3: Operating Income/Sales Volatility of  $\beta(\Delta w, \Delta y)$  Group



The figure shows the time series of cash flow volatility for different wage-output sensitivity  $\beta_{w,y}$  quantiles. Cash flow growth is measured using operating income scaled by sales:  $\frac{oibdpt - oibdpt-1}{0.5Sales_t + 0.5Sales_{t-1}}$ . Volatility is estimated as the standard deviation of cash flow growth over a ten-year rolling window. Within each  $\beta_{w,y}$  quantile, firm-level volatility is computed by taking a simple average at each year.

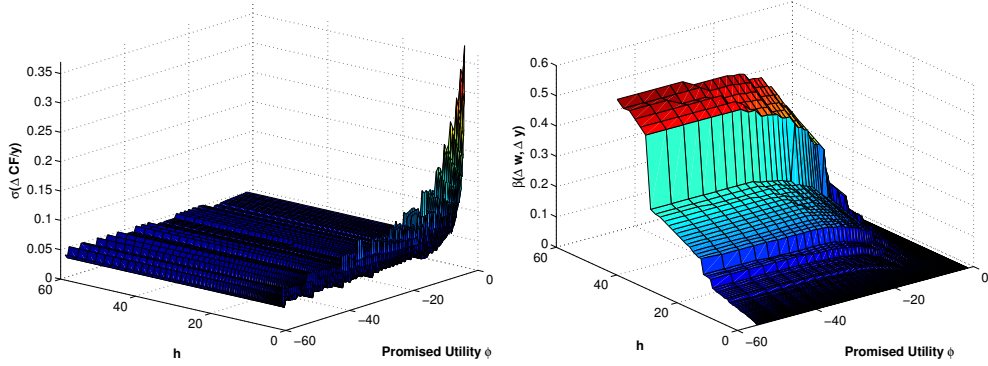
Figure 1.4: Within-Industry Operating Income/Sales Volatility of  $\beta(\Delta w, \Delta y)$  Group



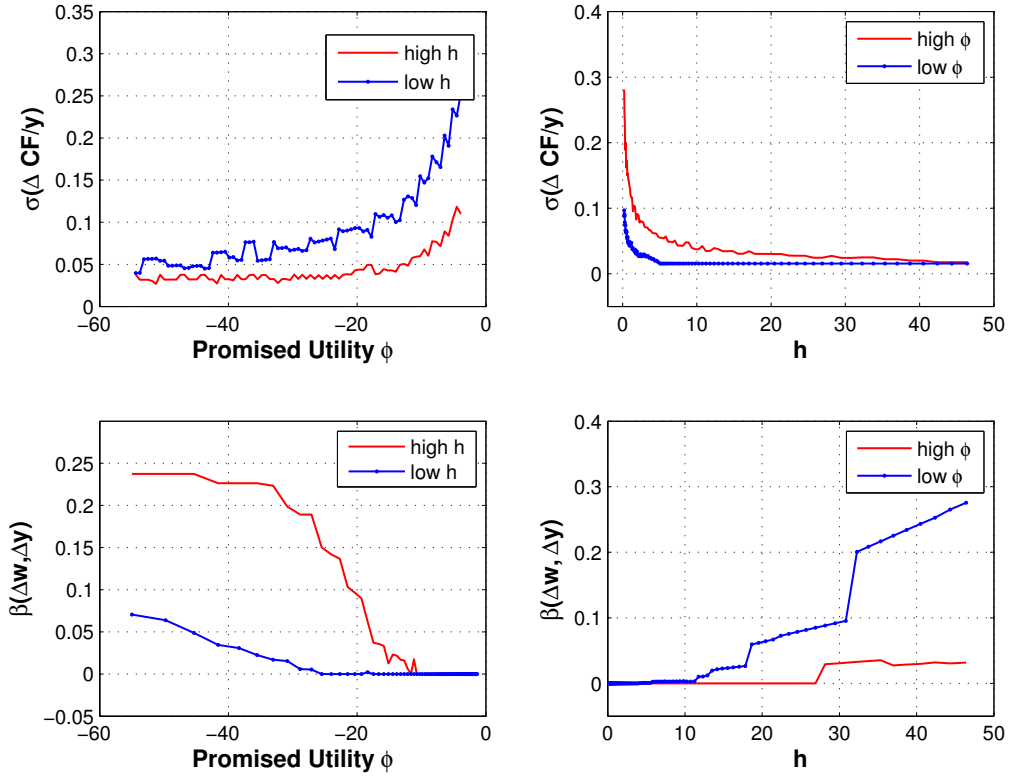
The figure shows the time series of cash flow volatility for different wage-output sensitivity  $\beta_{w,y}$  quantiles within-industry. Cash flow growth is measured using operating income scaled by sales:  $\frac{oibdpt - oibdpt-1}{0.5Sales_t + 0.5Sales_{t-1}}$ . Volatility is estimated as the standard deviation of cash flow growth over a ten-year rolling window. Within each  $\beta_{w,y}$  quantile, firm-level volatility is computed by taking a simple average at each year.



Figure 1.5: Policy Functions:  $\beta(\Delta w, \Delta y)$ ,  $\sigma(\Delta \frac{CF}{y})$   
 (a)  $\sigma(\Delta \frac{CF}{y})$  (b)  $\beta(\Delta w, \Delta y)$



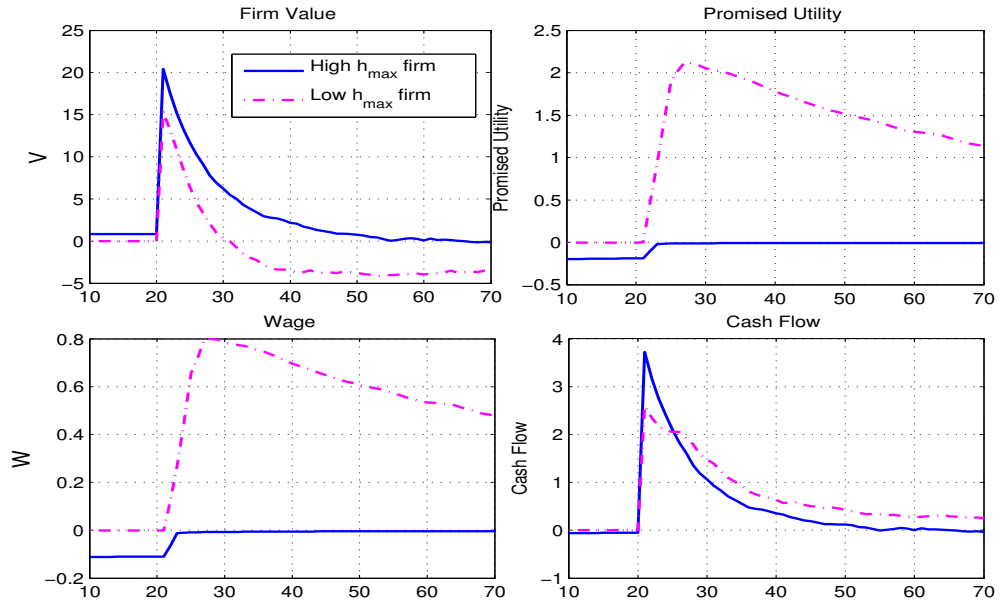
(c) Cross-Section of Policy Functions



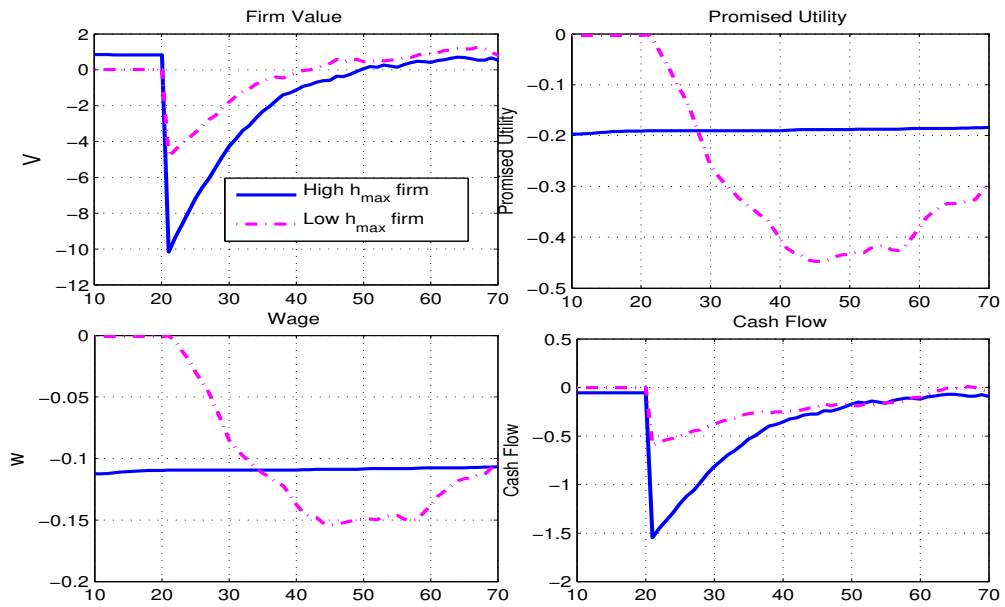
The figure reports the policy functions for  $\beta(\Delta w, \Delta y)$  and  $\sigma(\Delta \frac{CF}{y})$ . The parameter in the examples are  $\alpha = 0.85$ ,  $\gamma = 2$ ,  $\beta = 0.96$ ,  $\phi = 0.5$ ,  $\sigma = 0.3$ ,  $\rho = 0.7$ ,  $\xi_h = 3.2$ ,  $\delta_h = 0.2$ . The promised utility  $\phi$  represents  $h_{\max}$ . Figure (a) and (b) is obtained by fixing  $z$ , and the bottom panel are the cross-section of figure (a) and (b).

Figure 1.6: Impulse Response of a One-Standard Deviation Shock to  $z_t$

(a) Impulse Response to Positive Shock

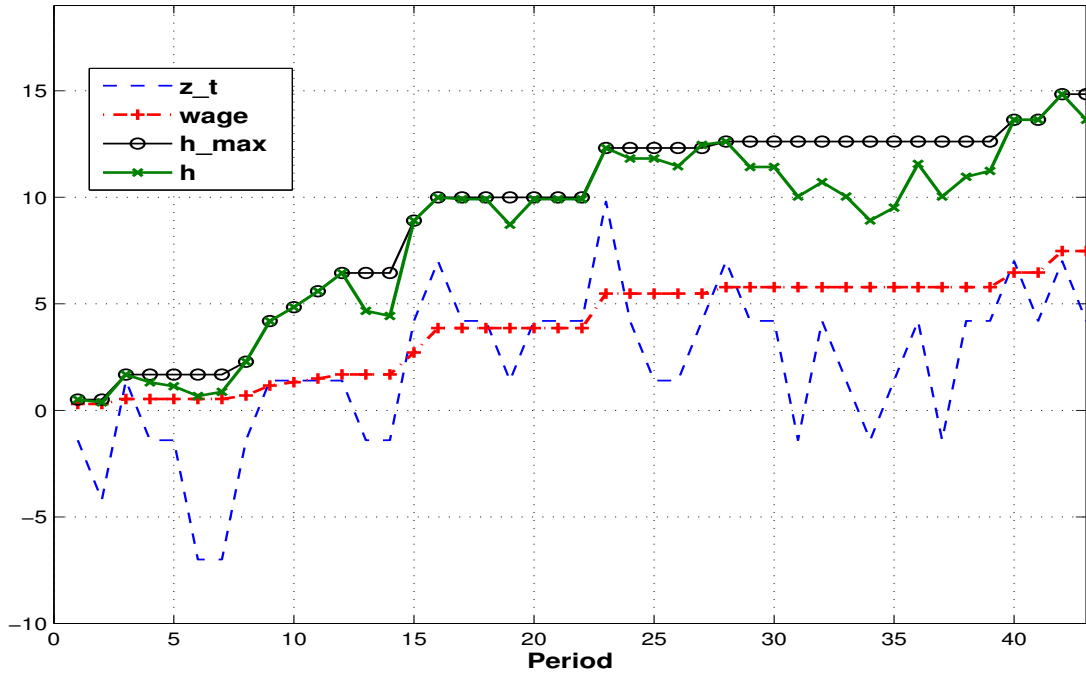


(b) Impulse Response to Negative Shock

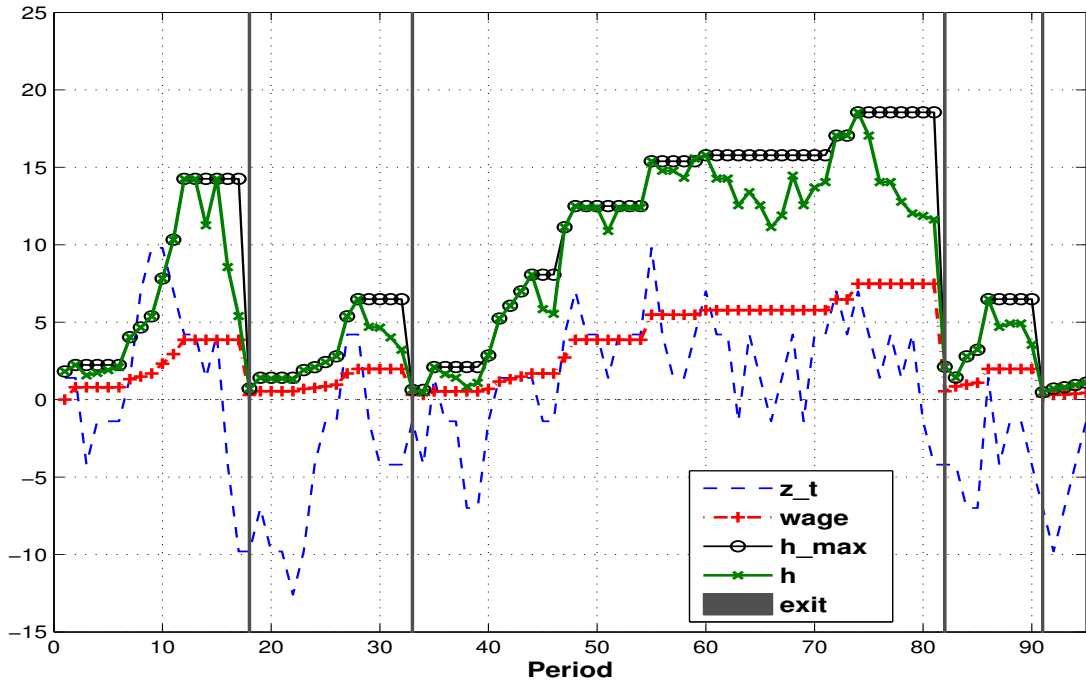


Impulse responses of cash flows and wage contracts to a one standard deviation shock to productivity level  $z_t$  of value function and policy function. Following Koop et al. (1996), all figures show the difference between the economy with and without the one standard deviation shock.

Figure 1.7: Wage Contract and Human Capital  
 (a) Optimal Wage Contract Before Exit

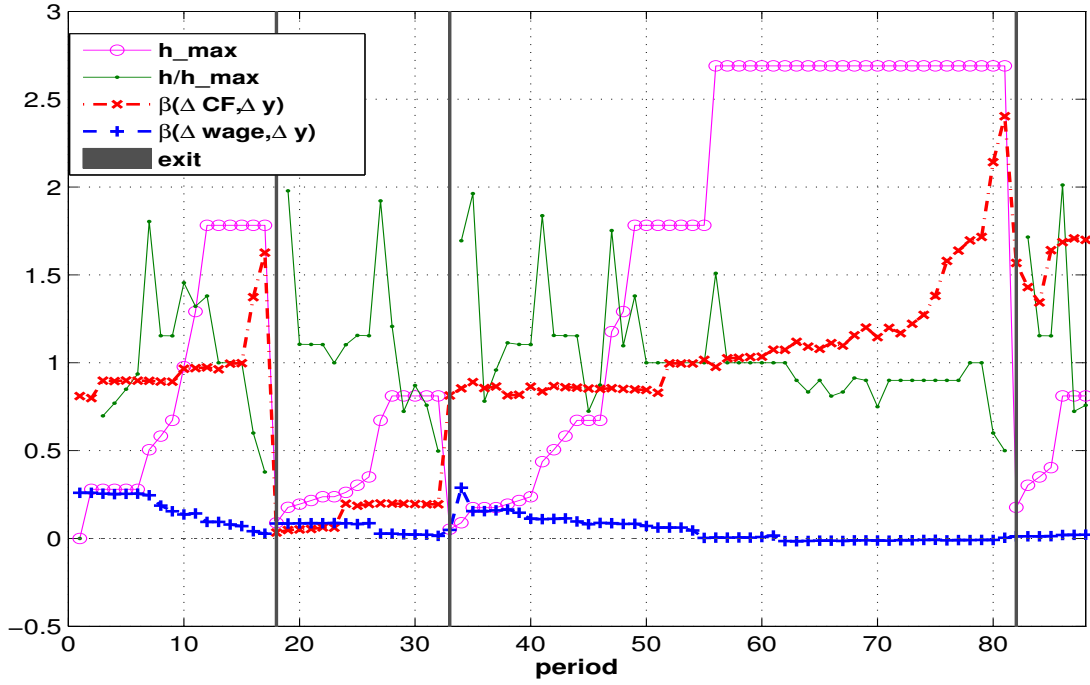


(b) Optimal Wage Contract With Exit

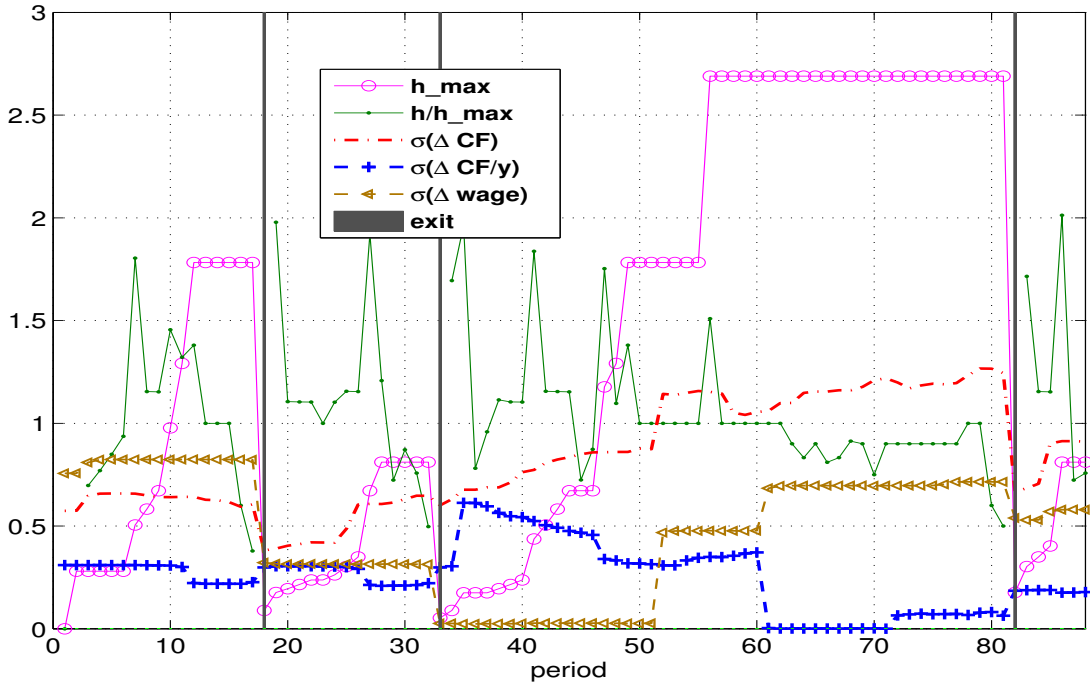


This figure plots the wage contract and its dynamics with respect to the human capital accumulation path. Figure (a) shows the wage contract dynamics before the termination of the match. Figure (b) shows the wage contract and the exit-and-entry dynamics, where the grey area indicates the termination of the capital-labor match. The unit of productivity shock  $z_t$  is scaled up ten times.

Figure 1.8: Risk Allocation in Equilibrium with Firm Dynamics  
 (a) Risk Allocation: Sensitivity

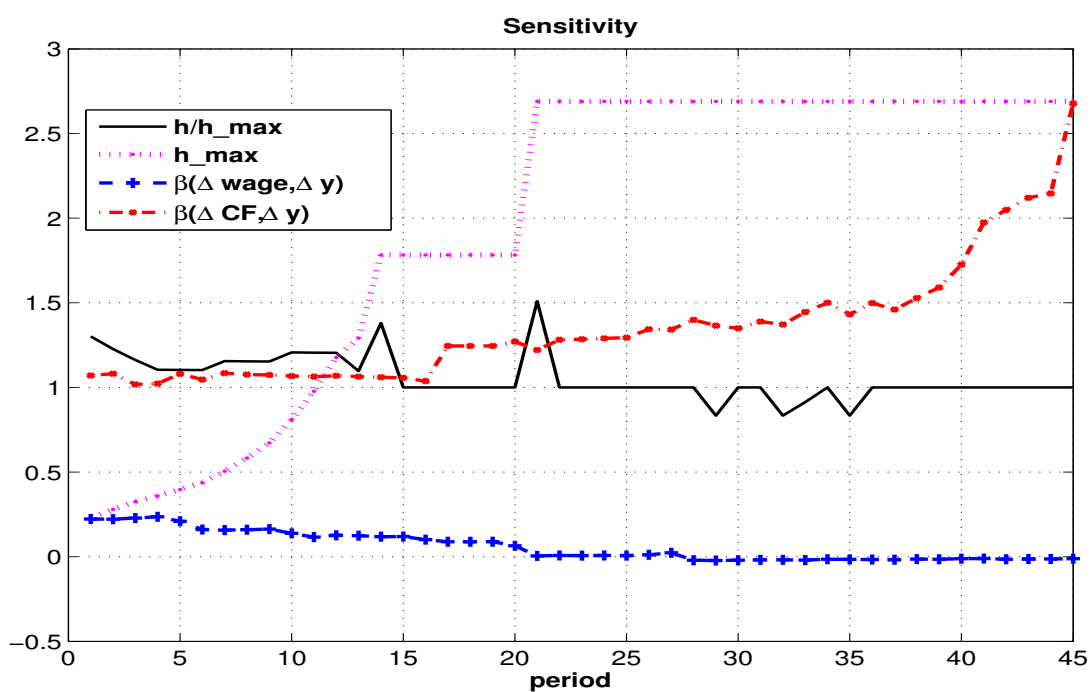


(b) Risk Allocation: Volatility

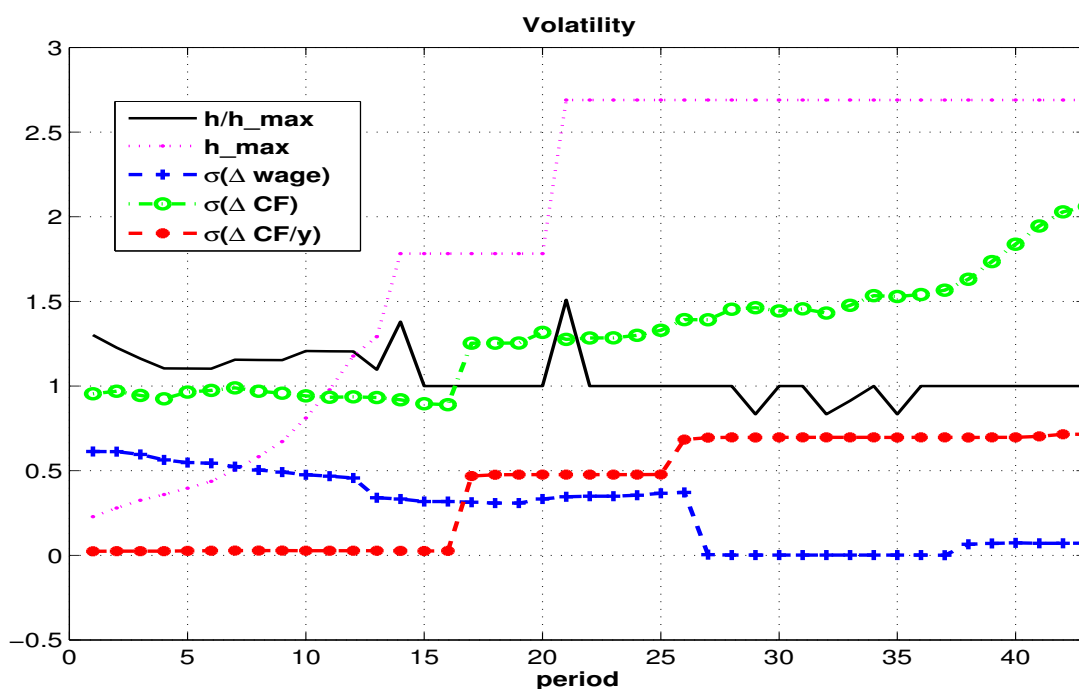


This figure shows cash flow volatility and contract sensitivity in equilibrium. Figure (a) shows the wage-output sensitivity with respect to the state variables. Figure (b) shows the wage growth volatility and cash flow volatility with respect to the state variables. The grey area indicates the stopping time of the contract.  $h_{\max}$  is scaled to the one-tenth of its original value.

Figure 1.9: Risk Allocation in Equilibrium  
 (a) Risk Allocation: Sensitivity

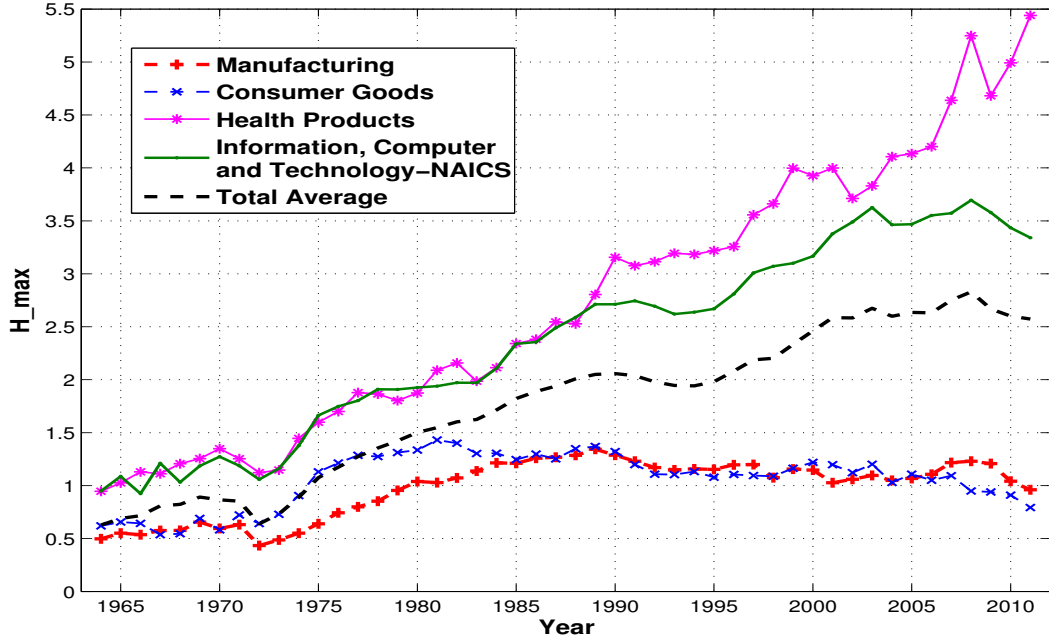


(b) Risk Allocation: Volatility

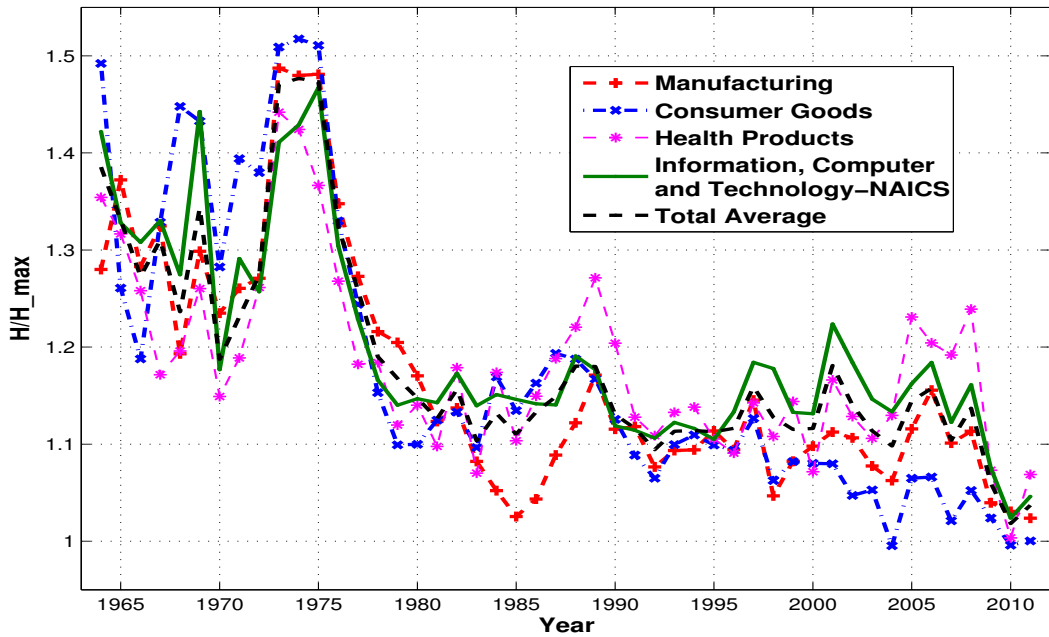


This figure shows the equilibrium risk allocation in the simulated economy. Cash flow-output sensitivity and wage-output sensitivity are measured by the regression coefficient of cash flow/wage growth on the output growth  $\Delta y$ . I estimate the regression coefficient the volatility  $\sigma_t$  at time  $t$  using ten periods (forward) simulated data points.

Figure 1.10: Time Series of State Variables: Industries  
 (a) Time Series of  $h_{\max}$  in Industry Groups



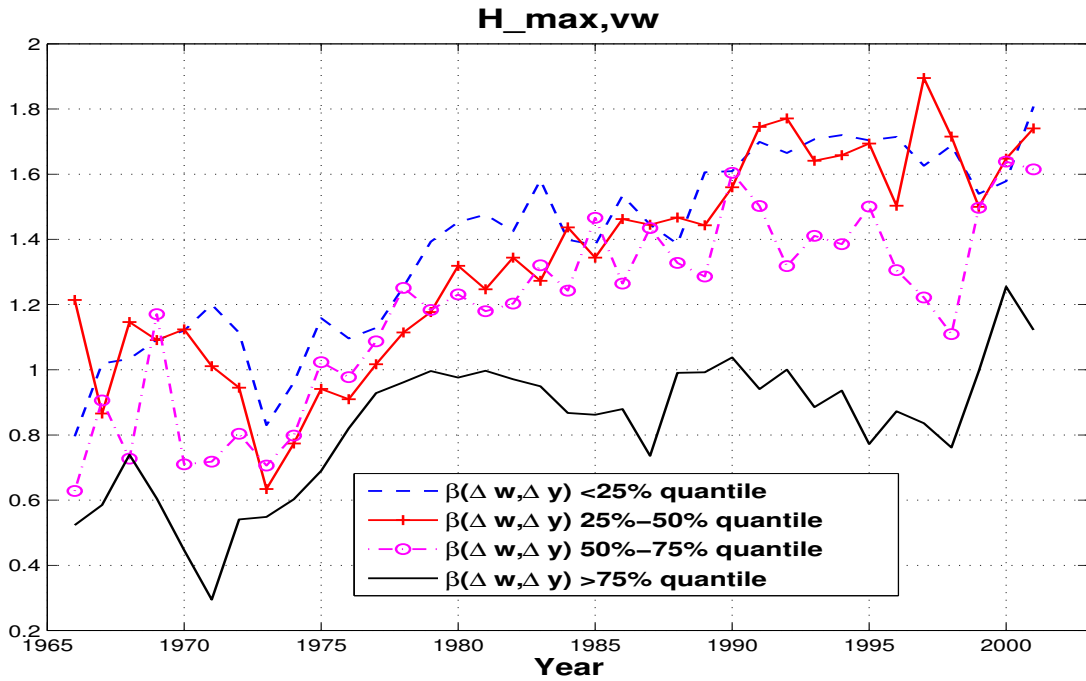
(b) Time Series of  $\frac{h}{h_{\max}}$  in Industry Groups



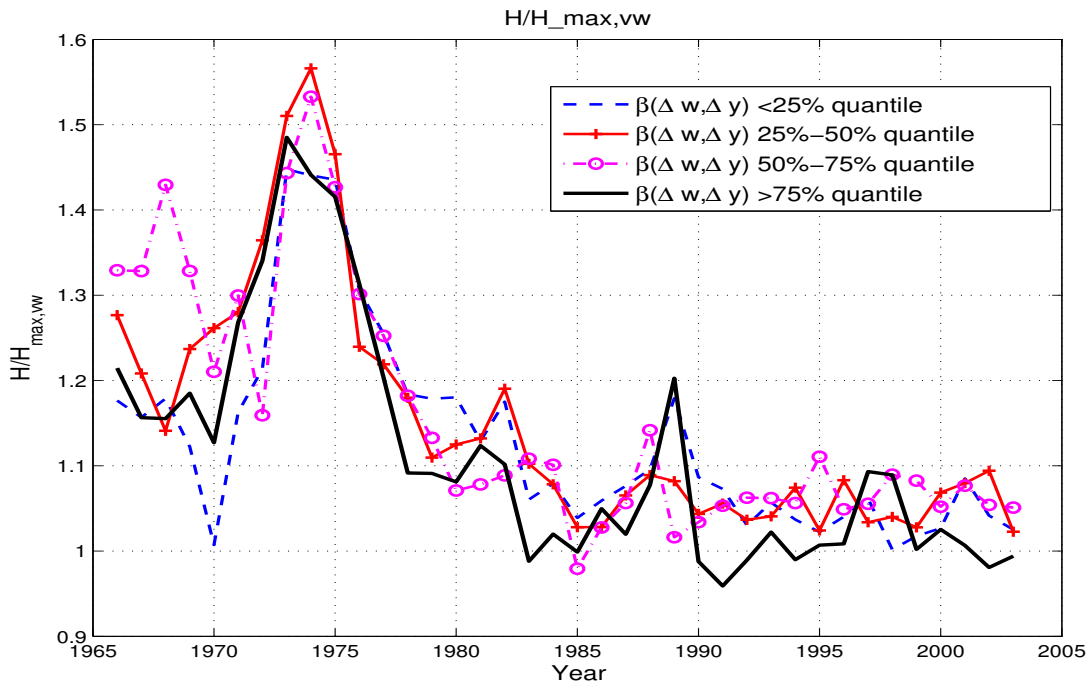
The figure shows the time series of the average  $\hat{h}_{\max}$  and  $\frac{\hat{h}_t}{\hat{h}_{\max,t-1}}$  for different industries. The sample is from the Compustat Fundamental Annual 1960-2010.  $\hat{h}_{\max}$  and  $\frac{\hat{h}_t}{\hat{h}_{\max,t-1}}$  are averaged across firms within an industry. The details of measurement and data construction are in Appendix 1.8.

Figure 1.11: Time Series of State Variables in  $\beta_{w,y}$  Groups

(a) Time Series of  $h_{\max}$  in  $\beta_{w,y}$  Groups



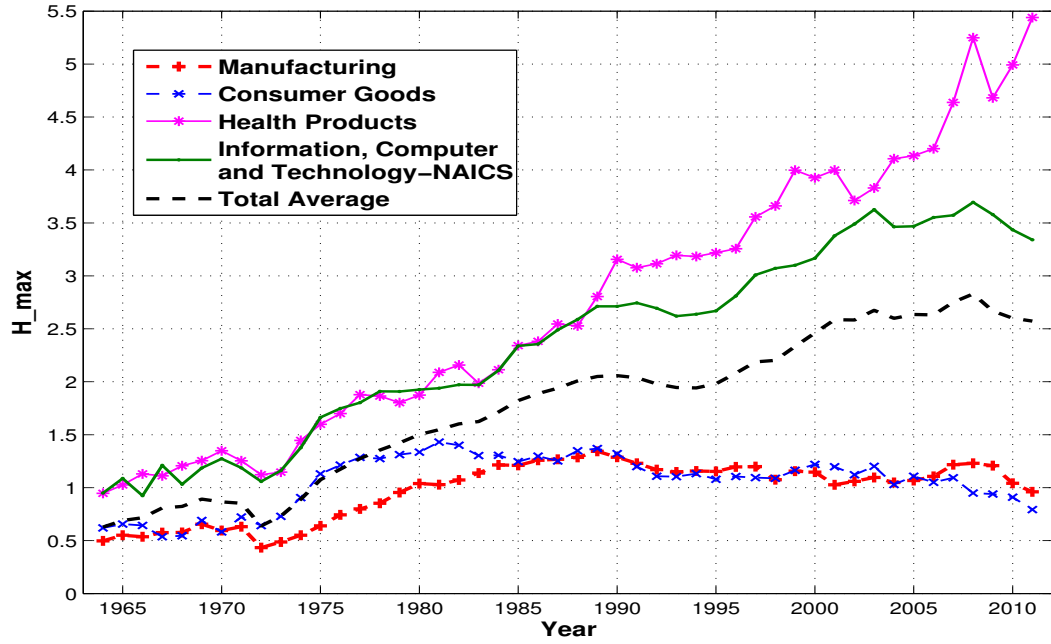
(b) Time Series of  $\frac{h}{h_{\max}}$  in  $\beta_{w,y}$  Groups



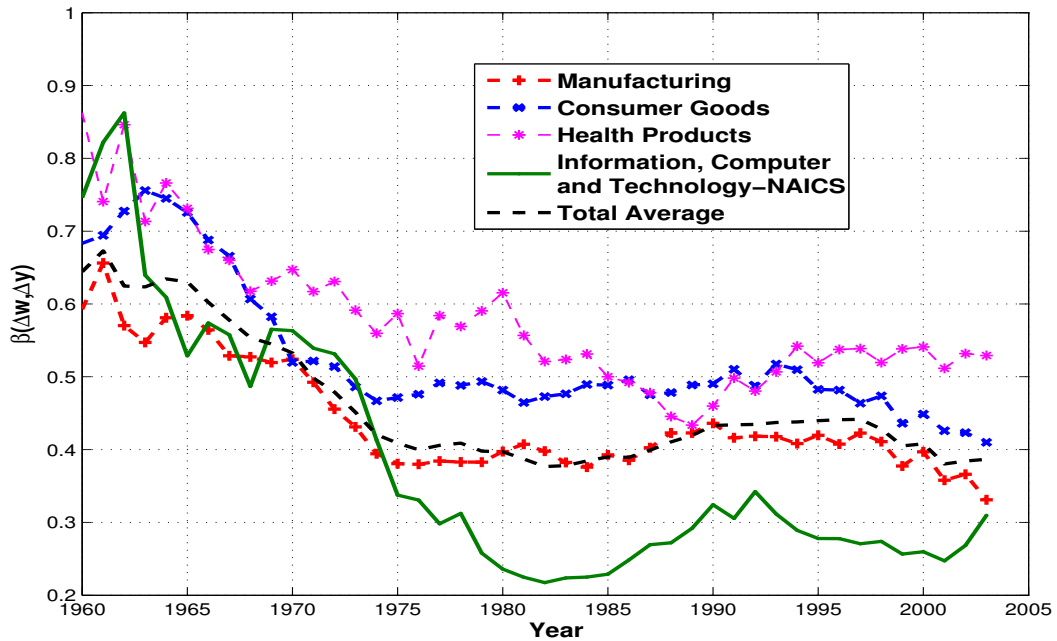
The figure shows the time series of  $h_{\max}$  and  $\frac{h}{h_{\max}}$  for different wage-output sensitivity  $\beta_{w,y}$  quantiles.  $h_{\max}$  is measured as the value-weighted firm-level human capital estimate  $h_t$  over the past five years.  $\frac{h}{h_{\max}}$  is the ratio between the current year firm-level human capital and the last year maximum human capital level,  $h_{\max,t-1}$ . Within each  $\beta_{w,y}$  quantile,  $h_{\max}$  and  $\frac{h}{h_{\max}}$  are computed by taking a simple average at each year.

Figure 1.12: Time Series Historical Maximum of Firm-Level Human Capital and Wage-Output Sensitivity

(a) Industry  $h_{\max}$



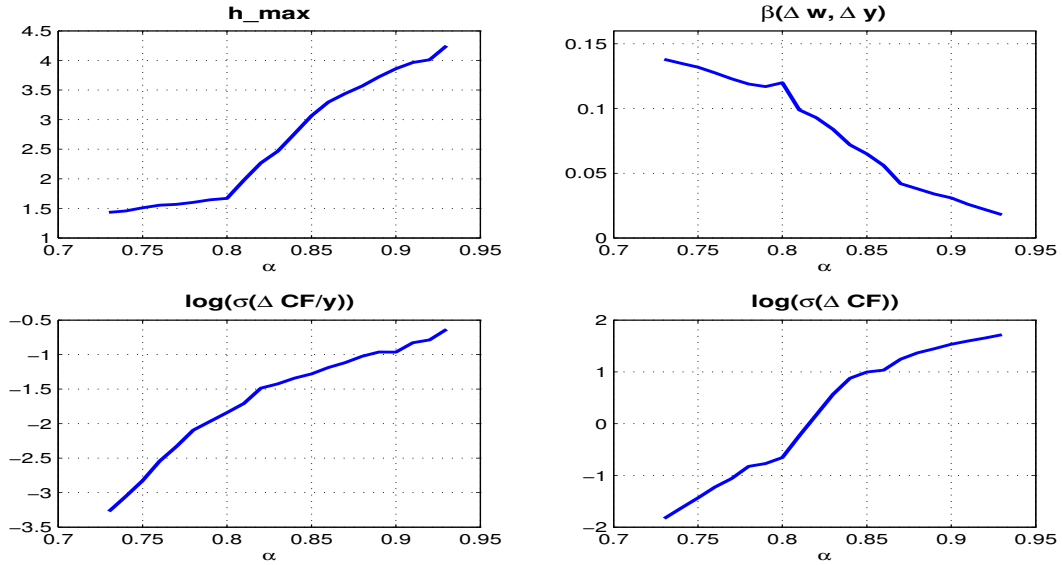
(b) Industry  $\beta(\Delta w, \Delta y)$



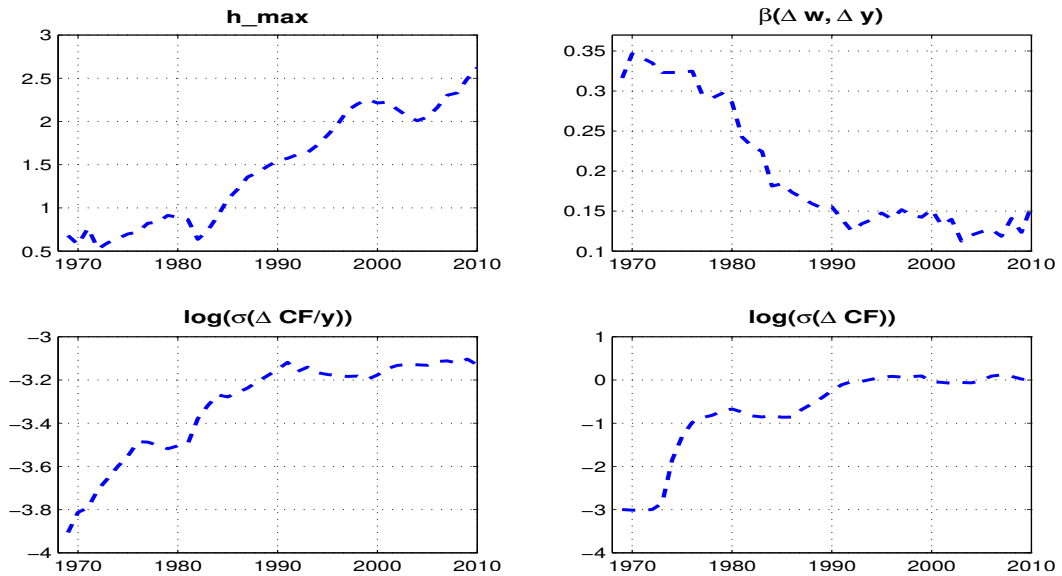
The figure shows the time series of historical maximum of firm-level human capital and wage-output sensitivity for different industries. The maximum human capital level  $h_{\max}$  is measured by the value-weighted  $h_t$  over the past five years and scaled by the physical capital stock over the same period. The wage-output sensitivity at the industry level is the average of wage-output sensitivity estimates of firms within the industry. Sample period: 1960-2010.



Figure 1.13: Comparative Statics in  $\alpha$  and Time-Series Cash Flow Volatility  
 (a) Comparative Statics:  $\alpha$



(b) Volatility and Sensitivity Time Series



This figure shows the volatility and sensitivity of wages and cash flows estimated from the simulated economy under different choices of  $\alpha$ . Simulate the economy for each  $\alpha$  ( $\alpha$ -simulated economy) under the same procedure described in Appendix 1.7.5.3. *CF* stands for cash flow. The standard deviation is computed within a ten-year rolling window. Sensitivity  $\beta$  is computed within a ten-year rolling window. I average both across firms within each  $\alpha$ -simulated economy. The volatility is the log standard deviation.

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## CHAPTER 2

# Financing Intangible and Capital Structure Dynamics

with Qi Sun

### 2.1 Introduction

Intangible capital has been increased dramatically over the last three decades (Falato et al. (2013), Corrado et al. (2006), etc.). The increasing reliance on the intangible capital in the production makes the financing needs of intangible the main task for the modern corporations. Financing intangible investment is a very different task from physical investment financing because the fact that intangible capital is embedded with the workers leads to complicated incentive issues. Intangible capital is becoming the key input of the production function, but how firms finance intangible capital and how the accumulation of this capital affects the financial structure of firms are rarely studied in finance literature.

In this paper, we explore the capital structure decision by first documenting the interesting patterns of both the intangible capital investment and firms' financing choice in the U.S. publicly traded firm sample. Two stylized facts are found in the sample. (1) Tangible investment is correlated with debt issuance, while intangible investment is highly associated with employee equity issuance. (2) Firms with relatively high intangible capital accumulation have low financial leverage. We show that the facts are robust across industries with a small variation. The data

suggest that there is a link between the fundamental economic forces and the financial choices, which still remains unresolved in the corporate finance literature.

We develop a new theory to model the financing channel through a non-financial contract, and further quantify the financial effects of intangible capital accumulation. In the model, firms produce final goods using the intangible capital, which is embedded in their employees. Firms have access to the credit market, where the intangible investment can be financed through issuing self-enforcing (collateralized) debt contracts to external investors. Also firms promise long-term wage contracts to retain the risk averse employees with limited commitment to stay in the production.

The optimal wage contract under limited commitment with endogenous capital accumulation relates the dynamics of incentive provision and the dynamics of financing. The long-term wage contracts trade off between insurance and incentive provision. Whenever the incentive motive dominates, firms defer the wage payment by cutting the current wage bill and raising workers' future consumption, i.e. firms borrow directly from workers who own the intangible capital. When the insurance motive dominates, firms provide smooth consumption to the workers. Shareholders obtain net worth larger than they could have had if they pay spot market wages to the workers, hence firms borrow from debt holders because of larger debt capacity but also more buffers are needed to prevent the future downturn.

The intangible capital accumulation have two effects on firm's financial decision making through the long-term wage contracts. The accumulation in intangible severs the "hold-up" problem between employees and firms, so more incentive provision are needed and debt capacity shrinks. This is the *overhang* effect from capital accumulation. Moreover, firms save liquidity buffers to prevent the fundamental downturn when firms need to pay the average wage higher than the market rate and also to pay back the financial debt. The unused debt capacity is due to

the precautionary motives.

We structurally estimate the model and quantify the effects of long-term wage contracts on firms' capital structure decision. Through the structural estimation, we are able to quantify the shadow borrowing cost from debt contract with the presence of wage contract, not just in full sample but also within industries. The full sample estimation shows that the model fits the data reasonably well in explaining the first and the second moments of leverage ratio. Also, model matches the high correlation between intangible investment and employee financing and low correlation between intangible investment and debt issuance.

In order to quantify the effects of changes in intangible capital accumulation on financing dynamics, we conduct the estimation into two split samples: information, computer and technology industry and manufacturing industry, whose leverage ratio and the financing dynamics are very distinguished. The estimation results confirm the model implications and also quantitatively identify the overhang effect and precautionary effect. We estimate the parameters that describe the capital generality in different industries, which we find is significantly different across industries. Compare the cases where workers' outside option is subject to different capital generality, we find that firms that have low debt capacity are firms in industries whose intangible capital is more general. More importantly, firms in high capital generality industries do not save buffers to prevent both financial distress and economic distress (as in the cash hoarding literature Bates et al. (2009), etc.), however, they borrow to finance investment through a non-financial channel which is economically significant and efficient.

Our paper contributes to the literature on understanding the determinants of firms' capital structure starting Miller (1977), with the special focus on the interesting characteristics of intangible capital accumulation. As in Berk et al. (2010), where the optimal debt level is shown consistent with the empirical findings with the introduction of the bankruptcy cost of human capital, our paper

emphasizes on the impact of endogenous accumulation of intangible capital on the leverage ratio and also the dynamics of financing. Compared to Berk et al. (2010), we explore the financing implications of this optimal employee contract. Related to Hennessy and Whited (2005), Hennessy and Whited (2007), we model the financing needs from investment on the intangible capital, not on the tangible capital, and we are the first that provide the theoretical underpinning of financing through non-financial contracts. Our model shares the same property, limited commitment, as in Li et al. (2014), Rampini and Viswanathan (2013), etc., but we explore the quantitative impact of intangible investment on capital structure. The race here is between the tightness of financial and economic constraints, instead of between the taxes benefit and bankruptcy costs.

Our theory fits into the literature on dynamic contracting with limited commitment. Closely related to Michelacci and Quadrini (2005), our paper provide quantitative examination on the interaction between the long-term wage contract and financial contract. Consistent with the predictions in Michelacci and Quadrini (2005) on the correlation with size and wages, we focus on the correlation with financing dynamics and wages. Theoretical papers use limited commitment (starting Harris and Holstrom (1982)) to understand variety of subjects as labor economics (Thomas and Worrall (1988), financial constraints and firm size (Albuquerque and Hopenhayn (2004)), investment (Quadrini et al. (2012), Schmid (2008)), macroeconomic dynamics (Cooley et al. (2004), etc.) and risk management (Rampini and Viswanathan (2010)). However, our paper is among one of the very few that quantify the financial effects of the limited commitment on the labor sector in the firm.

We conduct structural estimation to evaluate the different financial effects from the intangible capital investment. Related to the stream of the literature is the structural estimation of dynamic models in corporate finance, such as Hennessy and Whited (2007), Taylor (2010), Li et al. (2014), etc. We are not only interested

in the exogenous parameters on agency friction and financial constraints, but also we derive the optimal financial contract endogenously and quantified the implicit marginal cost of borrowing through different financing channels.

Our empirical findings are also new to the literature on corporate investments and the rising attention on the importance of intangible capital in corporations (Corrado et al. (2004), Eisfeldt and Papanikolaou (2013), etc.). Brown et al. (2009) found significant effects of cash flow and external equity for young firms on R&D investments. Benmelech et al. (2011) demonstrates the responsiveness of firms' employee decision on their financial health is quantitatively similar to the responsiveness of investment decision to cash flows. Our evidence is consistent with their findings, and we further decompose the external equity financing and found the strong correlation between employee-initiated equity issuance and R&D (or more generally, intangible capital) investment. Our findings contributes to the understanding on the ownership of intangible capital (Eisfeldt and Papanikolaou (2014)), and the different financing patterns indicates the distinguished properties from physical capital.

The rest of the paper is organized as follows. Section 2.2 describe the evidence on financing and investment patterns in the Compustat sample. Section 2.3 introduces the model. Section 2.4 and 2.5 analyze the model results and predictions. Section 2.6 describes the model solution. Section 2.7 reports the estimation results and Section 2.8 concludes.

## **2.2 The Evidence**

In this section, we describe the empirical findings on the financing and investment patterns in the Compustat sample.

### 2.2.1 Measurement

We measure intangible capital investment using two proxies. First, we use the annual data on expenses in three categories of intangible investment (following Corrado et al. (2004), Corrado et al. (2006), etc.): knowledge capital, organizational capabilities, and computerized information and software. In the Compustat sample, the accounting proxy for the relevant expenses is the past sales, general and administrative (SG&A) expenses (Lev and Radhakrishnan (2005), Hulten and Hao (2008), Eisfeldt and Papanikolaou (2013), etc). Those expenses are considered to enhance the value of brand names and other knowledge embedded in the firm-level human capital and structural resources, and include employee training costs, payments to white collar employees and consultants, etc. The second proxy for intangible capital investment used is the R&D expenses, which are the innovation and knowledge capital in the firm. The R&D expenses includes the investment to improve the innovation property including human resources and computerized information and software in the innovation department.

We follow the standard in the corporate finance literature to measure the financing dynamics. The net debt issuance as long-term debt issuance minus long-term debt reduction (DLTIS-DLTR). The construction of measurement on employee equity issuance and regular equity issuance is following McKeon (2013). We define employee equity issuance as those share issuances with proceeds below 3% of end-of-period market equity ( $SSTK1 : \frac{SSTK}{CSHO*PRCC_F} \leq 3\%$ ), and regular equity issuance as those with proceeds above 3% of end-of-period market equity ( $SSTK2 : \frac{SSTK}{CSHO*PRCC_F} \geq 3\%$ ).

### 2.2.2 Stylized Facts

Following Covas and Den Haan (2011), for each variable, we sum across firms to obtain an aggregate time series.



Figure 2.2 plots the time series of the aggregate tangible investment, intangible investment and financing dynamics of the U.S. publicly traded firm sample from 1970 to 2010. In Figure 2.2(a) shows high correlation between the tangible investment and debt issuance, while in Figure 2.2(b), the intangible investment is highly associated with employee equity issuance. The similar pattern is observed if we look at the average time series, as in Figure 2.4 (a) and (b).

We further decompose the equity issuance into firm-initiated regular equity issuance and employee-initiated equity issuance. In Figure 2.3(a), we compare the time series between intangible investment and different equity issuance components. The high correlation between intangible investment and the equity issuance is mainly from the correlation with employee-initiated equity issuance. The fact is also robust if we use R&D as proxy for intangible investment.

The correlation between intangible investment and equity issuance is not homogeneous cross sectionally. In Figure 2.5 and Figure 2.6, we observe that the correlation in information, computer and technology industry is about 0.94, much higher than that in manufacturing, 0.63. The empirical evidence points two interesting findings: 1) debt contract is not the main vehicle for intangible capital financing; 2) the level of accumulated intangible capital matters for firms' financial decision making.

### **2.3 A Model of Wage Contract with Financial Frictions**

In this section, we study a model of financing intangible capital investment. Intangible capital is embedded with workers, who can walk away from the wage contract whenever better outside options are available. To retain the workers, firms offer long-term wage contracts that allow for implicit borrowing from workers. Firms also issue standard debt contracts to finance investment. The model illustrates the dynamic rent-splitting rule among the shareholders, debt holders,

and workers and the implications on the liability allocation (financial liability vs. employee financing) and capital structure (liability vs. equity) of the firm.

### 2.3.1 The Economy

We consider an economy with frictional capital market and labor market.

**Technology** Firms, owned by risk neutral shareholders, conduct production with intangible capital  $h_t$ .

$$y_t = \exp(z_t)h_t^\alpha, \quad 0 < \alpha \leq 1, \quad (2.1)$$

subject to an i.i.d. idiosyncratic technology shock,  $z_t \sim Q(z_t|z_{t-1})$ , where  $Q(z_t|z_{t-1})$  is a stationary and increasing Markovian transition function.

The intangible capital is embedded with the workers, but the investment decision  $e_t$ , is made by the firm. The human capital evolves according to

$$h_{t+1} = (1 - \delta)h_t + \phi\left(\frac{e_t}{h_t}\right)h_t, \quad (2.2)$$

where the function  $\phi(\cdot)$  specifies the capital adjustment cost which is concave in  $e_t$  and decreases with  $h_t$ . The concavity of  $\phi(\cdot)$  captures the idea that quick adjustment of capital stock is more costly than slow adjustment.

**Debt Contract** Because interest payments to debt holders are tax deductible, firms have incentives to issue debt contracts. Firms issue single-period debt contracts at par  $b_{t+1}$  at the end of period  $t$ , with an effective interest rate  $R_t$ . The tax shield of debt contract gives  $R_t < \frac{1}{\beta}$  as assumed in Jermann and Quadrini (2012) and Hennessy and Whited (2005), where  $\beta$  is the firm owner's discount factor. Following the idea of Kiyotaki and Moore (1997), we consider the enforcement constraint on the firm to rule out the case in which firms issue debt contracts that

they cannot pay back:

$$\frac{b_{t+1}}{R_t} \leq \beta \xi_t E_t[V_{t+1}], \quad (2.3)$$

where  $E_t[V_{t+1}]$  is defined as the discounted value of the firm's dividend flows  $E_t \left\{ \sum_{s=t+1}^{\infty} \beta^{s-t} d_t \right\}$ , and  $\xi_t$  is the collateral rate governed by the capital market conditions. The debt capacity for the firm at time  $t$  depends the firm's net present value and financing conditions. The higher the debt level, the tighter the enforcement constraint.

**Wage Contract** Risk-averse workers are employed by the firm. Workers are endowed with preference  $u(\cdot)$ , where  $u'(\cdot) > 0, u''(\cdot) < 0$ , and have no access to the saving technology. Wage contract is the only technology for consumption smoothing.

Although the intangible capital is invested by the firm, it is portable with the worker. As a result, the firm pre-commits to a long-term wage contract to retain the worker in the production. The wage contract specifies the complete contingent compensation plan, and then determines how workers share the capital rent with the firm. However, the worker cannot commit to the wage contract, meaning that whenever the available outside option is higher than the current wage contract, the worker can walk away. The outside option is defined by the autarky where in each period the worker earns a spot wage rate  $a_t = \eta \exp(z_t)$  given his intangible capital, where  $\eta < 1$  governs the labor market mobility or the generality of the intangible capital embedded with the worker, and the constant  $z_t$  represents the productivity shock. The worker with the level of intangible capital  $h_t$  has the outside option exogenously specified as follows:

$$\omega(h_t) = \omega_0 + E_t \left\{ \sum_{s=t}^{\infty} \beta^{s-t} u(a_t h_t) \right\}, \quad (2.4)$$

where the discount factor of the worker is also  $\beta$ . Further, we assume  $\omega_0 \leq 0$  to make sure that it's socially optimal to retain the workers in the firm. The outside option is defined as the lifetime utility achieved by the consumption from re-entering the spot labor market each period, with the capital level  $h_t$ .

### 2.3.2 The Firm's Optimization Problem

The firm makes optimal choice on intangible capital investment, debt contract issuance and long-term wage contract by maximizing the discounted cash flow for the shareholders over the life time. Each period, the shareholders obtain the net payout  $d_t$  from the production after paying the wage  $c_t$ , investment in intangible capital and net debt issuance.

The firm commits to a long-term wage contract that promises a complete contingent consumption  $\{c(z^t)\}_t^\infty$  that maximizes the total expected payoff of the worker subject to the initial utility  $m_0$ :

$$m_0(z^t) = E_0 \left\{ \sum_{t=0}^{\infty} \beta^t u(c_t(z^t)) \right\} \quad (2.5)$$

where  $z^t = \{z_0, z_1, \dots, z_t\}$  is the entire history of productivity  $z$ . In order to solve the wage contract, we need to solve for all the wage payments contingent on the entire history  $z^t$ . To make the problem recursive, the worker's promised expected utility is treated as a new state variable  $m_t(z_t) = E_t \{ \sum_{s=t}^{\infty} \beta^{s-t} u(c_{s+1}) | z_t \}$  (See Appendix 2.9.1 for the equivalence of the recursive contract and the original contract). So now, the firm commits to deliver the promised utility  $m_t(z_t)$  today by delivering current consumption  $c_t(z_t)$  and committing to the state contingent promised utility  $m_{t+1}(z_{t+1}), \forall z_{t+1}$  tomorrow, which is characterized by the following promise-keeping constraint:

$$m_t = u(c_t) + \beta E_t[m_{t+1}] \quad (2.6)$$

Since the worker has limited commitment to the wage contract, the participation constraint of the worker in any  $h_{t+1}$  is given by:

$$\beta m_{t+1}(z_{t+1}) \geq \beta \omega(z_{t+1}, h_{t+1}), \quad \forall z_{t+1}, h_{t+1}. \quad (2.7)$$

The promised utility  $m_{t+1}$  is the labor liability which the firm commits to the worker at time  $t$ .

**Optimization Problem** We write down the firm's optimization problem  $\mathcal{P}$  recursively:

$$V(h, m, b; z) = \max_{e, c, m'(z'), b'} \left\{ d + \beta \mathbb{E}[V'(h', m'(z'), b'; z'|z)] \right\}$$

subject to:

$$\lambda \quad : \quad d = e^z h^\alpha - c - e + \frac{b'}{R} - b \geq 0 \quad (2.8)$$

$$q \quad : \quad h' = (1 - \delta)h + \phi \left( \frac{e}{h} \right) h \quad (2.9)$$

$$\mu \quad : \quad \xi \beta \mathbb{E}[V'|z] \geq \frac{b'}{R} \quad (2.10)$$

$$\theta \quad : \quad m = u(c) + \beta \mathbb{E}[m'(z')|z] \quad (2.11)$$

$$\gamma(z') \quad : \quad \beta m'(z') \geq \beta \omega(h') \quad \forall z', h' \quad (2.12)$$

Equation (2.8) is the budget constraint with a non-negative dividend requirement, where we exclude the channel of regular equity issuance  $d \geq 0$  in this section to facilitate the understanding of the general model estimated in Section 2.6. From the budget constraint, wage payment  $-c_t$  serves as a financing channel for the shareholders in the same way as debt contract. Firms can borrow from workers by reducing the wage payment  $c_t$  when it is necessary.

**Properties** The optimization takes into consideration of the interactions between debt contracts and labor contracts. The firm optimally allocates the liability depending on both the tightness of the debt enforcement constraint (2.10), which is the *financial distress* of the firm, and that of the participation constraint (2.12), which is the *economic distress* of the firm. The total liability is governed by the tightness of the non-negative dividend constraint (2.8).

The model is solved numerically, but we describe the solution properties and the dynamic interactions between the financial contract and the labor contract by deriving the first-order equations and Euler equations. The function  $V(h, m, b : z)$  is the value of the firm. Let  $\lambda$  be the multiplier on the budget constraint,  $\varphi$  be the multiplier on the non-negative dividend constraint,  $q$  be the multiplier on the investment constraint,  $\mu$  be the multiplier on the debt enforcement constraint,  $\theta$  be the multiplier on the promise-keeping constraint and  $\gamma(z')$  be the multiplier on the participation constraint. The problem's first-order conditions associated with  $b'$ ,  $m'$ ,  $h'$ ,  $d$ ,  $e$  and  $c$  are:

$$b' : \mu = \beta R(1 + \mu\xi)E[V'_b|z] + \lambda \quad (2.13)$$

$$m' : \gamma = -(1 + \mu\xi)E[V'_m|z] - \theta \quad (2.14)$$

$$h' : q = \beta(1 + \mu\xi)E[V'_h|z] + \lambda\alpha zh^{\alpha-1} - \beta\gamma\omega'(h') \quad (2.15)$$

$$d : \lambda = 1 + \varphi \quad (2.16)$$

$$e : q = \frac{\lambda}{\phi'(\frac{e}{h})} \quad (2.17)$$

$$c : \theta = \frac{\lambda}{u'(c)} \quad (2.18)$$

and the Envelope conditions associated with  $b$ ,  $m$  and  $h$  are:

$$b : V_b = -\lambda \quad (2.19)$$

$$m : V_m = -\theta \quad (2.20)$$

$$h : V_h = \lambda\alpha zh^{\alpha-1} + q[(1-\delta) + \phi(\frac{e}{h}) - \phi'(\frac{e}{h})\frac{e}{h}] \quad (2.21)$$

Equations (2.13)-(2.21) completely capture the firm's problem. The detailed derivation of the optimization is in Appendix 2.9.3. The variable  $\lambda$ , as the shadow price of dividend, is interpreted as the marginal cost of borrowing from the external investors. The variable  $\theta$ , as the shadow price of wage payment, is also the marginal cost of borrowing from the workers. The variable  $\mu$ , which governs the tightness of the enforcement constraint, is the marginal cost of financial distress. The variable  $\gamma$ , which is the tightness of the participation constraint, captures the marginal cost of labor-liability distress.

## 2.4 Financing Intangibles with Wage Contract

Investment of the intangible capital creates financial need. In this model, financing can be achieved through borrowing from workers and debt holders.

### 2.4.1 Employee Financing

Optimal wage contract under limited commitment trades off between incentive and insurance provision.

The wage contract is the only vehicle for insurance provision in the economy. Under the assumption of perfect capital market and labor market, the first-best wage contract provides constant life-time consumption  $c^*$  to the workers given the initial consumption level. Assuming  $\{c_t\}_{t=0}^{t=\infty}$  is the consumption stream from the spot labor market each period.  $\tau^* = \sum_{t=0}^{\infty} c^*(c_0) < \sum_{t=0}^{\infty} c_t = \tau_s$ . Firms

extract rents from the wage contract by paying an average wage lower than the average spot market wage. The optimal wage contract defines the rent-sharing rule between the risk neutral owners and the risk averse workers.

However, the *dynamics* of wage contract affect the financing channel of the firm directly. The wage payment can be deferred to the future period to provide capital for investment in this period. We define the present value of life time consumption stream from the wage contract  $\tau(h, m, b; z) = c + \frac{1}{\beta}E[\tau(h', m', b'; z'|z)]$ .  $\tau$  is the overall value from the technology allocated to the employee, so  $\Delta\tau = \tau_{t+1} - \tau_t = -c_t$  is the net amount in the deferred compensation. When firms increase in the intangible capital level  $h_{t+1}$ , borrowing from the workers facilitates the incentive provision. When firms defer the wage payment to facilitate financing need, wage contract serves as a financing instrument by lowering the current wage bill.

By looking at the difference between  $\tau - \tau^*$ , we can infer the value of the firm obtain from insurance provision, while  $\tau_{t+1} - \tau_t$  captures the dynamics of financing from employees.

### 2.4.2 Wage Dynamics

We capture the dynamics of optimal wage contract and its interaction with debt financing.

**Lemma 3** *Given the firm's optimization problem  $\mathcal{P}$ , the shadow price of dividend  $\lambda'$  increases on average whenever the debt enforcement constraint (2.10) is not binding; while the shadow price  $\lambda'$  decreases when the enforcement constraint is tight enough:  $\mu > (1 - \beta R)\lambda$ .*

*Proof:* From F.O.C (2.13) and Envelope condition (2.19), we obtain

$$\mu = \lambda - \beta RE[\lambda'|z] \tag{2.22}$$



- When  $\mu = 0$ ,  $\lambda = \beta RE[\lambda'|z]$ . Thus,  $\lambda'$  increases on average, since  $\beta R < 1$ .
- When  $\mu > 0$ ,  $\lambda = \mu + \beta RE[\lambda'|z]$ . Thus,  $\lambda'$  decreases on average whenever  $\mu > (1 - \beta R)\lambda$ .

Lemma 3 describes the interactions between the cost of financial distress and the shadow price of net payout. From equation (2.16), the shadow price of dividend  $\lambda$  is higher than one when the dividend is close to zero ( $\varphi > 0$ ). Because of the tax shield of holding debt, firms would choose to pay out dividend by borrowing from debtholders if the debt enforcement constraint is not binding ( $\mu = 0$ ). However, the equity adjustment is irreversible ( $d \geq 0$ ). Issuing more debt contracts now means that the firm will be more likely to hit the non-negative dividend constraint in the future ( $\varphi > 0$ ). Thus, the shadow price of dividend  $\lambda'$  increases as the firm borrows more. On the other hand, when the debt enforcement constraint tightens ( $\mu > (1 - \beta R)\lambda$ ), firms issue less debt and the shadow price of dividend  $\lambda'$  decreases.

**Lemma 4** *Given the firm's optimization problem  $\mathcal{P}$ , the shadow price of consumption/wage  $\theta'$  decreases over time whenever the workers' participation constraint (2.12) is not binding; while the shadow price  $\theta'$  increases when the participation constraint is tight enough:  $\gamma > \mu\xi\theta$ .*

*Proof:* From F.O.C. (2.14) and Envelope condition (2.20), we obtain:

$$\gamma = -\theta + (1 + \mu\xi)\theta' \tag{2.23}$$

- When  $\gamma = 0$ ,  $\theta' = \frac{\theta}{1 + \mu\xi}$ . Thus,  $\theta'$  decreases on average since  $\mu \geq 0$ .
- When  $\gamma > 0$ ,  $\theta' = \frac{\gamma + \theta}{1 + \mu\xi}$ . Thus,  $\theta'$  increases on average whenever  $\gamma > \mu\xi\theta$ .

Lemma 4 describes the impact of tightness of participation constraint on the marginal cost of borrowing from workers. The marginal cost of borrowing from

workers is high when the shadow price of wages (consumption)  $\theta$  is high. When the workers' participation constraint is not binding  $\gamma = 0$ , the marginal cost of borrowing from workers decreases. Firms choose to borrow from workers as long as the cost of financial distress is positive ( $\mu > 0$ ). However, when the workers' participation constraint becomes tight enough ( $\gamma > \mu\xi\theta$ ), the marginal cost of borrowing from workers increases.

To prepare Proposition 4, we also define the marginal rate of substitution between dividend and consumption as the ratio of the shareholder's marginal utility of dividend and the workers' marginal utility of consumption:  $MRS_{static} \equiv \frac{\lambda}{u'(c)}$ . This ratio also captures the marginal cost of external financing  $\lambda$  in terms of the marginal utility of workers  $u'(c)$ .

Notice that the lagrangian multiplier  $\theta$  is marginal cost of borrowing from the workers, thus, from the first order condition of consumption, equation (2.18), we have the *static* optimal liability allocation rule:

$$\frac{\lambda}{u'(c)} = \theta \tag{2.24}$$

which trades off between the marginal cost of borrowing from external investors  $\frac{\lambda}{u'(c)}$  and the marginal cost of borrowing from workers  $\theta$ .

Combining equation (2.14), (2.18) and (2.20), we obtain:

$$(1 + \mu\xi) \frac{\lambda'(z')}{u'(c'(z'))} = \gamma + \frac{\lambda}{u'(c)}. \tag{2.25}$$

Proposition 4 then summarizes the *dynamics* of the wage contract and its implications on employee financing.

**Proposition 4 (Wage Contract Dynamics)** *Conditional on the financial distress of the firm  $\mu$  and the economic distress  $\gamma$ , the current marginal rate of substitution between dividend and wage  $\frac{\lambda_t}{u'(c_t)}$  is a sufficient statistic of the marginal*

rate of substitution  $\frac{\lambda_{t+1}}{u'(c_{t+1})}$ ,  $\forall z', h'$ .

- The marginal rate of substitution  $\frac{\lambda_{t+1}}{u'(c_{t+1})}$  increases when the worker's participation constraint binds  $\gamma > 0$  and the collateral constraint does not bind  $\mu = 0$ .
- The marginal rate of substitution  $\frac{\lambda_{t+1}}{u'(c_{t+1})}$  decreases when the debt enforcement constraint binds  $\mu > 0$  and the worker's participation constraint does not bind  $\gamma = 0$ .
- The marginal rate of substitution  $\frac{\lambda_{t+1}}{u'(c_{t+1})}$  keeps constant if  $\mu = 0$  and  $\gamma = 0$ .
- Undetermined changes in the direction of the marginal rate of substitution  $\frac{\lambda_{t+1}}{u'(c_{t+1})}$  when  $\gamma > 0$  and  $\mu > 0$ .

*Proof:* See Appendix 2.9.2.

This proposition characterizes the wage contract by displaying the dynamics of marginal rate of substitution. The wage contract dynamics are driven by both the financial distress  $\mu$  and the economic distress  $\gamma$ .

First, the financial distress governs the dynamics of shadow price of dividend, i.e., the marginal cost of borrowing from debtholders. When  $\mu = 0$ , the marginal cost of issuing debt is low. Thus, the firm borrows from the financial market to pay out wage and dividend given the tax benefit of debt. When  $\mu > 0$ , the firm faces high financial distress costs, and hence it borrows less from debtholders and defers wage payments by increasing labor liability  $m_{t+1}$ . As a result, a high financial distress cost  $\mu$  tends to drive down the marginal rate of substitution between dividend and wage.

Second, the economic distress governs the marginal cost of borrowing from the workers by balancing the risk-sharing motive against the employee-retention motive. When the workers' participation constraint binds  $\gamma > 0$ , it means that the firm has to commit a high promised utility  $m_{t+1}$  to retain the workers, and

therefore the marginal cost of borrowing from workers increases and the marginal rate of substitution between dividend and wage rises. When the participation constraint does not bind  $\gamma = 0$ , the dynamics of marginal rate of substitution between dividend and wage are completely driven by the tightness of debt enforcement constraint. As a result, the marginal cost of borrowing from workers decreases whenever the firm is financially distressed ( $\mu > 0$ ).

Third, the workers attain the best consumption smoothing when there is no financial distress or labor-liability distress, that is, when  $\mu = 0$  and  $\gamma = 0$ .<sup>1</sup> The lagged marginal rate of substitution between dividend and wage  $\frac{\lambda_t}{w'(c_t)}$  contains all information we need to predict the expected marginal rate of substitution at time  $t + 1$ . However, when there are financial distress or economic distress, the optimal dividend-wage allocation trades off between the marginal cost of financing through labor contracts and that of debt contracts. The lagged marginal rate of substitution between dividend and wage is sufficient to predict the marginal rate of substitution only conditional on  $\mu$  and  $\gamma$ .

To sum up, our recursive wage contract with limited commitment and financial frictions shares the common properties of the wage contract dynamics from the standard literature (Harris and Holstrom (1982), Thomas and Worrall (1988), Kocherlakota (1996), etc.), but it deviates from the literature in the following perspectives: the optimal wage contract serves to provide insurance to the workers against the income fluctuation, but also it specifies the optimal rent-splitting rule between the shareholders and the workers. Also, because of financial frictions, shareholders may become more “risk averse” than workers when the cost of financial distress is high enough. As a result, in our model the marginal rate of substitution  $\frac{\lambda_t}{w'(c_t)}$  may decrease over time even if the worker’s participant con-

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<sup>1</sup>When the debt enforcement constraint or the workers’ participant constraint is not binding, we can define the slack of those constraints as precautionary liquidity buffers: Firms borrow less today in order to borrow more in the future; and firms allow workers to smooth consumption today in order to leave room to distort workers’ consumption in the future.

straint is binding. This happens when the firm's financial distress cost dominates the marginal benefit of workers' consumption smoothing, that is, when  $\mu\xi\theta > \gamma$ .

## 2.5 Capital Structure Dynamics

At any period after the realization of  $z_t$ , the liability capacity of the firm is fixed. Under the optimality conditions, the intertemporal marginal rate of substitution of labor liability and that of debt liability are equal.

**Proposition 5 (Optimal Liability Allocation)** *The firm dynamically trades off between financial debt and labor liability until their intertemporal marginal rates of substitution are equal.*

*Proof:* See Appendix 2.9.3.

Recall the multipliers on the debt collateral constraint (2.10) and on the participation constraint (2.12) as  $\mu$  and  $\gamma$ , respectively. From the optimality conditions, we obtain the tradeoffs between the debt contract and the wage contract:

$$R \frac{E[V'_b|z]}{V_b + \mu} = \frac{1}{\beta} \frac{E[V'_m|z]}{V_m - \gamma}. \quad (2.26)$$

The above equation illustrates the relationship between the firm's debt financing decision ( $b'$ ) and the investment decision on labor (promised utility  $m'$ ). The intertemporal substitution of debt contract is the same as the intertemporal substitution of labor contract.

Intuitively, the marginal rate of return on financial debt should be equal to the marginal rate of return on employee financing. From (2.26), the tradeoff is affected not only by the relative borrowing costs of debt contract and employee contract, but also by the curvature of the value function of the shareholder and that of the promised utility  $m$ . Hence, we can further decompose the determinants

of firms' capital structure.

### 2.5.1 Human Capital Overhang Effect versus Precautionary Effect

Given that marginal costs of borrowing affect the capital structure decision making in the first order, we first explore the impact of human capital accumulation on the time-varying marginal cost of financing.

The marginal cost of borrowing from workers  $\theta_{t+1}$  is increasing in the current human capital accumulation  $h_{t+1}$  (from Lemma 4), so we expect lower current wage level to maintain the firm's promise and also lower net worth of the shareholder. The accumulation of human capital leads to high future costs of borrowing from the workers, when the firm makes the borrowing decision today, it wants to reduce the amount of debt in order to save some debt capacity for the future. The expected borrowing capacity from debt holder shrinks. This is the *human capital overhang effect* of firms' financial decision making.

However, firms also choose the optimal financial structure in order to avoid both financial distress and economic distress, which is called the *precautionary purpose* on the financial decision making. Firms save the financial buffer  $\beta\xi\mathbb{E}(V') - \frac{b'}{R}$  and the economic buffer  $\beta m'(z', h') - \beta w(z', h')$  given that the distresses are costly. Since the marginal borrowing cost from employees is increasing in  $h_{t+1}$ , from equation (2.22), we have  $\mu$  is decreasing in  $h_{t+1}$ . Firms tend to save more debt buffer when they invest in human capital. In Section 2.7, we quantified the buffers from these two purpose and further justify our theoretical prediction in capital structure.

### 2.5.2 External Financing versus Internal Financing

**Proposition 6 (External Financing vs. Internal Financing)** *The firm's overall external financing capacity (financial debt plus employee financing) is governed*

by the rigidities of adjusting equity  $\lambda$ .

The firm's overall liability capacity is summarized by the shadow price of adjusting equity  $\lambda$ . In the model, the firm makes two tradeoffs regarding its capital structure. First, given the overall liability capacity, the firm makes choices between financial debt and employee financing as stated in Proposition 5. Second, the firm also considers the tradeoffs between regular equity and liability. Although holding debt has the tax shield, the irreversibility of equity would prevent the firm from borrowing through debt contracts. If currently the firm uses debt contract to finance intensively, reducing debt in later periods could become very costly. The optimal choice between equity and debt is achieved when the tax benefits of holding debt equal to the costs of adjusting equity. Similarly, although employee financing is a necessary device to retain workers, the rigidity of adjusting equity would also prevent the firm from borrowing too much through wage contracts. In other words, the optimal external financing capacity bounds the wage contract from above.

## 2.6 The Model Solution

In this section, we solve the model by normalizing the wage contract and show the model implied simulated capital structure dynamics.

### 2.6.1 Normalized Wage Contract

To solve the contract numerically, we first normalize the wage contract by redefining the optimization problem. We assume workers are endowed with log utility  $u(c) = \log(c)$ , and production function is linear  $y_t = \exp(z_t)h_t$  and  $\alpha = 1$ .

We define the normalized contract problem as  $\tilde{\mathcal{P}}$ , by using the transfer  $\tilde{m} = m - \frac{1}{1-\beta} \log(ah)$ ,  $g' = h'/h$ , and  $\tilde{x} = x/h$  for other variables.

As in Jermann and Quadrini (2012), we also replace the non-negative dividend constraint with a smooth equity adjustment cost function  $\varphi(\tilde{d}) = \tilde{d} + \kappa(\tilde{d} - \tilde{d}_{target})^2$ , where the parameter  $\kappa$  measures the rigidities of adjusting equity, and  $\tilde{d}_{target}$  is a targeted dividend payout ratio calibrated to match the average dividend payout ratio in the data. When the variable  $\tilde{d} < 0$ , it means that the firm is issuing equity.

The functional form of the capital adjustment cost is specified as

$$\phi(\tilde{e}) = \frac{a_1}{1 - \zeta} \tilde{e}^{1 - \zeta} + a_2,$$

where the variable  $\delta$  is the depreciation rate of organization capital and the value  $1/\zeta$  is the elasticity of investment to capital ratio with respect to the marginal  $q$ . The parameters  $a_1 = \delta^\zeta$  and  $a_2 = \frac{-\zeta}{1-\zeta} \delta$  are set so that in the steady state capital adjustment cost is zero and the marginal  $q$  is equal to one. This adjustment cost function has been widely used in the investment and production-based asset pricing literature (Jermann (1998), etc.).

As a result, the normalized problem  $\tilde{\mathcal{P}}$  can be written as:

$$\tilde{V}(\tilde{m}, \tilde{b}; z) = \max_{\tilde{e}, \tilde{c}, \tilde{m}', \tilde{b}'} \left\{ \tilde{d} + \beta g' \mathbb{E}_z [\tilde{V}'(\tilde{m}', \tilde{b}'; z')] \right\}$$

subject to:

$$\varphi(\tilde{d}) = z - \tilde{c} - \tilde{e} + g' \frac{\tilde{b}'}{R} - \tilde{b} \quad (2.27)$$

$$g' = (1 - \delta) + \phi(\tilde{e}) \quad (2.28)$$

$$\xi \beta \mathbb{E}_z [\tilde{V}'] \geq \frac{\tilde{b}'}{R} \quad (2.29)$$

$$\tilde{m} = \log(\tilde{c}) + \beta \mathbb{E}_z [\tilde{m}'] + \frac{\beta}{1 - \beta} \log(g') - \log(\bar{a}) \quad (2.30)$$

$$\beta \tilde{m}'(z') \geq \beta w_0(z') \quad (2.31)$$



Under the normalized contract, the normalized value of the workers' outside option  $w_0(z')$  is only a function of the productivity shock. As a result, the human capital overhang effect on financial debt is straightforward: One (normalized) unit increase in the workers' outside option  $w_0(z')$ ,  $\forall z'$  reduces the firm value by  $\gamma(z')$  units, which in turn reduces the debt capacity by  $\frac{\gamma(z')}{\mu}$  units. The reduce in debt capacity then forces the firm to cut down the financial leverage. We summarize this result in the following corollary:

**Corollary 3 (Overhang Effect)** *One unit increase in the workers' outside option  $w_0(z')$  reduces the firm value by  $\gamma(z')$  units, which in turn reduces the debt capacity by  $\frac{\gamma(z')}{\mu}$  units.*

Figure 2.10 is the simulated paths of financing dynamics and the marginal costs of borrowing. Both debt financing and employee financing is positive correlated with the intangible capital investment from Figure 2.10 (a) and (b). The debt issuance increases when the marginal cost of financial distress  $\mu$  is very small or equal to zero, while the financing through employee contracts is the main financing vehicle most of the time, especially when the marginal cost of economic distress  $\gamma(z')$  becomes very low. We can see correspondingly in (d), the financial leverage and labor-induced leverage are moving in the opposite direction, and are consistent with the issuance dynamics. Also from comparing the marginal costs of economic distress in high state with that in low state (see (e) and (f)), firms save more buffers for positive shocks, because the increase in the workers outside option involves the firms with more incentive motives in the wage contract, and hence leads to higher borrowing cost from the employees.

## 2.7 Structural Estimation

In this section we conduct the structural estimation of the model. The estimation is completed using both

### 2.7.1 Data

All variables used in the estimation are from Compustat annual files 1970-2012. We exclude financial firms and utilities with SIC codes in the intervals 4900-4949 and 6000-6999, and firms with SIC codes greater than 9000. We also drop firms with observations less than 10 years in Compustat. All variables are winsorized at 2.5% and 97.5% percentiles to limit the impact of outliers. Nominal variables are deflated by the Consumer Price Index. Following Covas and Den Haan (2011), for each variable, we aggregate the firm-level Compustat data to obtain an aggregate time series, since we are focusing on a *representative* firm.

We define tangible investment as Capital Expenditures (CAPX), and net debt issuance ( $b_{t+1} - b_t$ ) as long-term debt issuance minus long-term debt reduction (DLTIS-DLTR).<sup>2</sup>

As in Hulten and Hao (2008), we define intangible investment ( $e_t$ ) as 30% of Selling, General and Administrative Expense (XSGA). As a robust check, we also use Research and Development Expense (XRD) as an alternative definition of intangible investment.

The construction of measurement on employee equity issuance and regular equity issuance is following McKeon (2013). We define employee equity issuance ( $\tau_{t+1} - \tau_t$ ) as those share issuances with proceeds below 3% of end-of-period market equity ( $SSTK1 : \frac{SSTK}{CSHO*PRCC_F} \leq 3\%$ ), and regular equity issuance as those with proceeds above 3% of end-of-period market equity ( $SSTK2 : \frac{SSTK}{CSHO*PRCC_F} \geq 3\%$ ). Net equity payout ( $d_t$ ) is defined as dividends plus repurchase, minus regular equity issuance (DVC+DVP+PRSTKS-SSTK2). Finally, we define financial leverage ( $\frac{b_{t+1}}{V_t+b_{t+1}+\tau_t}$ ) as debt over lagged assets ( $(DLC+DLTT)/AT_{t-1}$ ).

Since we don't explicitly consider tangible capital investment in the model, we

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<sup>2</sup>As a robust check, we also define debt issuance as long-term debt issuance minus long-term debt reduction, plus change in current debt (DLTIS-DLTR+DLCCH). We do not include "Change in Current Debt", since this variable has many missing observations.

subtract tangible investment from total cash flows and calculate proceeds from production using Operation Income Before Depreciation minus Capital Expenditures (OIBDP-CAPX).

### 2.7.2 Simulated Method of Moments

The model is solved numerically as described in Appendix 2.9.4 and most of the model parameters are estimated through the simulated method of moments (SMM). The basic idea of SMM is to choose the parameters such that the moments generated by the model are close to those in the data.

The empirical data is for a panel of heterogeneous firms while the artificial data is generated by simulating one firm over a number of periods. To keep consistency between the empirical data and the simulated data, we use as targets the average moments for the sample firms. More specifically, we first calculate the empirical moments for each firm in the sample and then, for each moment, we compute the average across all firms. In the current version, we use the identical (scale-adjusted) weighting matrix  $\Omega$ .

The estimation procedure consists of several steps as described below:

1. For each firm  $i$ , we choose moments  $h_i(x_{it})$ , where  $x_{it}$  is a vector of variables included in the empirical data. The subscripts  $i$  and  $t$  identify, respectively, the firm and the year.
2. For each firm  $i$  we calculate the within-firm sample mean of moments as  $f_i(x_i) = \frac{1}{T} \sum_{t=1}^T h_i(x_{it})$ , where  $T$  is the number of years in the empirical sample.
3. The average of the within-firm sample mean is computed as  $f(x) = \frac{1}{N} \sum_{i=1}^N f_i(x_i)$ , where  $N$  is the number of firms in the data.
4. We then use the model to generate a panel of simulated data for  $N$  firms

and for  $S$  periods. The vector of simulated data in period  $t$  and for firm  $s$  is denoted by  $y_{is}$ . We set  $S = 100 \cdot T$  to make sure that the representative firm ends up in all possible states at least once.

5. At this point we calculate the average sample mean of moments in the model as  $f(y, \theta) = \frac{1}{N \cdot S} \sum_{i=1}^N \sum_{s=1}^S h(y_{is}, \theta)$ , where  $y_{is}$  is the simulated data and  $\theta$  denotes the parameters to be estimated.

6. The estimator  $\hat{\theta}$  is the solution to

$$\min_{\theta} \left[ f(x) - f(y, \theta) \right]' \cdot \Omega \cdot \left[ f(x) - f(y, \theta) \right].$$

### 2.7.3 Parameters and Moments

Model parameters are estimated with the exception of the shareholders' discount factor  $\beta$ , the effective interest rate after considering corporate tax  $R$ , the depreciation rate  $\delta$ , the worker's mobility  $\eta$ , and the workers' discount factor  $\beta_w$  which allowed to be different from the shareholders' discount factor in our quantitative analysis.

The shareholders' discount factor  $\beta$  is set to 0.96, which implies that the risk-free interest rate is around 4%. The corporate tax rate is approximately 30%. Given the discount factor and the corporate tax rate, the effective interest rate can be calculated as  $R = 1 + (1/\beta - 1) \cdot (1 - \tau) \approx 1.04$ .

The workers' discount factor is set to be lower than that of shareholders,  $\beta_w = 0.94$ . Thus, without labor market or financial market frictions, our model has the static pecking order of financing: firms prefer to debt finance to equity finance, and regular equity finance to employee equity finance.

Depreciation rate  $\delta$  is set to 0.15 higher than that of tangible capital investment, as in Eisfeldt and Papanikolaou (2013). The fixed component of the worker's outside option is normalized  $\omega_0 = -10$  in estimation using different samples, and

we will focus on the estimate of  $\eta$  which governs the mobility or generality of intangible capital in the firm.

After the calibration of above parameters, we are left with 6 parameters of interest: the persistence and volatility of the productivity shock,  $\rho_z$  and  $\sigma_z$ , the generality of human capital  $\eta$ , the debt enforcement parameter  $\xi$ , the financing cost parameter  $\kappa$ , and the capital adjustment cost parameter  $\phi$ . The productivity shock represents the fundamentals of the firm.

In order to successfully identify the model, we choose the moments that are sensitive to the variation of the parameters. We choose 7 moments to jointly identify the model parameters: the average financial leverage (net debt over total assets); the standard deviations of leverage, the autocorrelation of leverage, the standard deviation and autocorrelation of cash flow growth, correlation coefficient between intangible capital investment and employee financing, and correlation coefficient between intangible capital investment and debt issuance.

The parameters  $\rho_z$  and  $\sigma_z$  regarding technological progress are pinned down by the standard deviation and serial correlation of cash flow growth. The average leverage is determined by both the debt enforcement parameter  $\xi$  and the generality of human capital  $\eta$ . The correlation between intangible investment and employee equity issuance is useful to identify  $\eta$ , while the correlation between intangible investment and debt issuance pins down  $\xi$ . The higher  $\eta$ , more correlated between investment and employee financing. The correlation of investment and financing dynamics are also helpful for the determination of capital adjustment cost  $\phi$ . The average leverage also helps to determine  $\xi$  and  $\eta$  jointly.  $\xi$  governs the external financial market condition, so as  $\xi$  decrease, the debt capacity shrinks.  $\eta$  determines the average rent-splitting rule between shareholders and employees, so if the net worth of workers increases, the collateralized net worth of the firm decreases, and hence the financial leverage declines.

#### 2.7.4 Estimation Results

**Benchmark Result** The values of the estimated parameters are reported in Table 2.1. In the full sample estimation, the model fits the data reasonably well, especially in matching the mean and standard deviation of leverage, the standard deviation and autocorrelation of cash flow growth. Although the model does not produce high enough correlation between intangible investment and employee equity issuance, the correlation is higher than that between intangible investment and debt issuance. The estimated value of productivity shock is lower than the estimates in the literature (for example, DeAngelo et al. (2011)), since we used the "levered" cash flow to estimate the second moments in the data. The estimation picks the parameter  $\eta$  around 0.325 and  $\xi$  to be 1.439, meaning that the fundamental contracting friction is significantly different from zero.

From the estimation, we are also able to quantify the tightness of financial constraint  $\mu$  and that of the labor participation constraint  $\gamma$ . In the bottom section of Table 2.1, the buffer on workers' participation constraint in high state is higher than the buffer in low state, which is consistent with our theory.

**Industry Results** In order to examine the effects on financial leverage for firms that are ex ante homogenous firms, we conduct the structural estimation using the firm-level data within different industries. The classification of consumer goods, manufacturing and health product industries are taken from Fama-French 5-industry classification. The information, computer and technology industry classification (defined according to NAICS) is from BEA Industry Economic Accounts, which consists of computer and electronic products; publishing industries (includes software); information and data processing services; and computer systems design and related services. We report the main financing dynamics and investment dynamics with those four industries in Figure 2.5. In manufacturing and consumer goods industries, intangible investment is correlated with employee-

initiated financing, but the correlation is lower than that in ICT and health products industries. This correlation in ICT industry about 0.94, while it is only 0.67 in manufacturing industry. The industry results are focusing on the estimation using firm-level data within ICT and manufacturing industries. The main reason we chose these two industries is that they have very distinguished target moments in the sample, and help to identify the financial effects of wage contract predicted by our theory.

Panel A of Table 2.2 and Table 2.3 report the observed and simulated moments of interest. Average net debt ratio in ICT industry is 0.167, much lower than the net debt ratio in manufacturing industry. Higher correlation between intangible investment and employee financing in ICT industry helps identify the parameter  $\xi$  and  $\eta$ . In the column of simulated moments, we see that the model can match the average leverage and the standard deviation of financial leverage very well. The model also produces reasonably good match of the correlation between investment and employee equity issuance, i.e. the model obtains much higher correlation in ICT industry than that in the manufacturing industry.

Panel C of Table 2.2 and Table 2.3 report the estimated parameters. Cash flow volatility is picked at 0.186 in ICT industry, higher than that in manufacturing industry. The debt enforcement parameter  $\xi$  is lower in ICT indicates lower collateral rate in their gross assets. The mobility parameter  $\eta$  is then higher in the ICT industry than that in the manufacturing industry.  $\eta$  is higher implies the higher turnover rate in the labor market or higher portability in the human capital in firms.

### **2.7.5 Quantifying the Financial Effects of Wage Contract**

The estimation results from the split sample help us to identify and to quantify the different effects of wage contracts: precautionary effect and overhang effect.

The precautionary effect works through the motive of keeping low leverage to avoid future distress, so it can be identified by examining the liquidity buffers generated from the debt enforcement constraint and the buffers from the worker's participation constraint. The stronger the precautionary effect, the more unused debt capacity the firm holds. On the other hand, the overhang effect works through the collateral value of assets and therefore it can be identified by showing the changes in the firm's total debt capacity.

In Table 2.4, we report the value of total debt capacity as well as the value of unused debt capacity for the case of low labor market mobility ( $\eta = 0.309$ , manufacturing industry) and the case of high labor market mobility ( $\eta = 0.333$ , ICT industry), respectively. In the case  $\eta = 0.333$ , the debt enforcement constraint on average become tighter, or in other words, the marginal cost of borrowing from the debtholder is higher. Also, in ICT industry, the marginal cost of borrowing from the workers is on average lower, but much lower in the high state. As shown in the middle panel in the table, the precautionary effect is stronger in manufacturing industry than in ICT industry, and the latter on average save less buffers although they have low financial leverage. The estimation suggest that the industries adopt lower financial leverage because they have been looking into other financing channels, but not because of the precautionary motive suggested in the literature (Bates et al. (2009), etc).

As shown in bottom panel of Table 2.4, one unit increase in  $\eta$  shrinks the debt capacity by the value of 0.03—the size of overhang effect, while on the borrowing capacity from the employee financing, the committed utility to the employee is much higher in ICT industry. Firms who are accumulating more and more human capital are borrowing from their employee directly, and hence their debt financing needs are smaller.



## 2.8 Conclusion

In this paper, we provide the theoretical and empirical analysis on firms' dynamic capital structure decision making.

Firms finance the intangible investment using very different instruments from financing tangible investment. We are the first that documents that the intangible capital investment is highly correlated with employee initiated equity issuance, but not with regular investor initiated equity issuance. Identifying the different financing channel provides better understanding how the fundamental economic revolution affects on the financial decision of the firm and a new solution to the contrasting secular trend in corporate net debt ratio and the firms' growing reliance on intangible capital in the production.

We provide a theory in which firms issue self-enforcing debt contracts to external investors and also offer long-term wage contracts to internal workers who have limited commitment. The long-term wage contract serves as financing instrument for the shareholders. The firm dynamically trades off between financial debt and employee financing until their intertemporal marginal rates of substitution are equal. The accumulation of intangible capital in the production imposes two effects on the financial structure: precautionary effect and human capital overhang effect.

We then quantify these two effects using a structural estimation within two different industries. The estimation results indicate that overhang effect dominates the precautionary effect which are suggested in the literature. The new financing channel, through labor contract, opens a new window to better understand the link between fundamental economic forces and financial decision of firms.

## 2.9 Appendix

### 2.9.1 Equivalence of the Recursive Problem and the Original Problem

We can write down the firm's problem as follows:

$$V_0 = \max_{\{e_t, c_t, b_{t+1}\}_{t=0}^{\infty}} : \mathbb{E}_0 \left\{ \sum_{t=0}^{\infty} \beta^t d_t \right\}$$

subject to:

$$d_t = z_t h_t^\alpha - c_t - e_t + \frac{b_{t+1}}{R_t} - b_t \geq 0 \quad (2.32)$$

$$h_{t+1} = (1 - \delta)h_t + \phi(e_t/h_t)h_t \quad (2.33)$$

$$\xi_t \beta \mathbb{E}_t \sum_{n=0}^{\infty} \beta^n d_{t+1+n} \geq \frac{b_{t+1}}{R_t} \quad (2.34)$$

$$\beta \sum_{n=0}^{\infty} \beta^n u(c_{t+1+n}) \geq \beta w(z_{t+1}, h_{t+1}) \quad (2.35)$$

Equation (2.32) is the budget constraint, and equation (2.33) is the law of motion of organizational capital  $h$ . Equation (2.34) is the debt enforcement constraint, and equation (2.35) is the worker's participation constraint, at the end of period  $t$ .

Define  $\mathbf{m}_{\mathbf{t}+1}(z_{t+1}, h_{t+1}) = \sum_{n=0}^{\infty} \beta^n u(c_{t+1+n})$ , then equation (2.35) is equivalent to the following recursive form:

$$m_t = u(c_t) + \beta \mathbb{E}_t[\mathbf{m}_{\mathbf{t}+1}] \quad (2.36)$$

$$\beta \mathbf{m}_{\mathbf{t}+1}(z_{t+1}, h_{t+1}) \geq \beta w(z_{t+1}, h_{t+1}), \forall z_{t+1}, \forall h_{t+1} \quad (2.37)$$

where equation (2.36) is the promise-keeping constraint and equation (2.37) is the participation constraint. Substituting equation (2.35) with (2.36) and (2.37), we obtain the recursive problem  $\mathcal{P}$ .

### 2.9.2 Proof of Proposition 4

Let  $\lambda$  be the multiplier on the budget constraint,  $\varphi$  be the multiplier on the non-negative dividend constraint,  $q$  is the multiplier on the investment constraint,  $\mu$  is the multiplier on the collateral constraint (enforcement constraint),  $\theta$  is the multiplier on the promise-keeping constraint and  $\gamma$  is the multiplier on the participation constraint.

Write down the Lagrangian of the problem  $\mathcal{P}$ :

$$\begin{aligned}
L = & d + \beta E[V(m', b', h'; z')|z] \\
& + \lambda [zh^\alpha - c - e + \frac{b'}{R} - b - d] + \varphi d \\
& + q [(1 - \delta)h + \phi(\frac{e}{h})h - h'] \\
& + \mu [\xi \beta E[V(m', b', h'; z')|z] - \frac{b'}{R}] \\
& + \theta [\log(c) + \beta E[m'] - m] \\
& + \sum_{z'} \sum_{h'} \pi(z', h'|z, h) \gamma(z', h') [\beta m' - \beta \omega(z', h')]
\end{aligned}$$

Solve to obtain the problem's first order conditions:

$$b' : \mu = \beta R(1 + \mu\xi)E[V'_b|z] + \lambda \quad (2.38)$$

$$m'(z', h') : \gamma(z', h') = -(1 + \mu\xi)E[V'_m|z] - \theta \quad (2.39)$$

$$h' : q = \beta(1 + \mu\xi)E[V'_h|z] + \lambda \alpha z h^{\alpha-1} - \beta \gamma(z', h') \omega'(z', h') \quad (2.40)$$

$$d : \lambda = 1 + \varphi \quad (2.41)$$

$$e : q = \frac{\lambda}{\phi'(\frac{e}{h})} \quad (2.42)$$

$$c : \theta = \frac{\lambda}{u'(c)} \quad (2.43)$$

and the Envelope conditions:

$$b : V_b = -\lambda \quad (2.44)$$

$$m : V_m = -\theta \quad (2.45)$$

$$h : V_h = \lambda \alpha z h^{\alpha-1} + q[(1 - \delta) + \phi(\frac{e}{h}) - \phi'(\frac{e}{h})\frac{e}{h}] \quad (2.46)$$

(2.38)-(2.46) completely capture the system.

**Lemma 3** From F.O.C (2.38) and Envelope condition (2.44), we obtain

$$\mu = \lambda - \beta RE[\lambda'|z] \quad (2.47)$$

- When  $\mu = 0$ ,  $\lambda = \beta RE[\lambda'|z]$ . Thus,  $\lambda'$  increases on average, since  $\beta R < 1$ .
- When  $\mu > 0$ ,  $\lambda = \mu + \beta RE[\lambda'|z]$ . Thus,  $\lambda'$  decreases on average whenever  $\mu > (1 - \beta R)\lambda$ .

**Lemma 4** From F.O.C. (2.39) and Envelope condition (2.45), we obtain:

$$\gamma = -\theta + (1 + \mu\xi)\theta' \quad (2.48)$$

- When  $\gamma = 0$ ,  $\theta' = \frac{\theta}{1 + \mu\xi}$ . Thus,  $\theta'$  decreases since  $\mu \geq 0$ .
- When  $\gamma > 0$ ,  $\theta' = \frac{\gamma + \theta}{1 + \mu\xi}$ . Thus,  $\theta'$  increases whenever  $\gamma > \mu\xi\theta$ .

Define the marginal rate of substitution between dividend and worker's consumption as  $\frac{\lambda}{u'(c)}$ .

**Proposition 4** Combining equation (2.39), (2.43) and (2.45) to obtain

$$(1 + \mu\xi) \frac{\lambda'(z')}{u'(c'(z'))} = \gamma + \frac{\lambda}{u'(c)} \quad (2.49)$$

The following statements say that the marginal rate of substitution can be

predicted by the last period marginal rate of substitution conditional on  $\mu$  and  $\gamma(z', h')$ .

1. If  $\mu > 0, \gamma = 0$ ,  $(1 + \mu\xi) \frac{\lambda'(z')}{u'(c'(z'))} = \frac{\lambda}{u'(c)}$ , hence  $\frac{\lambda'(z')}{u'(c'(z'))} < \frac{\lambda}{u'(c)}$ .
2. If  $\mu = 0, \gamma = 0$ ,  $\frac{\lambda'(z')}{u'(c'(z'))} = \frac{\lambda}{u'(c)}$ .
3. If  $\mu > 0, \gamma > 0$ ,  $(1 + \mu\xi) \frac{\lambda'(z')}{u'(c'(z'))} = \frac{\lambda}{u'(c)} + \gamma > \frac{\lambda}{u'(c)}$ .
4. If  $\mu = 0, \gamma > 0$ ,  $\frac{\lambda'(z')}{u'(c'(z'))} = \frac{\lambda}{u'(c)} + \gamma > \frac{\lambda}{u'(c)}$ .

### 2.9.3 Proof of Proposition 5

Recall the systems of optimality conditions (2.38)-(2.46). Rearrange to obtain Euler equations for promised utility  $m$  and debt capacity  $b$ :

$$m : \gamma - V_m = -(1 + \mu\xi)E[V'_m|z] \quad (2.50)$$

$$b : \mu + V_b = \beta R(1 + \mu\xi)E[V'_b|z] \quad (2.51)$$

Combining two equations (2.50) and (2.51) and substituting out  $1 + \mu\xi$ , we obtain:

$$\frac{1}{\beta} \frac{E[V'_m|z]}{V_m - \gamma} = R \frac{E[V'_b|z]}{V_b + \mu} \quad (2.52)$$

$\frac{1}{\beta} \frac{E[V'_m|z]}{V_m - \gamma}$  is defined as the rate of return on borrowing from the workers  $m$ , and  $R \frac{E[V'_b|z]}{V_b + \mu}$  is defined as the rate of return on borrowing from the creditors  $b$ . Since  $V'_m < 0$  and  $V'_b < 0$ . The firm equalizes the marginal rate of return on  $m'$  and  $b'$  by rising one while reducing the other.

$$\frac{1}{\beta} \frac{E[V'_m|z]}{V_m} \leq \frac{1}{\beta} \frac{E[V'_m|z]}{V_m - \gamma} = R \frac{E[V'_b|z]}{V_b + \mu} \leq R \frac{E[V'_b|z]}{V_b}$$

1.  $\gamma > 0$ : the firm increases  $m'$  or decrease the debt level  $b'$ .
2.  $\mu > 0$ : the firm decrease the the debt level  $b'$  or increases  $m'$ .

#### 2.9.4 Numerical Procedure

We solve the contract numerically using the projection method. After writing down the first-order conditions and the envelope conditions, the firm's problem can be summarized by a system of non-linear equations associated with two expectation terms. Thus, by solving the non-linear equations (2.38)-(2.46), we get the solution of the firm's problem.

The numerical procedure takes three steps. First, we parameterize the two expectation terms. Second, given the parameterized expectations, we solve the system of non-linear equations on each grid. We discretize the productivity shock on seven grid points and each state variable on ten grid points. We also do a robust check by increasing the number of grids. We interpolate linearly between grids when calculating the expectations. Third, we iterate on the approximated expectations until convergence.

## 2.10 Tables and Figures

Table 2.1: Moments and Parameters (Full Sample)

Panel A: Target Moments	Observed	Simulated
Average leverage	0.261	0.262
Standard deviation of leverage	0.018	0.016
Autocorrelation of leverage	0.847	0.592
Standard deviation of cash flow growth	0.149	0.169
Autocorrelation of cash flow growth	-0.213	-0.233
Correlation between intangible investment and employee equity issuance	0.956	0.502
Correlation between intangible investment and debt issuance	0.378	0.353
PANEL B: PRE-SET PARAMETERS		
Workers' discount factor $\beta_w$ ,		0.94
Shareholders' discount factor $\beta$ ,		0.96
Debtholders' discount factor, $\beta_b$		0.97
Depreciation rate, $\delta$		0.15
PANEL C: ESTIMATED PARAMETERS		
Persistence productivity shock, $\rho_z$		0.560
Volatility productivity shock, $\sigma_z$		0.139
Debt enforcement, $\xi$		1.439
Financing adjustment cost, $\kappa$		0.389
Capital adjustment cost, $\phi$		0.496
Workers' mobility, $\frac{\eta}{z}$		0.325
PANEL D: BUFFERS		
Debt enforcement constraint, $\mu$	0.052	39.9bps
Workers' participant constraint, $\gamma_H$	0.198	1.8bps
Workers' participant constraint, $\gamma_L$	0.000	9.3bps

The reported data moments are estimated using Compustat Fundamental Annual 1970-2012. The estimation is done with SMM, which chooses structural model parameters by matching the moments from a simulated panel of firms to the corresponding moments from the data. The table contains the parameter from normalized moments.

Table 2.2: Moments and Parameters (ICT)

PANEL A: TARGET MOMENTS	Observed	Simulated
Average leverage	0.165	0.162
Standard deviation of leverage	0.028	0.023
Autocorrelation of leverage	0.746	0.724
Standard deviation of cash flow growth	0.187	0.233
Autocorrelation of cash flow growth	-0.103	-0.230
Correlation between intangible investment and employee equity issuance	0.948	0.658
Correlation between intangible investment and debt issuance	0.498	0.118
PANEL B: PRE-SET PARAMETERS		
Workers' discount factor $\beta_w$ ,		0.94
Shareholders' discount factor $\beta$ ,		0.96
Debtholders' discount factor, $\beta_b$		0.97
Depreciation rate, $\delta$		0.15
PANEL C: ESTIMATED PARAMETERS		
Persistence productivity shock, $\rho_z$		0.564
Volatility productivity shock, $\sigma_z$		0.186
Debt enforcement, $\xi$		0.626
Financing adjustment cost, $\kappa$		0.484
Capital adjustment cost, $\phi$		0.662
Workers' mobility, $\frac{\eta}{\bar{z}}$		0.333

The reported data moments are estimated using data from Compustat Fundamental Annual 1970-2012, NAICS code classified as ICT industry. The estimation is done with SMM, which chooses structural model parameters by matching the moments from a simulated panel of firms to the corresponding moments from the data. Panel A contains the observed and simulated moments from estimation, Panel B is the preset parameters, Panel C reports the parameters estimated using SMM.



Table 2.3: Moments and Parameters (Manufacturing)

PANEL A: TARGET MOMENTS	Observed	Simulated
Average leverage	0.272	0.271
Standard deviation of leverage	0.016	0.016
Autocorrelation of leverage	0.802	0.540
Standard deviation of cash flow growth	0.256	0.146
Autocorrelation of cash flow growth	-0.281	-0.082
Correlation between intangible investment and employee equity issuance	0.674	0.474
Correlation between intangible investment and debt issuance	0.168	0.288
PANEL B: PRE-SET PARAMETERS		
Workers' discount factor $\beta_w$ ,		0.94
Shareholders' discount factor $\beta$ ,		0.96
Debtholders' discount factor, $\beta_b$		0.97
Depreciation rate, $\delta$		0.15
PANEL C: ESTIMATED PARAMETERS		
Persistence productivity shock, $\rho_z$		0.742
Volatility productivity shock, $\sigma_z$		0.133
Debt enforcement, $\xi$		1.414
Financing adjustment cost, $\kappa$		0.378
Capital adjustment cost, $\phi$		0.458
Workers' mobility, $\frac{\eta}{z}$		0.309

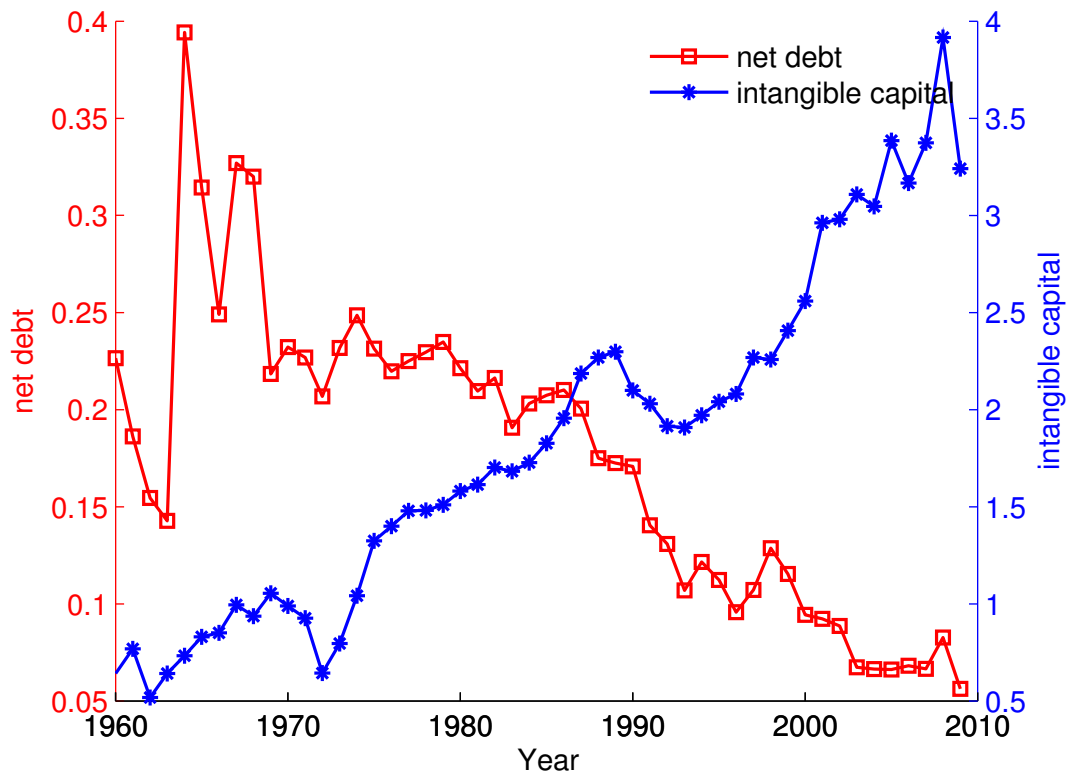
The reported data moments are estimated using data from Compustat Fundamental Annual 1970-2012, SIC code classified as manufacturing industry. The estimation is done with SMM, which chooses structural model parameters by matching the moments from a simulated panel of firms to the corresponding moments from the data. Panel A contains the observed and simulated moments from estimation, Panel B is the preset parameters, Panel C reports the parameters estimated using SMM.

Table 2.4: Decompose the Financial Effects of Wage Contract

MULTIPLIER	$\eta = 0.309$	$\eta = 0.333$
Debt enforcement constraint, $\mu$	42.7bps	66.8bps
Workers' participant constraint, $\gamma_H$	2.0bps	1.3bps
Workers' participant constraint, $\gamma_L$	8.9bps	9.7bps
PRECAUTIONARY EFFECT		
Debt buffers, $\xi\beta\mathbb{E}[V'] - \frac{b'}{R}$	0.092	0.046↓
Promise buffers, $\beta m' - \beta w(z'_H)$	0.942	0.306↓
Promise buffers, $\beta m' - \beta w(z'_L)$	0.000	0.000
OVERHANG EFFECT		
Debt capacity, $\xi\beta\mathbb{E}[V']$	0.21	0.18↓
Committed promise, $\beta m'$	-19.9	-16.7↑

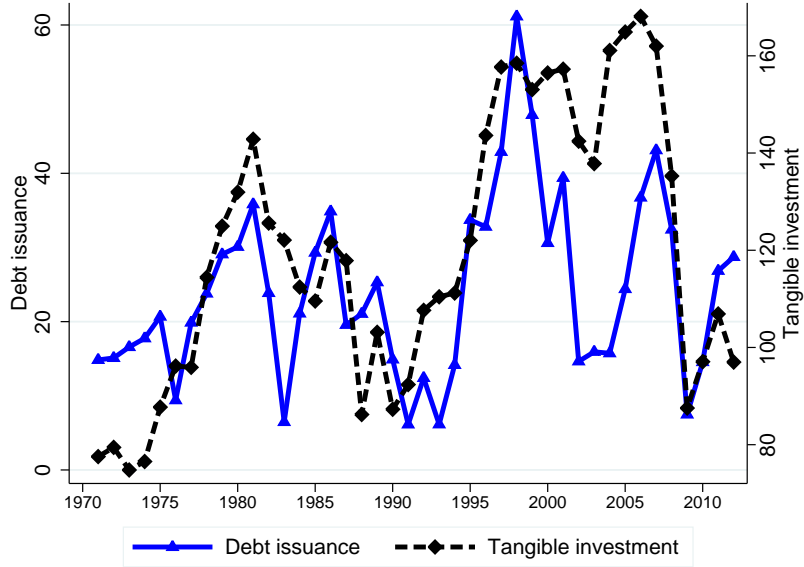
The first column uses the parameters estimated from the manufacturing industry 1970-2010 , while the second column replaces the value of the outside option  $\eta$  by that from ICT industry. The first panel reports the value of Lagrangian multipliers of the two occasionally-binding constraints in the model. The second panel shows the slackness of the constraints, that is, the liquidity buffers. The third panel shows the firm's total debt capacity and the total committed promise.

Figure 2.1: Firm-Level Net Debt Ratio and Intangible Capital Intensity

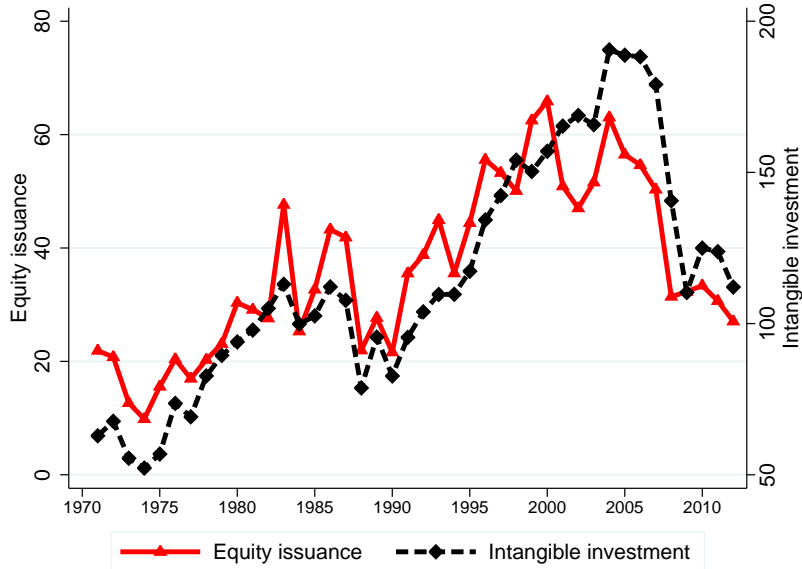


The net debt ratio is defined as the  $(\text{Total Debt} - \text{Cash}) / \text{Total Assets}$ . The intangible capital ratio is the stock of organizational capital Selling, General and Administrative Expenses scaled by book value of physical capital (Total Property, Plant and Equipment). Within each year, we take the average of the net debt ratio and the intangible capital intensity across firms. Data Source: Compustat Fundamentals Annual 1960-2010.

Figure 2.2: Financing Investment (Aggregate)  
 (a) Financing Tangible Investment

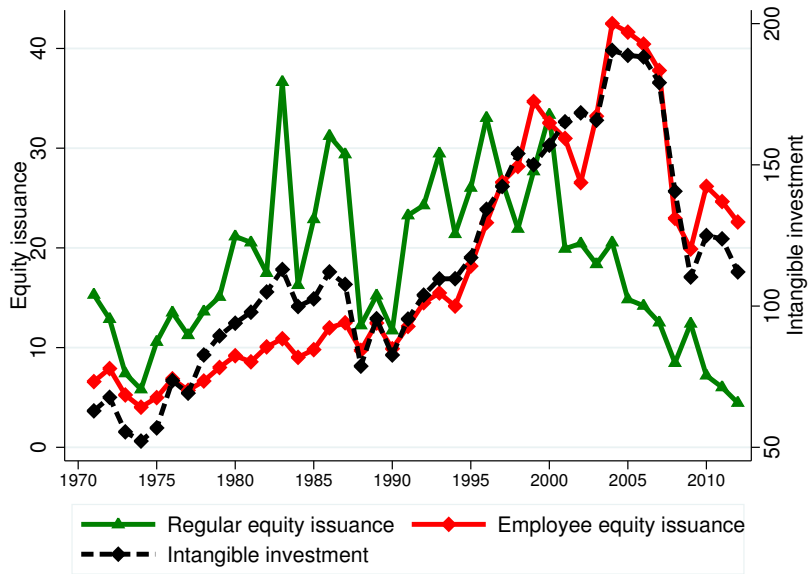


(b) Financing Intangible Investment

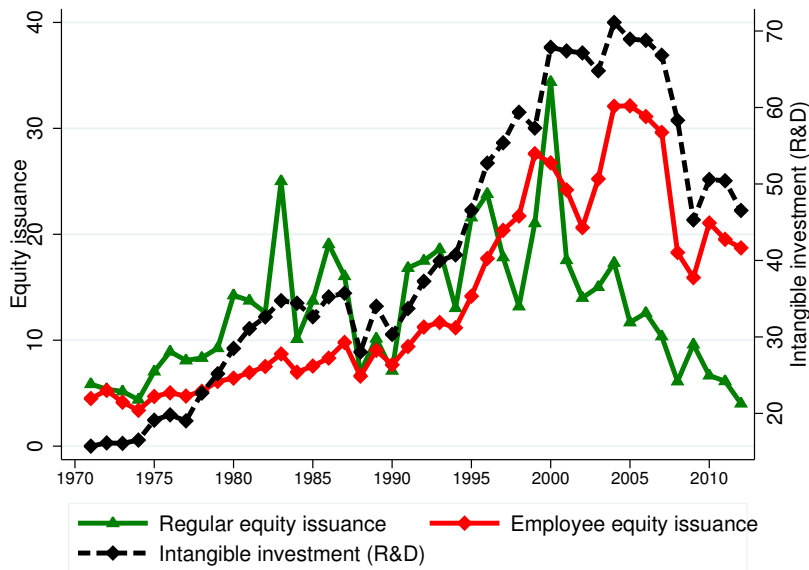


The figure (a) plots the time series of aggregate tangible capital investment (CAPX) and the aggregate net debt issuance. (b) plots the time series of aggregate intangible capital investment (XSGA) and the aggregate sales of common stocks (SSTK). Data Source: Compustat Fundamentals Annual 1970-2010. Measurement unit: billion.

Figure 2.3: Decompose Equity Issuance (Aggregate)  
 (a) XSGA

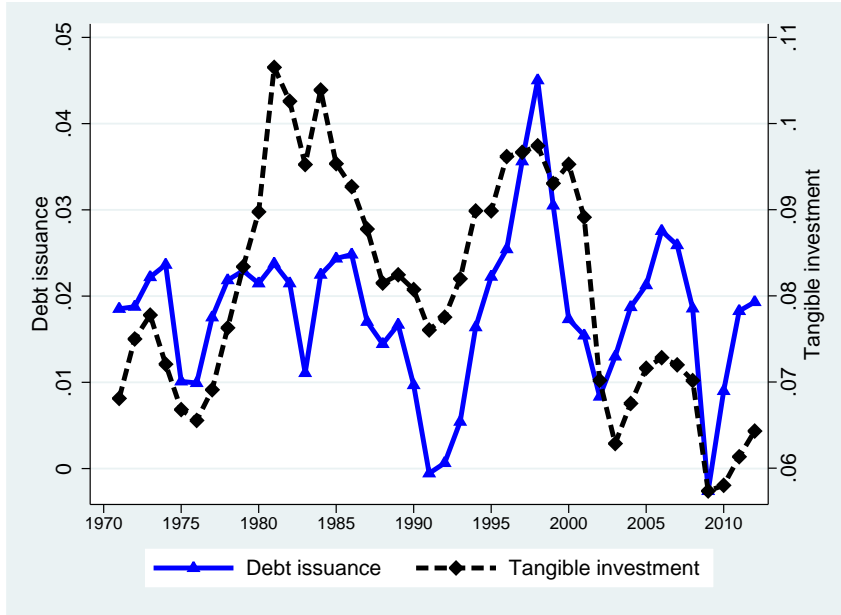


(b) R&D

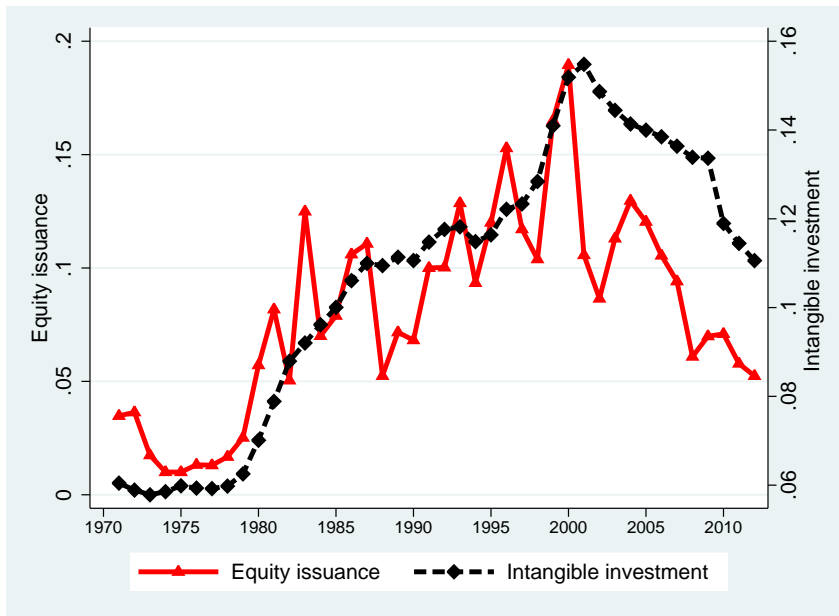


The figure plots the time series of aggregate intangible capital investment, the aggregate equity issuance (initiated by investors) and the aggregate equity issuance (initiated by employees). In (a), Selling, General and Administrative Expense (XSGA) is used as the proxy for intangible capital investment, and in (b), R&D expense is used as the proxy for intangible capital investment. Data Source: Compustat Fundamentals Annual 1970-2010. Measurement unit: billion.

Figure 2.4: Financing Investment (Average)  
 (a) Financing Tangible Investment

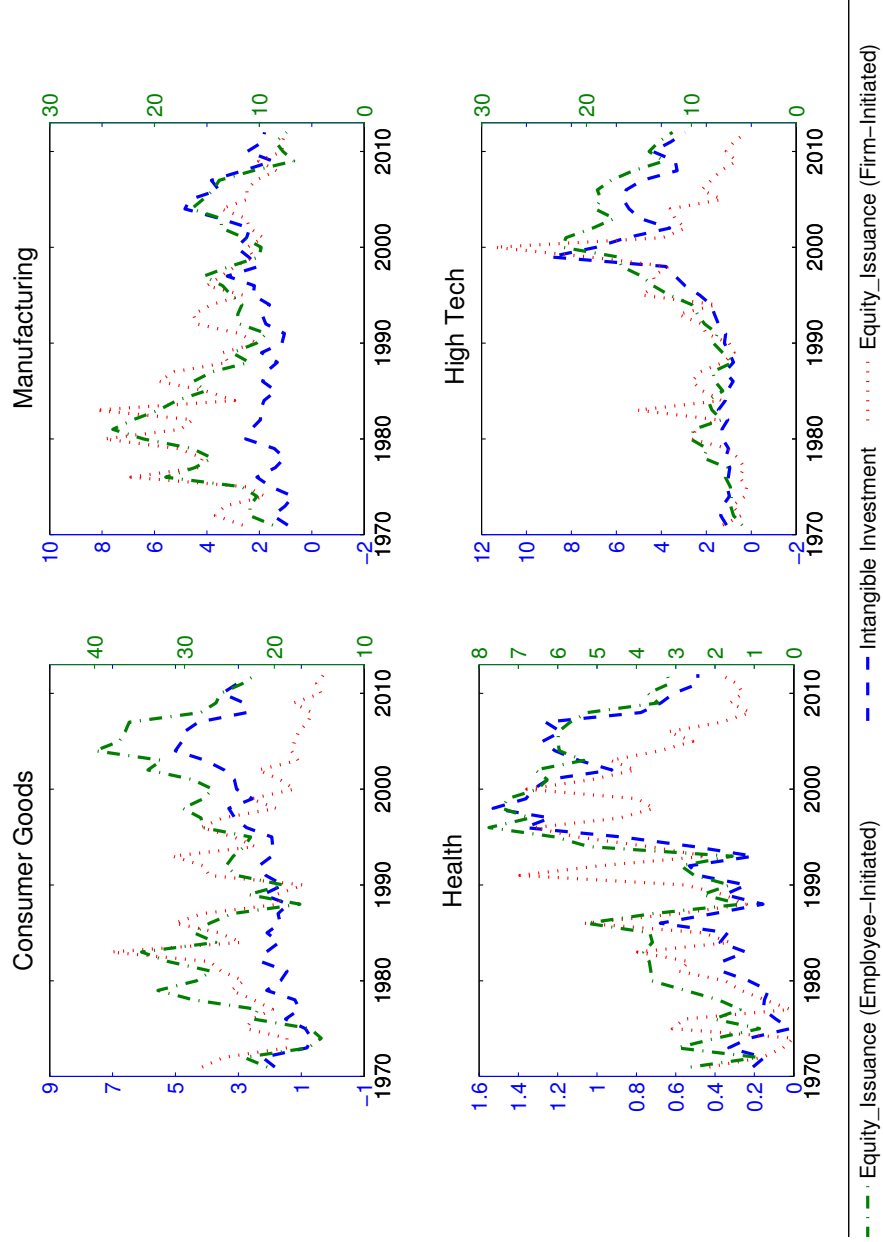


(b) Financing Intangible Investment



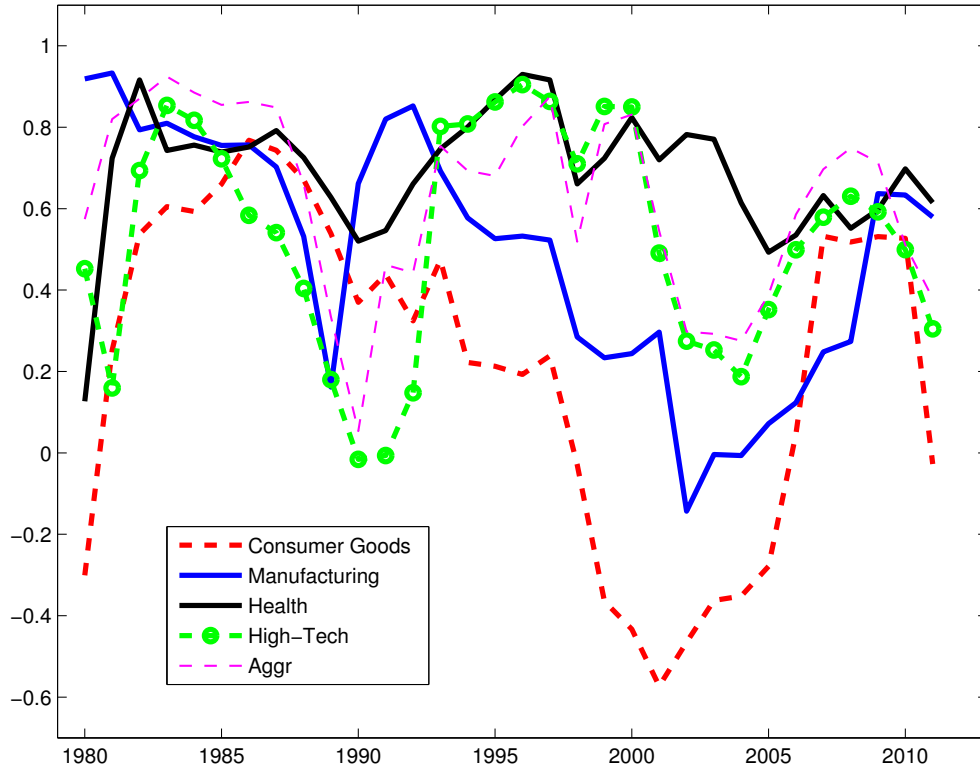
The figure (a) plots the time series of average tangible capital investment (CAPX) and the average net debt issuance. (b) plots the time series of average intangible capital investment (XSGA) and the average sales of common stocks (SSTK). Data Source: Compustat Fundamentals Annual 1970-2010. Measurement unit: billion.

Figure 2.5: Industry Intangible Financing



The figure plots the time series of industry aggregate intangible capital investment (XSGA), the aggregate equity issuance (initiated by investors) and the aggregate equity issuance (initiated by employees). The industry classification are taken from Fama-French 5-industry definition. The high-tech industry classification (defined according to NAICS) is from BEA Industry Economic Accounts.

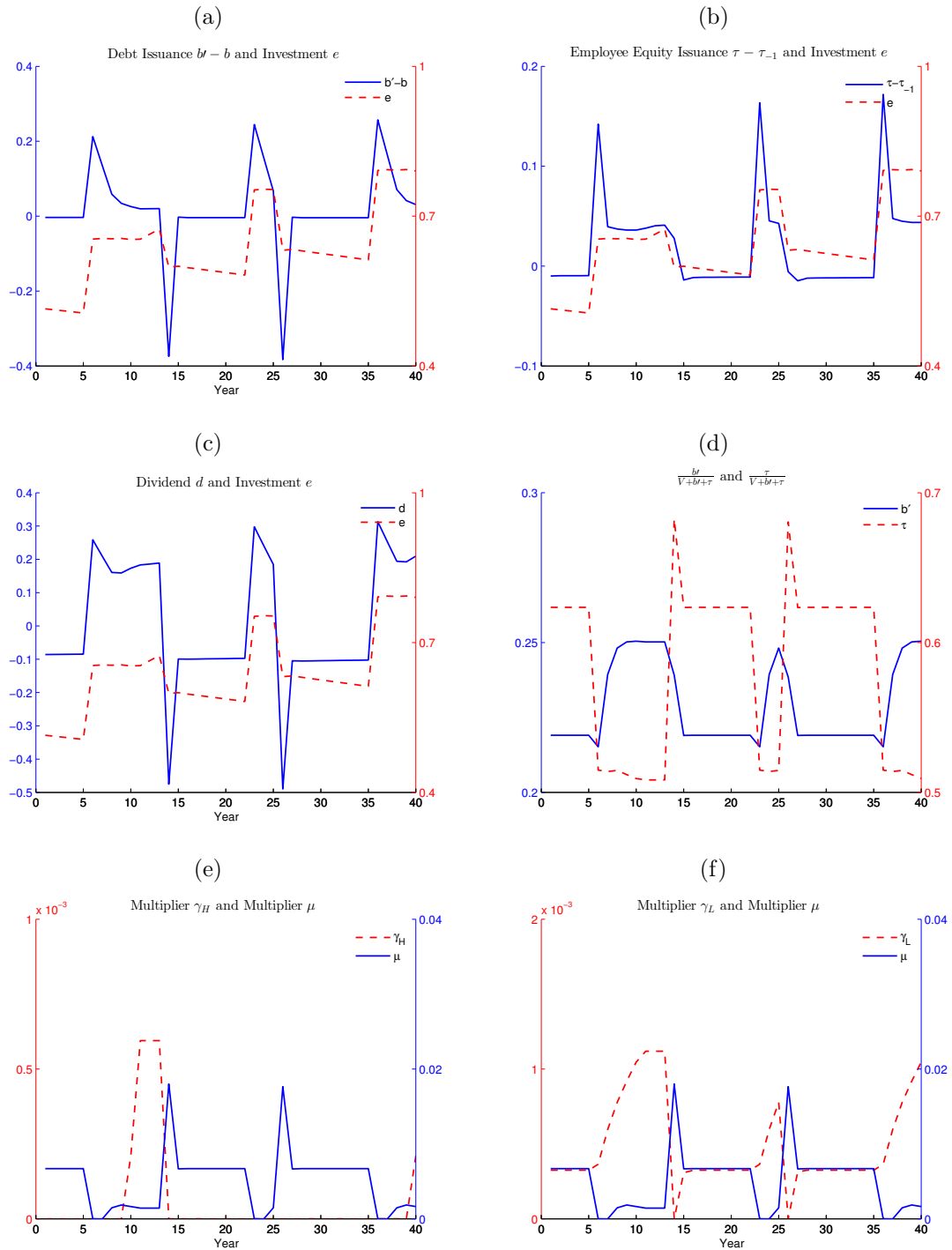
Figure 2.6: Industry Correlation  
 Industry Corr(Equity Issuance, Intangible Inv)



The figure plots the estimated correlation coefficient between industry aggregate intangible capital investment (XSGA), and the industry aggregate equity issuance (initiated by employees). The correlation coefficient is estimated over 10-year rolling window. The classification of consumer goods, manufacturing and health product industries are taken from Fama-French 5-industry classification. The information, computer and technology industry classification (defined according to NAICS) is from BEA Industry Economic Accounts, which consists of computer and electronic products; publishing industries (includes software); information and data processing services; and computer systems design and related services.



Figure 2.7: Financing Dynamics and Marginal Costs: Simulation



This figure shows the simulated path of investment, debt issuance, wage payments and leverages from the theory. The parameters are chosen from the benchmark estimation using the full sample.

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