The Persistent Effects of Financial Crises on the Composition of Real Investment *

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Abstract

Our paper provides the first cross-country evidence on the distinct dynamics of tangible and intangible investments during and after the global financial crisis. The pre-crisis rise of intangible-to-tangible capital ratio was reversed due to a greater decline of intangible investment relative to tangible investment during the crisis and a much slower recovery of intangible investment after the crisis. Tangible capital can be externally financed, and its post-crisis recovery benefits from the restoration of credit supply. In contrast, Intangible investment relies on firms' liquidity holdings that were drawn down in the crisis and can only be rebuilt gradually through retained profits. We provide a unified account of the findings through a dynamic model of corporate investment and liquidity management. Consistent with our model predictions, the divergence between tangible and intangible investments is more prominent in countries with weaker intellectual property protection (less external financing options for intangibles) and riskier government bonds (less robust corporate liquidity holdings).

Keywords: Intangible investment, capital heterogeneity, cash holdings, slow recovery

JEL classification: E22, E23, E41, E44, G01, G15, G31, G32

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1 Introduction

It has been more than a decade since the Global Financial Crisis (GFC). While enormous progress has been made in analyzing the impact of financial crises on the real economy and post-crisis recovery, the heterogeneity of firms' productive capital has drawn little attention. Tangible and intangible investments are distinct in their means of financing and impact on long-run productivity growth of firms. We provide the first evidence on the remarkably different responses of tangible investment and intangible investment to GFC and the sharp cross-country differences in the recovery of intangible capital.[1] We develop a dynamic model of corporate investment and liquidity management that offers a unified account of our empirical findings. The implications of our findings go beyond GFC. Capital heterogeneity is becoming increasingly important as advanced economies are becoming increasingly intangible-intensive (Corrado and Hulten, 2010; Eisfeldt and Papanikolaou, 2013; Crouzet and Eberly, 2021b; Crouzet, Eberly, Eisfeldt, and Papanikolaou, 2022).

During the financial crisis, investment in both tangible and intangible capital declined across countries.[2] However, the decline of intangible investment is much sharper, which is a very robust finding in our sample. The key to understanding the heterogeneous responses is the difference between tangible capital and intangible capital in financing flexibility.

Tangible capital can be financed both internally and externally because its collateral value and revenue-generating capacity are largely observable and contractable. Therefore, in the crisis, when firms are running out of cash, they can still maintain their tangible investment via external funds. Even though the financing costs are likely to rise, the option of external financing is still valuable. Moreover, certain firms can be more affected by the crisis than the rest of the economy, in which case external financing is essentially a way of risk sharing.

[1] Our sample include Belgium, Czech Republic, Denmark, France, Germany, Hungary, Ireland, Italy, Japan, South Korea, Netherlands, Poland, Romania, Slovak Republic, Spain, Sweden, Turkey, and the U.K. Our sample does not include the U.S. Corrado, Haskel, Jona-Lasinio, and Iommi (2016) documented that intangible capital investment was resilient in U.S. during the crisis but declined in EU countries.

[2] We consider three crisis indicators, the crisis time dummy, local property prices, and domestic bank CDS spread. The second and third measures exhibit country-level variation.

In contrast, investment in intangibles, such as brand name, organizational capital, firm-specific human capital, and proprietary technologies, mostly rely on firms' internal funds.[3] During the crisis, firms have to slash intangible investment as they run down their cash holdings, especially so for those that are disproportionately affected by the crisis.

The fact that tangible investment is less affected in GFC than intangible investment may also be attributed to government intervention that mostly takes the form of liquidity injection through the financial intermediation sector. As financial intermediaries were recapitalized, credit supply flows towards tangible investment that firms can externally finance, while intangible investment benefits less from the public liquidity support.

The reduction of intangible investment translates into a persistent decline in the ratio of intangible capital to tangible capital. Pre-crisis, this ratio trends up steadily. While certain countries performed better than others during the GFC, the average trend was reversed. If intangible capital is less productive than tangible capital, the reversal may as well be attributed to the rational choice of firms to shun away from intangible over-build. This is not case. We find that the reduction in intangible investment negatively predicts a firm's post-crisis productivity and profitability. Such negative impact is stronger than that of reduction in tangible investment, in line with the observation that relative to tangible investment, intangible investment is more associated with long-run productivity growth (Hall, 2001; Corrado, Hulten, and Sichel, 2009; McGrattan and Prescott, 2010; Eisfeldt and Papanikolaou, 2013; Garcia-Macia, 2017; McGrattan, 2020; Crouzet and Eberly, 2021a).

To investigate whether financing flexibility drives the heterogeneous responses of tangible and intangible investments in GFC, we divide countries by indices of intellectual property protection, motivated by the findings of Calomiris, Larrain, Liberti, and Sturgess (2017) on

[3] Investment need is a key determinant of firms' cash holdings (Denis and Sibilkov, 2010; Duchin, 2010). Firms with less collateral tend to hold more cash (Almeida and Campello, 2007; Li, Whited, and Wu, 2016). It has been well documented that intangible investment relies on firms' internal liquidity (for example, R&D investments in Hall (1992), Himmelberg and Petersen (1994), and Hall and Lerner (2009)) and intangible-intensive firms hold more cash (Opler, Pinkowitz, Stulz, and Williamson, 1999; Bates, Kahle, and Stulz, 2009; Brown and Petersen, 2011; Pinkowitz, Stulz, and Williamson, 2015; Kaoru, Daisuke, and Miho, 2017; Kahle and Stulz, 2017; Begenau and Palazzo, 2021; Falato, Kadyrzhanovaz, Sim, and Steri, 2021).

legal system and asset pledgeability. Stronger IP protection improves the pledgeability and liquidity of intangible capital (Akcigit, Celik, and Greenwood, 2016) and thus improves the availability of external financing. In these countries, the financing flexibility gap between tangible capital and intangible capital is narrower. Indeed, we find that in countries with strong IP protection, firms' intangible investment is less affected by the crisis, and the gap between tangible and intangible investments during and after the crisis is narrower.

Intangible investment relies on internal funds (Hall, 1992; Himmelberg and Petersen, 1994; Opler, Pinkowitz, Stulz, and Williamson, 1999; Hall and Lerner, 2009; Brown and Petersen, 2011; Begenau and Palazzo, 2021; Falato, Kadyrzhanovaz, Sim, and Steri, 2021). Firms hold cash in the form of debt instruments issued by the government and financial intermediaries (e.g., deposits) (Li, 2015). In a crisis, the safety of such assets is of paramount importance because, if the market values of these assets decline in the crisis, firms are deprived of liquidity precisely when they are in need (Eisfeldt and Rampini, 2009). Risk exposure compromised the hedging value of liquidity assets (Holmström and Tirole, 1998).

We proxy the riskiness of firms' liquidity holdings by the correlation between VIX and government bond yields in firms' home countries.[4] A positive correlation indicates that bond prices decline when VIX rises in crises. The negative impact of GFC on intangible investment is indeed stronger and the divergence between tangible and intangible investments wider in countries with riskier bonds. This lends support to our mechanism that intangible investment relies on firms' liquidity holdings while tangible capital can be externally financed so shocks to liquidity holdings hit intangible investment more. In fact, the coefficient of interaction between bond riskiness and crisis dummy is insignificant in explaining tangible investment.

We also construct other measures of a country's general financial soundness, such as government debt-to-GDP ratio, bank tier 1 capital ratio, non-performing loans-to-total loans ratio, and reach similar conclusions that weakened financial health of the country amplified the crisis impact on intangible investment and that, across all measures, the coefficient of

[4]Graham, Leary, and Roberts (2014) find that the issuance of government bonds is correlated with increase in corporate liquidity holdings.

interaction between financial soundness measure and crisis dummy is insignificant in explaining tangible investment. Note that a weakened banking sector has two negative effects on firms. First, as previously discussed, firms' liquidity holdings (e.g., deposits) become unsafe. Second, it is more difficult for firms to obtain bank financing. Therefore, our interpretation of the results based on bank-centric measures of financial soundness is broad and, specifically, beyond the safety of firms' liquidity portfolio in the crisis. The fact that weakened financial health does not amplify the crisis impact on tangible investment suggests that policy intervention aiming to restore credit supply was effective.

After characterizing the heterogeneous responses of tangible and intangible investments to GFC, we further explore the recovery dynamics. Tangible investment rate started to recover in 2010 and, by the end of our sample (2017), it almost reached the pre-crisis level. In contrast, intangible investment rate only bottomed in 2015 and, by 2017, it is still far from the pre-crisis level. The divergence is most prominent in countries with weaker IP protection and riskier government bonds, suggesting that our mechanism of heterogeneous financing flexibility and liquidity management not only explains the difference between tangible and intangible investments in crisis responses but also the difference in their recovery trajectories. The post-GFC slump in intangible investment is fully driven by countries with below-median IP protection and above-median bond riskiness.

To provide a complete account for firms' crisis response and post-crisis recovery in investment, we build a continuous-time model of a firm's investment, financing, and liquidity management decisions following the literature on dynamic investment and liquidity management (Gomes, 2001; Riddick and Whited, 2009; Bolton, Chen, and Wang, 2011; Décamps, Mariotti, Rochet, and Villeneuve, 2011; DeAngelo, DeAngelo, and Whited, 2011; Hugonnier, Malamud, and Morellec, 2015; Décamps, Gryglewicz, Morellec, and Villeneuve, 2017; Eisfeldt and Muir, 2016). Our model formalizes the main mechanism and produces the empirical patterns. A key feature is that the firm's cash holdings act as the key state variable, generating an intertemporal amplification mechanism which we further investigate empirically. A firm with a high level of cash holdings cuts investment less in a crisis (more so for intangible investment), and during the crisis, the firm draws down its cash balance.

The key intertemporal linkage arises between intangible investment and the future build-up of cash balances. As predicted by our model, we find that the reduction of intangible investment negatively predicts future growth of revenues and cash holdings. This is consistent with our finding that the reduction of intangible investment negatively predicts future productivity and profitability (the key finding that refutes the explanation of intangible slump based on firms' rational choice of leaning towards more productive tangible capital).

A full picture of our empirical findings emerge from the theoretical framework. Intangible investment is hit harder in GFC, especially in countries with weaker IP protection and riskier liquid asset, because as firms draw down their cash balances, they reduce internally financed intangible investment. Tangible investment can be sustained, partly due to policy intervention that supports credit supply. We find that firms' debt to cash ratio declined significantly during the GFC, in line with our focus on capital heterogeneity in means of financing (debt for tangible investment and cash for intangible investment). As the firm emerges from crisis, the lack of intangible capital compromises its revenue-generating capacity and thus slows down the rebuild of cash holdings, which in turn causes intangible investment to recover slowly. While intangible investment is trapped at a low level, tangible investment picks up as the external financing environment improves thanks to the successful recapitalization of financial intermediation sector and accommodative monetary policies around the world.

Literature. Campello, Graham, and Harvey (2010) review the literature on the negative impact of GFC on investment. Our paper makes three contributions to the literature and the more recent literature on the decline of intangible investment in recessions.[5] First,

[5] Brown, Fazzari, and Petersen (2009) document a significant link between financing supply and R&D. Using French firm-level, Aghion, Berman, Eymard, Askenazy, and Cette (2012) document a decline of R&D spending among the financially constrained firms in recession and slow recovery. Fabrizio and Tsolmon (2014) also documented the procyclicality R&D spending. De Ridder (2019) provide similar findings for large U.S. corporations. Corrado, Haskel, Jona-Lasinio, and Iommi (2016) provides a cross-country comparison of GFC impact on intangible investment. Peia (2017) documented a decline of aggregate R&D investment following banking crises. Garcia-Macia (2017) find that financial shocks dampen productivity growth through the exti

our analysis goes beyond the total investment or one particular type of investment. By comparing the distinct dynamics of tangible investment and intangible investment during and after GFC, we show that GFC cast a long shadow over capital composition in the production sector. Second, we document an intangible investment trap. The reduction of intangible investment in the crisis negatively predicts firms' future profits and productivity, which implies a slow rebuild of cash holdings and in turn less future intangible investment. This channel does not apply to tangible investment that can be externally financed and thus benefit from the post-crisis recovery of capital markets and financial intermediation. Third, we document cross-country differences and, in particular, show that the divergence between intangible and tangible investment does not exist among countries with strong IP protection.

The amplification and persistence of crisis impact are due to the dynamic linkage between cash holdings and intangible investment, which we formalize in a dynamic liquidity management model (Eisfeldt and Rampini, 2009; Riddick and Whited, 2009; Bolton, Chen, and Wang, 2011; Décamps, Mariotti, Rochet, and Villeneuve, 2011; DeAngelo, DeAngelo, and Whited, 2011; Hugonnier, Malamud, and Morellec, 2015; Li, 2015; Décamps, Gryglewicz, Morellec, and Villeneuve, 2017; Eisfeldt and Muir, 2016; He and Kondor, 2016; Alfaro, Bloom, and Lin, 2018; Malamud and Zucchi, 2019). Our contribution is to model two types of capital that differ in financing flexibility (Ward, 2018; Falato, Kadyrzhanovaz, Sim, and Steri, 2021; Chen, Li, Thakor, and Ward, 2022). Our model generates different responses of intangible and tangible investments to productivity shocks.[6]

The cash-intangible investment link has strong empirical support. Investment need is a key determinant of firms' cash holdings (Opler, Pinkowitz, Stulz, and Williamson, 1999; Denis and Sibilkov, 2010; Duchin, 2010). Firms with less collateral also tend to hoard more cash (Almeida and Campello, 2007; Li, Whited, and Wu, 2016; Falato, Kadyrzhanovaz,

of intangible-intensive firms, which provide positive spillover effects. Hardy and Sever (2019) find a long-lasting decrease in patenting behavior after banking crises that is correlated with slower long-run growth. Duval, Hong, and Timmer (2019) documented a persistent effect of GFC on firm productivity. Kerr and Nanda (2015) provides an excellent review on the design of innovation financing and potential frictions.

[6]Eberly and Wang (2008) model two types of capital that differ in physical attributes, such as productivity and adjustment costs, rather than means of financing.

Sim, and Steri, 2021). Intangible investments rely heavily on firms' internal liquidity, and intangible-intensive firms hold more cash (Hall, 1992; Himmelberg and Petersen, 1994; Bates, Kahle, and Stulz, 2009; Hall and Lerner, 2009; Brown and Petersen, 2011; Pinkowitz, Stulz, and Williamson, 2015; Begenau and Palazzo, 2021; Kaoru, Daisuke, and Miho, 2017; Kahle and Stulz, 2017; Falato, Kadyrzhanovaz, Sim, and Steri, 2021). The rise of intangible firms offers an explanation to the rise of corporate cash holdings (Bates, Kahle, and Stulz, 2009; Gao, Whited, and Zhang, 2018; Falato, Kadyrzhanovaz, Sim, and Steri, 2021).

Intangible investment relies on cash holdings and affects the future growth of cash holdings through its impact on productivity. This building block is key to our model that generates slow recovery of intangible investment relative to that of tangible investment. Our findings support this channel and is consistent with related findings. Brown and Kimbrough (2011) find that intangible investment improves firms' earnings because it allows firms to differentiate their products from those of their rivals. Faulkender, Hankins, and Petersen (2019) documented that firms with more intellectual properties are more able to transfer and seize tax savings and production opportunities in foreign countries, which in turn allowed these firms to build up cash holdings after GFCs.

Our paper provides the first evidence that the riskiness of firms' liquidity holdings negatively affects intangible investment during and after crises. In contrast, tangible investment does not depend on the riskiness of firms' liquidity holdings. Holmström and Tirole (1998) emphasized that risk exposure of firms' liquidity portfolio hurts investment. Our model incorporates this channel as a building block for the mechanism of divergent perofrmances of tangible and intangible investments. The risk of firms liquidity portfolio has not attracted much attention with Duchin, Gilbert, Harford, and Hrdlicka (2017) as a notable exception.

Our findings on the distinct dynamics of intangible and tangible investments around GFC contribute to the broad literature on intangible capital. A recent literature focuses on the measurement of intangible capital (Lev, 2001; Corrado, Hulten, and Sichel, 2005; Atkeson and Kehoe, 2007; Corrado, Hulten, and Sichel, 2009; McGrattan, 2020). Previous studies have shown that the rise of intangible capital is important for explaining the secular trends in corporate profits and investment (McGrattan and Prescott, 2010; Gourio and Rudanko, 2014; Gutiérrez and Philippon, 2017; Peters and Taylor, 2017; Daniel, Naveen, and Yu, 2018; Farhi and Gourio, 2018; Andrei, Mann, and Moyen, 2019; Corhay, Kung, and Schmid, 2019; Crouzet and Eberly, 2021b). Dell'Ariccia, Kadyrzhanova, Minoiu, and Ratnovski (2020) and Döttling and Perotti (2017) emphasize the decline of firms' borrowings from banks due to lack of collateral assets. The literature also explores broad implications of intangible capital on equity valuation (Hall, 2001; Hansen, Heaton, and Li, 2005; Ai, Croce, and Li, 2013; Eisfeldt and Papanikolaou, 2013, 2014; Belo, Lin, and Vitorino, 2014; Belo, Gala, Salomao, and Vitorino, 2019; Eisfeldt, Kim, and Papanikolaou, 2020; Hou, Mo, Xue, and Zhang, 2020).

2 Theoretical Framework and Hypotheses

In Section 2.1, we discuss the theoretical mechanism behind the hypotheses in our empirical exercises. The mechanism is formalized in a dynamic model of corporate investment, financing, and liquidity management in Section 2.2. We solve the model in Section 2.3.

2.1 The Mechanism

In Figure 1, we show the theoretical mechanism behind our empirical hypotheses. A firm relies on tangible and intangible capital for production. The two types of capital differ in the means of financing. The firm externally finances tangible capital, for example through debt issuances that are backed repossessible assets value or contractable future cash flows. In contract, intangible capital is of limited pledgeability, so the firm relies on internal liquidity to accumulate intangibles (Hall, 1992; Himmelberg and Petersen, 1994; Hall and Lerner, 2009; Falato, Kadyrzhanovaz, Sim, and Steri, 2021). Firms' internal liquidity is held in the form of government debts and financial intermediaries' debts (e.g., deposits) (Li, 2015).

In Figure 1, we show that following negative shocks to operating cash flows, the firm falls into a vicious cycle that explains the sharp decline of intangible investment and the slow recovery. As the accumulation of internal liquidity slows down, the firm reduces intangible investment. Such reduction is more severe when cash-flow shocks are correlated with shocks to the value of its liquid assets. For example, in a financial crisis, the soundness of financial intermediaries' balance sheets and even the solvency of a country's government are being challenged. The reduction in intangible investment is also more severe if the dependence of intangible investment on firms' internal funds is stronger due to lack of legal definition and protection of intangible assets (e.g., intellectual properties).

The mechanism also explains why tangible investment is less affected by a crisis. A slow-down of intangible investment pushes the firm to adjust its production technology and, specifically, to rely more on tangible capital that, in contrast to intangible capital, can be externally financed. Therefore, the reduction of tangible investment is ameliorated.

However, leaning more towards tangible capital in the production process may reduce production efficiency and operating cash flows. The cash-flow reduction is greater in a financial crisis when the (debt) cost of financing tangible capital is higher due to the impairment of bank balance sheets and other disruptions in capital markets or financial intermediation. Note that a financial crisis strengthens the vicious cycle in two ways. First, it threatens the firm's liquidity position as the financial health of issuers of liquid assets becomes problematic. Second, credit-supply contraction implies a higher cost of financing tangible capital.

The vicious cycle propagates over time, slowing down the recovery of the firm's cash position and intangible investment. In our model, the firm builds up intangible capital over time through internally financed investment, and accumulating intangibles is akin to endogenously growing the firm's productivity. Therefore, the lack of intangible investment negatively affects future production and cash flows. Under this intertemporal linkage, our model features amplification and persistence of shock impact. Before we formalize and solve the model, we list below the main hypotheses that will be tested in our empirical exercises:

1 In a crisis, firms cut intangible investment more than tangible investment. After the

crisis, intangible investment recovers slower than tangible investment.

2 The reduction of intangible investment in a crisis is greater and recovery slower in countries with weaker pledgeability of intangible capital (greater dependence of intangible investment on firms' liquidity holdings).

3 The reduction of intangible investment in a crisis is greater and recovery slower in countries where firms' cash and cash equivalents tend to decline in value in crises.

4 The reduction of intangible investment negatively predicts firms' future productivity and profitability and slows down the rebuild of cash holdings post-crisis.

5 Firms draw down their cash balances during a crisis, and those with more cash holdings cut intangible investment less.

6 In a crisis, as firms lean towards externally (debt) financed tangible capital and draws down cash to sustain intangible investment, their debt-to-cash ratio increases.

2.2 Model

We present a continuous-time model of a single firm's production, intangible investment, and liquidity management under financial constraints that offers a unified theoretical foundation for our empirical findings. The firm combines tangible capital, K_t^T, and intangible capital, K_t^I, to produce output over time period dt:

$$\left(K_t^I\right)^\theta \left(a_t^\theta K_t^T\right)^{1-\theta} \mu dt \,, \tag{1}$$

where μdt is the productivity parameter and the parameter θ captures the intangible intensity of production process. The firm may choose a_t ($\in [0, \overline{a}]$), to adjust production technology.[7]

We draw the distinction between tangible and intangible capital in financing and operational flexibility (Ward, 2018; Chen, Li, Thakor, and Ward, 2022). Specifically, while

[7]The modelling choice is inspired by the literature of variable capital utilization rate (Greenwood, Hercowitz, and Huffman, 1988; Cooley, Hansen, and Prescott, 1995; Chari, Kehoe, and McGrattan, 2007; Jaimovich and Rebelo, 2009).

tangible capital can be rented and its usage freely adjusted, intangible capital is stored internally (Crouzet, Eberly, Eisfeldt, and Papanikolaou, 2022).

The firm can adjust the usage of tangible capital, and the acquisition can be externally financed. Whether the firm leases tangible capital or acquire it on borrowed money does not affect the mechanism. In the former case, let γdt denote the rent of one unit of tangible capital over dt. This users' cost of capital includes an interest rate component and depreciation (Jorgenson, 1963). In the latter case, the firm still faces an overall cost of γdt as it incurs loan interest expenses and depreciation that reduces the capital resale value.

The firm accumulates intangible capital internally as follows

$$dK_t^I = \left(X_t - \delta K_t^I\right) dt\,, \tag{2}$$

where X_t represents the quantity of newly created intangible capital, and the parameter δ represents the obsolesce rate. To create $X_t dt$ units of intangible capital, the total expenses are $G(X_t, K_t^I)dt$, which incorporates the potential adjustment cost. In particular, the slow adjustment of intangible capital may reflect gradual build-up of customer base (Gourio and Rudanko, 2014). Intangible investment may also consume other constrained resources, for example, personnel, which is not modelled explicitly but captured by the fact that the marginal cost of adjusting the production technology via a_t, $C(a_t, X_t)dt$, increases in X_t (i.e., $C_{aX}(a_t, X_t) > 0$). As we will show shortly, a_t and X_t are the two key control variables.

Let Y_t denote the (undiscounted) cumulative cash flow. The cash flow over dt is

$$dY_t = \left(K_t^I\right)^\theta \left(a_t^\theta K_t^T\right)^{1-\theta} \mu dt + K_t^I \sigma dZ_t - \gamma K_t^T dt - G\left(X_t, K_t^I\right) dt - C(a_t, X_t) dt\,. \tag{3}$$

Z_t is a standard Brownian motion. $K_t^I \sigma dZ_t$ captures productivity shock through intangible capital. The shock size is σ per unit of capital. This specification of productivity shock is motivated by the connection between intangibles and productivity (Hall, 2001; Corrado, Hulten, and Sichel, 2009; Corrado and Hulten, 2010; McGrattan and Prescott, 2010; Eisfeldt and Papanikolaou, 2013; Garcia-Macia, 2017; McGrattan, 2020; Crouzet and Eberly, 2021a).

Let M_t denote the firm's cash holdings, which has the following law of motion:

$$dM_t = dY_t + (r - \lambda)M_t dt + \omega M_t dW_t + dF_t - dU_t \,, \tag{4}$$

where the process W_t is a standard Brownian, and the instantaneous correlation between dW_t and dZ_t is ϕdt. Firms invest cash in money market instruments typically issued by financial intermediaries and the government. Such instruments may lose their safe-asset status in crises due intermediaries' and sovereign insolvency risks. The parameter ω captures the size of such shocks. Empirically, firms also hold risky assets in liquidity portfolios (Duchin, Gilbert, Harford, and Hrdlicka, 2017). Following Riddick and Whited (2009), we introduce λ for agency cost of holding cash. Let F_t denote the cumulative process of external equity financing, and U_t denote the the cumulative process of dividend payout.

The shareholders are risk-neutral with a discount rate r.[8] The firm maximizes shareholders' value by choosing the optimal processes of dividend payout, U, equity issuance, F, tangible capital, K^T, production technology, a, and intangible investment, X, subject to the equity issuance costs (denoted by H_t in the cumulative form):

$$\max_{\{U,F,K^T,X,a\}} \mathbb{E}\left[\int_{t=0}^{\tau} e^{-rt}\left(dU_t - dF_t - dH_t\right)\right] , \tag{5}$$

where, following Bolton, Chen, and Wang (2011), we specify the equity issuance (dilution) costs as having a proportional component and a size-dependent component:

$$dH_t = \chi_1 dF_t + \chi_0 K_t^I \,. \tag{6}$$

Equity issuance costs are key ingredients in dynamic models of investment and financing

[8]We may interpret the model as set up under the risk-neutral probability measure and adopt an implicit assumption that the single firm's decision making does not affect the aggregate consumption process that drives the stochastic discount factor (in other words, the firm-level risk is diversifiable).

(Gomes, 2001; Riddick and Whited, 2009; Décamps, Mariotti, Rochet, and Villeneuve, 2011; DeAngelo, DeAngelo, and Whited, 2011; Hugonnier, Malamud, and Morellec, 2015; Décamps, Gryglewicz, Morellec, and Villeneuve, 2017).[9] The intangible-dependent cost of equity issuance, captured by χ_0, reflects the finding of Hottenrott and Peters (2012) that financial constraints depend on firms' innovation capacity.

As will be shown later, the firm's value function and choice variables are all scaled by K_t^I, which then naturally measures the firm size. Intuitively, the amount of intangible capital, such as organizational capital and managerial talents, determines the scale of operations (Lucas, 1978; Atkeson and Kehoe, 2005, 2007; Eisfeldt and Papanikolaou, 2013, 2014).

Before we solve the dynamic optimization problem, we summarize the firm's balance sheet. At any time t, the firm has cash, M_t, intangible capital, K_t^I, and tangible capital, K_t^T on the asset side and debt and equity on the liability side. As previously discussed, tangible capital is financed by debt in the form of either leasing or loan, and in both cases, the cost is γdt per unit of tangible capital. Thus, the value of debt liability corresponds to the value of tangible capital. This is standard in production models but the fact that renting capital implies a debt contract between a producer and its creditors is often not explicitly stated.

The firm's holdings of cash and intangible capital are financed by equity, which is consistent with the findings of Lerner, Shane, and Tsai (2003) and Brown, Fazzari, and Petersen (2009) that R&D intensive firms are likely to be equity-financed.[10] As shown in (7), the issuances of equity increase cash holdings and thus allows the firm to invest more in intangibles, while shareholder payout drains cash holdings and reduces the internal liquidity for intangible investment. In Section 2.3, we highlight that it is not optimal for the firm to finance tangible capital out of its own cash holdings or by issuing equity. Therefore, there is a convenient dichotomy between debt (corresponding to tangible capital) and equity (corresponding to intangible capital and cash). Under this dichotomy, equity issuance costs can be motivated by asymmetric information (Myers and Majluf, 1984) or investors' heterogeneous

[9] Altınkılıç and Hansen (2015) provide evidence on the variable and fixed costs of equity issuances.

[10] Kerr and Nanda (2015) provides an excellent review on innovation financing and potential frictions.

belief (Dittmar and Thakor, 2007) on the value and productivity of intangible capital.

The firm raises costly equity when it runs out of liquidity. If intangible capital is fully illiquid, the firm raises equity when M_t falls to zero. While the firm's net worth (equity) is $M_t + K_t^I$, the accessible amount of liquidity is only M_t. We can extend our model to incorporate limited pledgeability of intangible capital. Specifically, we allow M_t to fall below zero without triggering costly equity issuance and interpret a negative cash balance as drawdown of lines of credit (Lins, Servaes, and Tufano, 2010; Acharya, Almeida, and Campello, 2013). The firm raises equity when M_t falls to $-\eta K_t^I$ ($\eta < 1$), the pledgeable value of intangible capital (e.g., intellectual properties).[11] For simplicity, it is assumed that lines of credit has a unit cost of r (i.e., the same interest rate that shareholder use to discount cash flows and the yield on cash balance). The law of motion of M_t (7) is modified to accommodate $M_t < 0$:

$$dM_t = dY_t + (r - \lambda \mathbb{I}_{\{M_t>0\}})M_t dt + \omega M_t \mathbb{I}_{\{M_t>0\}} dW_t + dF_t - dU_t\,, \tag{7}$$

where the indicator functions in the second and third terms show, respectively, that a negative cash balance (drawdown of credit lines) does not carry agency costs and the interest expenses, unlike the interest income on a positive cash balance, do not load on shocks.

When the firm raises equity at $M_t = -\eta K_t^I$, the firm still has a strictly positive net worth (i.e., the equity, $M_t + K_t^I > M_t + \eta K_t^I = 0$) but it has run out of liquidity to support its operations. When η is smaller (for example, due to weaker IP protection), the firm faces a tighter liquidity constraint and has to raise costly equity at a higher threshold of M_t.

Financial shocks. A crisis can be captured by negative productivity shocks, $dZ_t < 0$, or shocks to liquidity holdings, dW_t, and it can also be reflected in changes in three parameters. An increase in χ_0 or χ_1 represents high costs of issuing equity, which may be due to capital market dislocations. An increase in γ (i.e., the debt financing cost of acquiring tangible capital) is often attributed to the impaired lending capacity of financial intermediaries. The

[11] Tangible capital has been pledged for the associated debt so it can no longer back lines of credit.

third parameter, which is a unique angle in this paper, is the increase in ω, that is the firm's liquidity holdings become riskier in a crisis. A crisis heightens the solvency risks associated with the issuers of money-market instruments, such as financial institutions and the domestic government. And, because such a shock, dW_t, is positively correlated with the productivity shock, dZ_t, the challenge is that liquidity is depleted precisely when it is needed, as emphasized in the seminal work by Holmström and Tirole (1998) .

2.3 Solution

There are two stock variables, M_t and K_t^I, that are adjusted gradually (i.e., by the order of dt). They are the state variables. The firm's value function at time t is defined as follows

$$V(M_t, K_t^I) = \max_{\{U,F,K^T,X,a\}} \mathbb{E}\left[\int_{s=t}^{\tau} e^{-r(s-t)}\left(dU_s - dF_s - dH_s\right)\right] . \tag{8}$$

Given the time-homogeneous nature of the Markov decision-making problem, we suppress the time subscripts to simplify the notations going forward. The firm pays out dividend only when the marginal value of retaining cash is less or equal to one, i.e.,

$$V_M(M, K^I) = 1\,, \tag{9}$$

and under the super-contact condition (Dumas, 1991):

$$V_{MM}(M, K^I) = 0\,, \tag{10}$$

The firm raises equity and pays the issuance costs only when the increase of existing shareholders' value after issuance overweighs the dilution from issuing new shares to the equity investors, dF, and paying the issuance costs, dH:

$$V\left(M + dF, K^I\right) - V\left(M, K^I\right) \geq dF + dH = dF + \chi_1 dF + \chi_0 K^I\,, \tag{11}$$

and under the smooth-pasting condition:

$$V_M\left(M + dF, K^I\right) = 1 + \chi_1\,. \tag{12}$$

Equation (12) states that the marginal value of equity is equal to the marginal cost of issuance. The optimality conditions for payout and issuances, (9) to (12), lay out the boundaries in the space of (M, K^I). Within the boundaries, the firm does not pay out dividends or raise equity. The value function satisfies the Hamilton–Jacobi–Bellman (HJB) equation:

$$\begin{aligned} r\,V(M,K^I) = \max_{\{K^T\geq 0,\, x\geq 0,\, a\in[0,\bar{a}]\}} & V_M(M,K^I)\left[(K^I)^\theta(a^\theta K^T)^{1-\theta}\mu - \gamma K^T - G(X,K^I)\right. \\ & \left.-C(a,X) + (r-\lambda)M\mathbb{I}_{\{M>0\}}\right] + V_{K^I}(M,K^I)(X-\delta K^I) \\ & + \frac{1}{2}V_{MM}(M,K^I)\left[(\sigma K^I)^2 + 2\sigma\omega\phi K^I M\mathbb{I}_{\{M>0\}} + (\omega M)^2\mathbb{I}_{\{M>0\}}\right] \end{aligned} \tag{13}$$

Following investment literature (Hayashi, 1982), we adopt following parametric forms:

$$G(X,K^I) = \xi_1 X + \frac{\xi_2}{2}\left(\frac{X}{K^I}\right)^2 K^I\,, \tag{14}$$

and the cost of adjusting production function is specified as

$$C(a,X) = \frac{\zeta a^2 X}{2} \tag{15}$$

to capture that intangible investment and adjusting the production function compete for limited (unmodeled) resources as previously discussed.

Under these parametric forms, the value function takes a particular functional form

$$V(M_t, K_t^I) = v(m_t)K_t^I\,, \tag{16}$$

where

$$m_t = \frac{M_t}{K_t^I} \,. \tag{17}$$

This function has the following properties: $V_M(M_t, K_t^I) = v'(m_t)$, $V_{K_t^I}(M_t, K_t^I) = v(m_t) - v'(m_t)m_t$, and $V_{MM}(M_t, K_t^I) = v''(m_t)/K_t^I$. The boundary conditions (9) to (12) are:

$$v'(m) = 1 \,, \tag{18}$$

$$v''(m) = 0 \,, \tag{19}$$

$$v(m + dF/K^I) - v(m) \geq (1 + \chi_1)dF/K^I + \chi_0 \,, \tag{20}$$

$$v'(m + dF/K^I) = 1 + \chi_1 \,. \tag{21}$$

The HJB equation can be rewritten as an ordinary differential equation (ODE) for $v(m)$ in the interior region where $dU = 0$ and $dF = 0$:

$$\begin{aligned} r\,v(m) = & \max_{\{K^T \geq 0,\, x \geq 0,\, a \in [0,\bar{a}]\}} v'(m) \left[\left(\frac{a^\theta K^T}{K^I} \right)^{1-\theta} \mu - \frac{\gamma K^T}{K^I} - \xi_1 x - \frac{\xi_2}{2} x^2 - \frac{\zeta a^2 x}{2} \right] \\ & + v'(m)(r - \lambda) m \mathbb{I}_{\{m>0\}} + [v(m) - v'(m)m](x - \delta) \\ & + \frac{1}{2} v''(m) \left(\sigma^2 + 2\sigma\omega\phi m \mathbb{I}_{\{m>0\}} + \omega^2 m^2 \mathbb{I}_{\{m>0\}} \right) \,, \end{aligned} \tag{22}$$

where x is investment per unit of intangible capital $x = \frac{X}{K^I}$. The solution structure can be summarized as follows. The second-order ODE (22) has the first boundary condition (18) at the dividend payout boundary denoted $\overline{m}$, where the optimality condition (19) determines $\overline{m}$, and the second boundary condition (20) at $m = -\eta$ (i.e., $M + \eta K^I = 0$ where the firm raises equity). The optimal dF/K^I is determined by (21). The firm will not raise equity before m falls to $-\eta$ because, as will be shown in the solution, $v(m)$ is concave in m.

To simplify the HJB equation, we first solve the optimal choice of K_t^T:

$$K^T = \arg\max_{K^T} \left(\frac{a^\theta K^T}{K^I}\right)^{1-\theta} \mu - \frac{\gamma K^T}{K^I} = \left(\frac{(1-\theta)\mu a^{\theta(1-\theta)}}{\gamma}\right)^{\frac{1}{\theta}} K^I \,. \tag{23}$$

Substituting the optimal K^T into the HJB equation, we obtain

$$\begin{aligned} r\,v(m) = \max_{\{x\geq 0,\, a\in[0,\bar{a}]\}} \; & v'(m)\left[\theta\left(\frac{1-\theta}{\gamma}\right)^{\frac{1}{\theta}-1} \mu^{\frac{1}{\theta}} a^{1-\theta} - \xi_1 x - \frac{\xi_2}{2}x^2 - \frac{\zeta a^2 x}{2} + (r-\lambda)m\mathbb{I}_{\{m>0\}}\right] \\ & + [v(m) - v'(m)m](x-\delta) + \frac{1}{2}v''(m)\left(\sigma^2 + 2\sigma\omega\phi m\mathbb{I}_{\{m>0\}} + \omega^2 m^2 \mathbb{I}_{\{m>0\}}\right). \end{aligned} \tag{24}$$

Once we solve the optimal a and x as functions of m, we substitute the solutions to back into the HJB equation and obtain a complete characterization of an ODE for $v(m)$. To solve optimal a and x, we isolate the related components in (24):

$$\max_{\{x\geq 0,\, a\in[0,\bar{a}]\}} v'(m)\left[\theta\left(\frac{1-\theta}{\gamma}\right)^{\frac{1}{\theta}-1} \mu^{\frac{1}{\theta}} a^{1-\theta} - \xi_1 x - \frac{\xi_2}{2}x^2 - \frac{\zeta a^2 x}{2}\right] + [v(m) - v'(m)m]x \tag{25}$$

The objective given by (25) is concave in a given x and concave in x given a, but the optimal a and x cannot be determined simply by first-order conditions because there exist multiple local optimums. Given a low a, the marginal cost of x is low, so a high x is optimal, which causes a high marginal cost of a and confirms that the optimal a should be low. Similarly, given a high a, it is optimal to choose a low x. To address the problem of multiple local optimums, we deploy a global optimization algorithm when we numerically solve the model.

In Figure 2, we plot the numeric solutions of key endogenous variables. From Panel A to C, we report the value function and its first and second derivatives to show that the solution satisfies the boundary conditions. In this baseline solution, we set $\eta = 0$ so the firm raises equity at $m = 0$. The firm pays out dividend at the optimal upper bound of m where the marginal value of liquidity, $v'(m)$, is equal to one. The marginal value of liquidity is strictly greater than one in the interior region and the firm retains liquidity instead of pay out dividends because, to replenish liquidity, the firm has to pay issuance costs to raise equity. An implication of $v'(m) > 1$ is that the firm finances tangible capital externally rather taps into its internal liquidity. The financing cost is $1 + rdt$ (one plus infinitesimal) which is smaller than $v'(m) > 1$.

In Panel D to F of Figure 2, we report the optimal choices of tangible-to-intangible capital ratio, K^T/K^I, the dependence of production technology on tangible capital, a, and the ratio of intangible investment to intangible capital stock, x. In the low-m region, the firm's holdings of liquid assets, M, is low relative to illiquid intangible assets, K^I, so the firm relies more on externally financed tangible capital in production, choosing high K^T/K^I and a. As m increases, the firm invest more in intangibles, as shown in Panel F of Figure 2. Importantly, once the firm has accumulated enough liquidity, the joint optimization over a and x in (25) switches from favoring a to favoring x. As previously discussed, there are two local optimums. The numeric algorithm calculates the objective (25) on a fine grid to search for a global optimum of (a, x). When m is sufficiently high, the intangible investment-to-capital ratio, x, jumps upward and the dependence of production on tangible capital, a, jumps downward (bringing down K^T/K^I as shown in (23)).

The solutions in Figure 2 are behind the hypotheses in Section 2.1. In a crisis where the firm experiences a sequence of negative shocks (either $dZ_t < 0$ or $dW_t < 0$), the firm's liquidity holdings decline (see 7). When we read the graphs from the right to the left, intangible investment declines in Panel F. According to (23), the firm's tangible investment over dt (i.e., $K^T_{t+dt} - K^T_t$) is proportional to intangible investment by a scaling factor that increases in a. Because a increases as m declines (Panel E), the crisis impact on tangible investment is smaller than the impact on intangible investment. As the firm rely on tangible capital, its debt increases, so the debt-to-cash ratio, $K^T/M = (K^T/K^I)/m$, where K^T/K^I is in Panel D, increases. If the pre-crisis level of m is sufficiently high (close to the upper boundary and above the jump point), the decline of intangible investment is small; otherwise, the decline is larger. And (23) implies that the firm's operating cash flow is proportional to its intangible capital, K^I. While the adjustment of a softens the negative impact of crisis, it cannot reverse. A lack of intangible investment implies a reduction in future cash flows.

A key friction in our model is the equity issuance cost, which, as previously discussed, arises from the asymmetric information or investors' heterogeneous belief on the value and productivity of intangible capital. The issuance costs are typically higher in crises due to capital market dislocations. In Panel A to C of Figure 3, we show the comparative statics results from an increase in the equity issuance cost (the dashed line). For simplicity, we focus on the proportional cost χ_1. Increasing χ_0 generates similar results. A higher equity issuance cost strengthens the mechanism. At any given m, the firm relies more on tangible capital, choosing a higher K^T/K^I and a, and invest less in intangible capital. In Panel D to F, we explore another key aspect of the illiquidity of intangible capital. Comparing the baseline solution where intangible capital is fully unpledgeable ($\eta = 0$) and the solution with $\eta = 0.1$, we can see that at any given m, the firm relies less on tangible capital (lower K^T/K^I and lower a) and invest more in intangible capital. Moreover, the pledgeability of intangible capital allows the firm to raise costly equity at a lower level of m shifting the whole region of m leftward (implying a lower threshold of m for dividend payout).

In Panel A to C of Figure 4, we compare the solutions under different tangible capital financing cost, γ. A financial crisis is often associated with a higher γ, which directly causes the decline of tangible investment. Moving from the solid lines to the dashed lines in Panel C, we see the firm reduces intangible investment. A higher cost of financing tangible capital negatively affects intangible investment because it reduces cash flows and ability to accumulate internal liquidity, which drives intangible investment. In response, the firm increases a, the multiplier of tangible capital in the production function (Panel B). In Panel A, we show that if the firm enters the crisis with a relatively higher level of cash holdings (i.e., a higher m), the tangible-to-intangible capital ratio increases, counteracting the decline in intangible investment, so that the negative impact of the crisis on tangible investment is weaker than that on intangible capital. When the firm enters the crisis with a low m, the tangible-to-intangible capital ratio declines because the rise of financing cost, γ, overwhelms the increased reliance on tangible capital in production, a.

In a financial crisis, the firm's holdings of liquid assets can become riskier because the issuers of such assets, typically financial intermediaries and the domestic government, experience financial stress. This is captured by an increase in ω. In Panel D to F of Figure 4, we report the comparative statics results. Specifically, we show that given m, an increase in ω causes the firm to reduce intangible investment, x (Panel C), rely more on tangible capital in production, a (Panel B), and deploy more tangible capital in production (Panel D).

Discussion: limited pledgeability of tangible capital. The maximum amount of lines of credit is ηK_t^I, so the haircut on intangible capital is $1-\eta$. Such a collateral requirement may also apply to debts that finance tangible capital. In the model, we assume a zero haircut. Consider an extension of the model where debts backed by tangible capital also require a haircut equal to $1-\psi$ (i.e., the collateral value of tangible capital is ψK_t^T). The additional collateral has to come from the firm's cash or intangible capital, $M_t + \eta K_t^I$. Therefore, the optimization of tangible capital in (23) is subject to the following constraint:

$$(1-\psi)K_t^T \leq M_t + \eta K_t^I\,, \tag{26}$$

or equivalently, $(1-\psi)K_t^T/K_t^I \leq m_t + \eta$. This extension features one more dimension of a financial shock, that is a decrease in ψ, the pledgeability parameter of tangible capital. The extension bring additional complexity to the solution. At $M_t > 0$, the cost of choosing a high K_t^T and hitting the constraint (26) of magnitude dt, in which case the marginal production of tangible capital (of magnitude dt) is equal to γdt plus the Lagrange multiplier of the constraint (26).[12] At $M_t = 0$, a binding constraint (26) implies equity issuances because

[12] As previously discussed, the firm will not use cash to finance tangible capital because the marginal value of cash is strictly above one, which greater than the value of tangible capital that is equal to one plus infinitesimal (marginal production). By the same logic, the firm will also not spending cash to internally

the firm can no longer obtain lines of credit backed by intangible capital ($M_t + \eta K_t^I$ already pledged to finance tangible capital). Therefore, at $M_t = 0$, the cost of a binding constraint (26) includes the costs of equity issuances and is thus no longer one plus infinitesimal.

3 Data Description

We now move on to empirical analysis in which we empirically test the implications generated by our theoretical framework. In this section, we discuss the data sources utilized for our empirical analysis. We also discuss how we construct measures for some important economic variables in our theoretical analysis.

3.1 Firm Balance Sheet Data

The key data source of cross-country balance sheet panel is from BvD ORBIS. The data features rich information on the balance sheet condition (total asset, tangible and intangible fixed assets, cash holding, total employees) for a broad set of countries. Moreover, the data covers not only public companies, but also smaller private companies. The various previous studies have utilized this database to study questions related to firms' productivity, asset conditions and financial frictions (Gopinath, Kalemli-Ozcan, Karabarbounis, and Villegas-Sanchez, 2017; Duval et al., 2019). The countries in our sample include Belgium, Czech Republic, Denmark, France, Germany, Hungary, Ireland, Italy, Japan, South Korea, Netherlands, Poland, Romania, Slovak Republic, Spain, Sweden, Turkey, United Kingdom. The sample period is from 2002 to 2017. To ensure consistency of our sample construction, we keep firms that have at least three consecutive years of observations and we require that the firms in our sample were in operation before 2007. We winsorize all the variables at 2.5

accumulate tangible capital to relax the collateral constraint. A related question is whether the firm has incentive to accumulate tangible capital and pledge it as collateral to obtain debt financing for intangible investment. The firm optimally chooses not to because accumulating cash is more efficient as cash does not have a haircut when pledged for financing. Moreover, it is more costly to accumulate tangible capital than cash if the cost of tangible investment features increasing marginal cost.

and 97.5 percentile and at country-year level. We define the crisis years as the year of 2009 and the year of 2010. The reason is that all of the economies in our sample are non-U.S. economies, although the financial crisis first hit U.S. in 2008, it took time for the crisis to transmit to other economies; and for majority of economies, economic performance in 2010 was still expected to be below the pre-crisis level (IMF (2009).)

Table 1 shows the summary statistics of firms' balance sheet in our sample. Panel A shows the summary statistics of key balance sheet variables and the first column of Panel B shows the number of firms in each country in our sample. The key outcome variables of our analysis are: (1) the percentage change in intangible fixed asset and percentage change in tangible fixed assets, formally, $\frac{\text{Intangible}_t - \text{Intangible}_{t-1}}{\text{Intangible}_{t-1}}$ and $\frac{\text{Tangible}_t - \text{Tangible}_{t-1}}{\text{Intangible}_{t-1}}$, we denote these by "Δ Intangible" and "Δ Tangible" respectively; (2) changes in a firm's cash holding scaled by total assets, mathematically, it is defined as $\frac{\text{Cash}_t - \text{Cash}_{t-1}}{\text{Assets}_t}$ we denote this as ΔCash/Assets. Intangible assets reported in ORBIS data use International Accounting Standard (IAS) 38 Ribeiro, Menghinello, and Backer (2010). Under that standard, An intangible asset is an identifiable non-monetary asset without physical substance and that is expected to generate income in the future. Such an asset is identifiable when it is separable, or when it arises from contractual or other legal rights. Separable assets can be sold, transferred, licensed, etc. Examples of intangible assets include computer software, licences, trademarks, patents, films, copyrights and import quotas.[13]

Following previous literature studying firms' investment behavior (Leary and Roberts, 2014; Denis and Sibilkov, 2010), we add control variables such as return on assets, total debt scaled by total assets, tangibility and logarithm of total employees.

3.2 Country Level Data

The main country-level variables for our comparative statics analysis is the intellectual property protection index. This variable measures the degree of intellectual property pro-

[13] According to this Standard, "Goodwill" acquired in a business combination is accounted for in accordance with IFRS 3 and is outside the scope of IAS 38.

tection and the value of intellectual property in an economy. A higher value of the measure indicates greater pledgeability of intangible assets that relaxes firms' financial constraints.

The first measure we use is the intellectual property protection index ("IP index-1") constructed by Park (2008). The index incorporates the effects of global-wise technology development as well as country-specific improvement in legal system during the 2000s, legislation dealing with emerging technologies such as software and biotechnology, and the revisions in national patent laws required to conform to international and regional agreements such as the North American free trade agreement (NAFTA), European patent convention (EPC), etc. We use the 2005-index value provided in Park (2008).

The second intellectual property index ("IP index-2") is from Property Rights Alliance (Protection of Intellectual Property) and the earliest year available (from 2007 to 2009).[14] The index is based on patent strength, copyright piracy and trademark protection.

We obtain other country-level variables from IMF financial soundness database and international financial statistics. The variables in this part includes a country's sovereign debt as a percentage of GDP, external debt as a percent of GNP, domestic banks' tier-1 capital ratio, and domestic banks' non-performing loan as a percent of total loan.

3.3 The Safety of "Safe Assets"

Another important country-level variable for our comparative statics analysis is the degree of safety of a country's government bond. Previous literature has documented the fact that firms frequently hold considerable amount of government bonds as a liquidity buffer to smooth their investment, especially in firms that heavily rely on intangible assets (Pinkowitz et al., 2015; Graham and Leary, 2018; Falato, Kadyrzhanova, Sim, and Steri, 2018; Li, 2015). Through government bond holdings as internal liquidity buffer, firms located in countries with financially sound government are less impacted by financial shocks. The effectiveness of government bonds as a liquidity buffer depends to a large degree on whether the government

[14] For most of the countries in our sample, the second intellectual property index is available in year 2007, Japan joined the list in year 2008 and Slovak Republic joined the list in 2009.

bond prices depreciate during negative shock period or when uncertainty heightens.[15]

To measure the degree of safety of a country's government bonds, we refer to Habib, Stracca, and Venditti (2020) and use the correlation between the changes in 10-year government bond yield and changes in VIX up until 2007 (to avoid the impact of the global financial crisis), formally, $z_i^1 = Corr(\Delta Y_{i,2007}, \Delta \text{VIX}_{2007})$ for country i. VIX is the expected volatility of the S&P 500 Index measured from option prices, and is frequently used as a measure of risk.[16] The more negative this measure is, the safer this country's government bond is, as it indicates that this bond's yield (price) decreases (increases) whenever VIX increases. As a supplement, we also construct $z_i^2 = Corr(\Delta Y_{i,2007}, \Delta \text{FCI}_{2007})$, the correlation between changes in government bond yield and FCI ("Financial Condition Index"), as a second measurement for government bond safety. The summary statistics are provided in the last two columns of Table 1.

Finally, as pointed out by Li (2015), a major component of firms' liquidity holdings consists of debt instrument issued by financial intermediaries. Therefore, we construct a measurement of the financial soundness of domestic banks. Specifically, we calculate the average change in domestic banks' CDS spread one month after September 15, 2009 (i.e., the onset of global financial crisis marked by the bankruptcy of Lehman Brothers) compared with that one month before the Lehman shock (similar to the construction in Duval et al. (2019)). Banks' CDS spread data is extracted from Datastream. Note that this measure of financial soundness of domestic bank may proxy for both the safety of financial intermediaries' debts (held by firms as internal liquidity buffer) and the fragility in credit supply (that limits firms' access to external financing).

[15] For instance, Gorton (2017) defines safe asset as one almost always sold at face value, and agents need not fear adverse selection in trading; Caballero, Farhi, and Gourinchas (2017) describes safe asset as a debt instrument that is expected to preserve its value during adverse systemic events; He, Krishnamurthy, and Milbradt (2016) emphasizes that safety of safe assets depends on the relative fiscal surplus of a country relative to other countries, and the safe assets in the world are largely government debt, money and bank debt as a result of investors' coordination.

[16] See Habib and Stracca (2012), Bruno and Shin (2015), Avdjiev, Gambacorta, Goldberg, and Schiaffi (2020).

4 Empirical Specification and Results

In this section, we start our analysis by first examining the trajectories of firms' investment in tangible capital and intangible capital before and after the 2008/09 global financial crisis. We then study how firms' investment profiles and cash holdings evolved both at the onset and in the aftermath of the crises.

4.1 Persistent and Heterogeneous Crisis Impact on Investment

Despite the abundance of study that documents the persistence of shock impact on firm performance and productivity of the recent financial crisis, little progress has been made on understanding such persistence of shock impact—what is preventing firms from getting back to their pre-crisis trajectory when macroeconomic statistics have presumably recovered to the pre-crisis states? Moreover, did the responses of firms' tangible and intangible investment to crisis and the post-crisis recovery differ?

Figure 5 shows the dynamics of firms' intangible assets as a proportion of tangible assets over time. The y-axis is the mean of $\frac{\text{Intangible assets}}{\text{Tangible assets}}$ of all firms in the sample. As is shown in the figure, firms' input ratio as measured by the ratio of intangible asset over tangible asset was on a steady rise before the financial crisis. But since the crisis, the trend of this ratio has been significantly flatter than the pre-crisis level, and didn't recovery back to pre-crisis level even after five years.

Figure 6 displays firms' intangible asset investment rate over time by country groups. The y-axis of both figures are the mean of year-to-year intangible asset growth rate of firms in a specific country group. In the top panel, we decompose countries into "High IP" countries and "Low IP " countries. The group labeled as "Low IP" is the group of countries whose IP protection score (IP-index 2) is below median, the countries in this group include: Czech Republic, Hungary, South Korea, Italy, Poland, Portugal, Romania, Slovak Republic, Spain, Turkey. In the bottom panel, we decompose countries into "High safety" and "Low safety". The "Low safety" countries are those with above-median "Corr with VIX". The summary statistics of "IP-index 2" and "Corr with VIX" are provided in Table 1. The two figures indicate that firms in countries with stronger IP protection and countries with safer government bond saw better recovery in their intangible asset build-up since the crisis.

In a more quantitative analysis of how firms' investment in tangible and intangible capital evolves before and after the financial crisis, we run the following regression specification:

$$\Delta y_{i,c,t} = \alpha_i + \mu_c + \sum_{j=2003, j\neq 2007}^{2018} \beta_j \mathbb{1}[\text{Year j} = t] + \pi \mathbf{X} + \epsilon_{i,c,t} \tag{27}$$

$\Delta y_{i,c,t}$ is either $\Delta\text{Intangible}_{i,c,t}$ or $\Delta\text{Tangible}_{i,c,t}$, where i refers to firm, c refers to country and t refers to year. β_j is a series of year-specific coefficients and $\mathbb{1}[\text{Year} j = t]$ is a series of year dummy. X is a vector of control variables including logarithm of employees, total debt scaled by assets, return on assets and tangibility. Firm and country fixed effects are included, standard errors are clustered at country-year level.

The coefficients plot are demonstrated in Figure 7. The coefficient plots show that since the Great Financial Crisis, both tangible asset investment rate and intangible asset investment rate of the firms in our sample have been significantly lower than the pre-crisis level. Before the financial crisis, average intangible asset investment rate has been higher than tangible asset investment rate. Since the punctuation of financial crisis, while the average tangible and intangible asset investment rate have been lowered compared with their pre-crisis levels, the size of reduction are different for two. In particular, the degree of downward adjustment of intangible asset investment rate has been significantly more severe than the downward adjustment of tangible asset investment rate. This result highlight that the financial shock in 2009 seemed to have more permanently and negatively changed firms' intangible asset build-up rate.[17]

[17] Using French firm-level data, Aghion et al. (2012) documented that R&D investment tends to be pro-cyclical for credit-constrained firms and importantly, for these firms, R&D plummet more significantly during crisis, but does not increase proportionally during upturns. Using aggregate level data, Corrado et al. (2016) documented that intangible capital investment was resilient in U.S., but lagged behind in EU countries.

In Figure 8, we conduct the same set of analysis as in Figure 7 and decompose countries into two groups based on their IP protection strength (upper two figures), as well as the safety of domestic government bond as firms' liquidity buffer (bottom two figures). As is shown in the figure, for "Low IP protection" countries, intangible investment rate has been significantly lowered compared with the base-year (2007) level, reflected in that all the coefficients since 2008 are statistically significantly smaller than zero. In addition, the intangible investment rate has also been much statistically lower than tangible investment rate for these countries since the global financial crisis. For "High IP Protection" economies, however, no such change in intangible investment rate is observed during the post-crisis period relative to the pre-crisis period or the tangible asset investment rate. Moreover, there is no statistical difference in intangible investment and tangible investment during the post-crisis period, which is in sharp contrast to the pattern in "Low IP Protection" countries.

To supplement the above time-trend specification, Figure A1 and Figure A2 display the aggregate trend of firms' intangible investment rate over time. Figure A1 shows the average intangible investment rate weighted by total asset sizes for "High IP Protection" countries in our sample; Figure A2 shows the average intangible investment rate weighted by total asset sizes for the "Low IP Protection" countries. As is shown in the figures, in "High IP Protection" countries, firms' intangible asset investment rate is overall much more resilient, they tend to go back to the pre-shock levels quickly and there were no permanent transition from a high intangible asset investment rate to a lower one since the global financial crisis. However, for the "Low IP Protection" countries, firms' intangible investment rates have persistently shifted to a much lower level compared to the pre-crisis level.

These findings suggest a non-transitory yet asymmetric impact of financial shocks on firms' capital investment. In particular, such impact on investment is more prominent and enduring in economies where IP protection is weaker or domestic bonds are less safe. Moreover, the asymmetric impact of financial shock on firms' tangible investment versus that on intangible investment is more pronounced when firms are operating in these countries. In what follows in this section, we conduct a closer examination of individual firms' investment response as well as their balance sheet changes during and after the financial crisis to better understand the above aggregate patterns.

4.2 Pecking-Order Responses of Investment to Financial Shocks

Intangible capital and intangible capital differ in their pledgeability in raising finance from external sources. Investment in intangible capital relies heavily on internal funds.[18] In a crisis, as firms struggle to survive and, in particular, avoid running out of cash, the marginal value of internal liquidity increases, dampening firms' incentive to invest in intangible capital. In contrast, tangible capital can serve as collateral and is more easily finance externally, so it does not drain internal liquidity as badly as intangible investment does. Therefore, even if financing costs may rise in a crisis, the fact that tangible capital can be externally financed gives firms more flexibility and thus encourage firms to prioritize tangible investment over intangible investment.

Investment response during the crisis. To investigate firms' crisis reaction in their investment decisions, we run the following regression:

$$\Delta y_{i,c,t} = \alpha_i + \gamma_c + \beta \Delta \text{Property Price}_{c,t} \text{ or } \mathbb{1}[\text{Crisis}] + \pi X + \epsilon_{i,c,t} \tag{28}$$

where $\Delta y_{i,c,t}$ is either tangible capital investment rate or intangible capital investment rate of firm i in country c in year t. ΔProperty Price$_{c,t}$ is the change house price index of country c in year t. $\mathbb{1}[\text{Crisis}]$ is a dummy variable that equals to 1 for year 2009 and 2010. The control variables are the same as in Equation 27. Firm fixed effects and country fixed effects are included, and we cluster standard errors at country-year level. Table 3 and Table 4 show the

[18] Previous research documented empirical patterns pointing to the difference between tangible and intangible asset when serving as collateral Dell'Ariccia et al. (2020), Döttling and Perotti (2017). An economic report by OECD confirms that for majority of EU economies, IP-based financing is less than developed and innovative firms still rely on internal financing to fund project that primarily utilize intellectual input.

results of the above regression specification. Column (1) and (2) are baseline regressions with no control variables, column (3) and (4) are regressions with control variable but without fixed effects, and column (5) and (6) are regressions with both fixed effects and control variables. As is shown in the table, during the 2-year crisis period, tangible asset investment rate is on average 9.2% lower than during normal period, intangible asset investment rate goes down more significantly, which is around 34% lower than during normal years and is also more statistically significant.[19]

The dummy variable "$\mathbb{1}$[Crisis]" captures the negative financial shock. We conduct a parallel analysis by using a country's property price as the main explanatory variable. One underlying assumption here is that most small and medium sized firms use plant, buildings and land as collateral. Thus when property prices go down, firms' debt capacity will be decreased, and as firms lose their flexible flexibility, cash becomes more valuable and intangible investment thus becomes more costly.[20] As a result, firms are expected to see a cut in their intangible asset investment once hit by negative shocks on their property price. The estimation results are displayed in Table 4. On average, a 10% decrease in house prices is associated with a 11.6% decrease in firms' tangible asset growth, and a noticeably higher 23.8% decrease in the intangible asset growth.[21]

Using the same specification, we conduct a diff-in-diff (DiD) analysis to compare firms' investment rate in tangible capital and intangible capital. The left-hand side variable is the change in average tangible/intangible investment rate during the two-year time window after the Lehman Brothers' bankruptcy announcement in 2008, relative to the average investment rate of tangible/intangible capital two years before the crisis. On the right-hand side, we

[19]Campello et al. (2010) documented in the survey that constrained firms planned to cut their tech spending, employment, and capital spending. Our findings highlight that firms tend to shed their intangible spending more significantly than tangible spending. Peia (2017) financially constrained sectors persistently downward adjust their R&D investment in their total investment, suggesting a shift in the composition of investment that is specific to recessions following banking crises. Our paper highlights that the asymmetric adjustment is true at firm level on average.

[20]Related, Borisova and Brown (2013) document that tangible asset sale allows firms to invest more in intangible. This is consistent with our model where when firms divest tangible capital (i.e., reducing K_t^T), the saved cash flows increase firms' cash balances and support intangible investment.

[21]Similar findings are also documented in Li (2015).

use a measure of the degree of financial shock. The measure is constructed as the average change in a country's domestic banks' CDS spread 30 days after the Lehman's collapse (on Sep 15, 2008) compared with 30 days before the collapse. The results are reported in Table 5.[22] The results are consistent with the results in Table 3. Specifically, a 100-basis point higher increase in domestic banks' CDS spread as a measurement of exposure to financial shock translated into 47% more slower intangible asset investment rate during crisis, while there is no significant impact of financial shock on tangible asset build-up rate.

Post-crisis investment performances. Our findings above unveil a set of novel facts: during the crisis, firms tend to adjust their investment profile by significantly slashing intangible investment, while the reduction in tangible investment is much less pronounced. In addition to the larger magnitude, the reduction in intangible investment also exhibits significantly stronger persistence.

While this pattern regarding firms capital adjustment during the crisis is by itself interesting, one question that naturally follows is the economic consequence of such a capital adjustment response. To understand the economic implication of this pecking order in firms' capital investment response to financial shocks, we study the impact of slashing intangible investment during the crisis on firms' post-crisis performance. Our analysis also helps rule out the hypothesis that the reduction in intangible investment is a rational choice of firms to avoid intangible over-build and to lean towards more productive tangible capital.

We run the following regression:

$$\text{Performance}_{i,c,t} = \alpha_i + \mu_{c,t} + \beta \Delta y_{i,09-10} + \pi X + \epsilon_{i,c,t} \tag{29}$$

where the left-hand side variable is some specific firm-level performance variable such as profit margin or profit per employee. The main explanatory variable $\Delta y_{i,09-10}$ is the average

[22] Banks suffered more erosion on their liquidity and capital saw more dramatic increase in their CDS spread (Brunnermeier (2009), Afonso, Kovner, and Schoar (2011)), and thus countries with more severely hit banking sectors are also perceived to have worsen-off credit supply condition.

tangible or intangible investment rate of firm i during the crisis period of 2009-2010. X is the set of control variables defined as above, firm and country-year fixed effects are included, and standard errors are clustered at country-year level.[23]

The estimation results are reported in Table 2. Overall, firms that experienced smaller cut of intangible investment during the crisis saw a higher profit margin post-crisis, while the impact of cutting tangible investment on ex-post profit margin is significantly less. A one percentage higher drop in intangible asset investment rate is associated with 4.4% lower profit margin during the recovery period; while a one percentage higher drop in intangible asset investment rate is only associated with 1.1% lower profit margin. Similarly, a one percent higher drop in intangible asset investment rate is associated with about 10,000 dollars lower profit per employee; while one percent higher drop in tangible asset investment rate is associated with 1500 dollars lower profit per employee. These findings suggest that the observed downward adjustment in firms' intangible investment is likely to entail a productivity loss in firms' subsequent operation, consistent with the setup of our theoretical model and its main prediction on the intertemporal linkages.

4.3 The Cash-Intangible Investment Dynamics

Given that intangible assets are not as pledgeable as tangible assets, firms normally need to preserve cash holdings (internal funds) for future opportunities of intangible investment.[24] Therefore, one natural and important dimension of our empirical analysis is how firms'

[23]Similar findings about the loss of intangible asset on output or productivity was also made by previous literature: for instance, Garcia-Macia (2017) demonstrated that financial shock could lead to persistently low GDP growth because of the lack of spillover of intangible-intensive firms, which are faced with extra-high exit pressure during financial shock. Our work emphasizes the within-firm loss of intangible accumulation after financial shock will cause long-term loss in profitability. De Ridder (2019) documented that tightened credit constraint even reduced intangible investments even for large corporations in U.S., and significantly slowed down revenue growth between 2010 and 2015. Hardy and Sever (2019) documented the long-lasting decrease in patenting behavior is particularly significant after banking crisis and correlated with the slower long-term growth. Duval et al. (2019) documented the persistently lower firm TFP and labor productivity after financial crisis of set of advanced economies.

[24]Previous literature has documented the relationship between firms' R&D behavior and cash holding: R&D intensive firms tend to hold more cash, such as Brown and Petersen (2011), He and Wintoki (2016), Kaoru et al. (2017), Kahle and Stulz (2017), and Thakor and Lo (2018).

investment response in the crisis depends on with their pre-crisis cash holdings, which, as shown in our theoretical analysis, is an important endogenous state variable that governs firms dynamic decision making. Specifically, we examine how firms' pre-crisis cash holdings affect the response of intangible investment to the crisis, how firms' drawn down cash holdings during the crisis, and how cutting intangible investment compromises the post-crisis recovery of firms' cash positions (via its negative impact on profitability as previously discussed).

Pre-crisis cash holdings and intangible investment. We start by investigating whether firms with more cash holdings right before the crisis can better withstand the impact of the crisis, reflected in a less severely impact on intangible investment. The regression is specified as follows:

$$\Delta\text{Intangible}_{i,\text{post}} = \mu_c + \beta\text{Cash/Assets}_{i,\text{pre-crisis}} + \pi X + \epsilon$$

The estimation results are shown in Table 9. We find that a 10% higher cash as a share of total assets right before the crisis is associated with an average of 2.95% faster growth in intangible asset (or 2.95% less reduction) during the crisis. The results establish a crucial link between cash holdings and intangible investment, consistent with previous studies.[25]

Cash drawdown during the crisis. In our theoretical framework, cash is the important state variable that drives firms' dynamic investment decisions and production-function adjustment in terms of the relative importance tangible and intangible capital. In this regard, we examine how the evolution of firms' cash holdings during the crisis and how it drives with firms' investment. Table 10 show the results of the following regression:

$$\text{Cash/Assets}_{i,c,t} \text{ OR } \text{Revenue/Assets}_{i,c,t} = \alpha_i + \mu_{c,t} + \beta\mathbb{1}[\text{Crisis}] + \pi X + \epsilon_{i,c,t}, \tag{30}$$

[25] Joseph, Kneer, and van Horen (2020), Ding, Levine, Lin, and Xie (2021) documented that firms with more cash holding right before a crisis tend to recover better and gain advantage during the post-crisis period.

where the left-hand side is either the cash stock scaled by total assets or operating revenues (as proxy for cash inflows) scaled by total assets. On average, firms' cash holdings during the crisis is about 0.8% lower than the level in normal times, and the decrease is likely attributed to the dramatic crisis response in firms' operating revenues, which is about 15.8% lower than the level in normal times.

Investment in the crisis and post-crisis cash recovery. As shown in our theoretical framework, slashing intangible investment during the crisis reduces firms' revenue-generating capacity after the crisis. As a result, firms' profit making and thus the build-up of their cash holdings post-crisis can be negatively affected. To empirically test this prediction, we examine how the reduction in intangible investment during the crisis is associated with post-crisis trajectory of cash build-up. Specifically, we run the regression:

$$\Delta\text{Cash/Assets}_{i,c,\text{post}} \text{ OR } \Delta\text{Revenue/Assets}_{i,c,\text{post}} = \alpha_i + \mu_c + \beta\Delta\text{Intangible}_{i,c,09-10} + \pi X + \epsilon_{i,c,t}$$

where the left-hand side is the cash build-up rate post-crisis of firm i in country c, and the main explanatory variable is the average intangible investment rate in the crisis.

The estimation results are reported in Table 11. Our findings suggest that firms less affected in their intangible investment during the crisis period exhibit greater resilience and recover quickly in revenues after the crisis. In line with this finding, such firms were also able to build up their cash holdings faster in the post-crisis period.[26] A quick build-up in cash flow can thus allow these firms to better seize future opportunities in intangible investment that rely on internal funds, forming a virtuous cycle.

[26] Brown and Kimbrough (2011) demonstrated that intangible asset investment enables firms to generate earnings fast because it allows firms to obtain firm-specific earning factors that differentiate themselves economically from their rivals. Faulkender et al. (2019) documented that firms with more intellectual properties are more able to transfer and seize tax saving/production opportunities in foreign countries, which in turn allowed these firms to build up more cash since the Great Financial Crisis. Crouzet and Eberly (2021b) demonstrated the rent-generating intangible assets enabled particular groups of firms to grow faster and gain high valuation.

Leverage during crisis. Another prediction of the model is that leverage ratio will go up significantly during crisis. This is tested in Table 12, where we regress the ratio of total debt over cash holding and long-term debt over cash holding on the dummy variable indicating the financial crisis. The results show that during crisis, debt-over-cash ratio go up by 39% (28 divided by 71 as the mean of debt-over-cash ratio) and long-term debt-over-cash goes up by 51% (60 divided by 116 as the mean of long-term debt-over-cash ratio). And both coefficients are statistically significant.

4.4 Investment Dynamics and Firms' Operating Environment

We relate back to our cross-country comparison of the shock impact in section 4.1 through a set of comparative statics analysis regarding firms' operating environment. In particular, we investigate how firms' tangible/intangible investment, as well as their cash evolution, differ across countries during and after the crisis. In our sample, countries differ in their IP protection, the safety of government bonds held by firms as their liquidity buffer, and the financial soundness of the intermediation sector that both drives firms' marginal cost of external financing and issues safe assets for firms to hold in their internal liquidity portfolios.

IP Protection. A strong protection of intangible asset ownership improves the marketable and pledgeable value of intangible assets, making it easier to finance intangible investment. As predicted by our model, firms operating in countries with different degrees of IP protection exhibit different investment behavior in a crisis. To formally test this conjecture, we run the following regression:

$$\Delta y_{i,c,t} = \alpha_i + \beta \mathbb{1}[\text{Crisis}] \times \text{IP protection index}_c + \pi X + \epsilon_{i,c,t}$$

The results are reported in Table 6. Column (1) and (2) show tangible and intangible investment responses to crisis and the interaction of crisis and IP-index 1. Column (3) and (4) show the investment responses to crisis and the interaction of crisis and IP-index 2. For both IP protection measures, the interaction term with the crisis dummy have positive and significant coefficients, this indicates that although on average firms' demonstrate "pecking order" in the reduction of intangible and tangible investment in crisis, firms in countries with stronger IP protection exhibit a much less downward adjustment in intangible investment.

To supplement our analysis, we demonstrate in a set of figures how firms' intangible investment rates vary across countries with different IP protection. In Figure 9 we show the scatter plot of the intangible recovery rate against the two intellectual property protection indices. The plot shows a strong positive correlation: the stronger the IP protection, the more robust the recovery of intangible investment post-crisis.[27]

Financial soundness. As demonstrated in our model, a country's financial soundness affects firms' investment and liquidity in two ways. First, because firms hold government bonds in their liquidity portfolio, the financial health of government determines how robust firms' liquidity positions are in the crisis. Firms also hold financial intermediaries' debts as "cash and cash equivalents". Therefore, the financial health of intermediation sector is another important factor that determines the safety of firms' internal liquidity. Second, a country's financial soundness affect firms' crisis responses through the supply of external financing, which also relies on a well-functioning and well-capitalized intermediation sector.

In Table 7 and Table 8, we report the results of the following regression:

$$\Delta y_{i,c,t} = \alpha_i + \beta \mathbb{1}[\text{Crisis}] \times \text{Safety}_c \text{ OR Financial Soundness}_c + \pi X + \epsilon_{i,c,t}$$

In Table 7, "Gov bond cov" is the correlation between the country's 10-year government bond yield and VIX. "Gov debt" is government debt as a proportion of GDP. In Table 8, "Tier 1 capital" is the "Regulatory Tier 1 Capital to Risk-Weighted Assets (percent)" of domestic banking sector. "NPL" is the proportion of non-performing loan in banking sector's asset.

[27]Related, previous literature documented the impact of strength of legal system on financial development and long-run growth: Calomiris et al. (2017), Levine (1998).

These two variables are extracted from IMF's Financial Soundness Indicator data series. Both of the two variables are constructed at the pre-crisis level by using the values in 2007. "Commercial real estate loan/Total loan" is the proportion of commercial real estate loan in total loan of a country's domestic banking sector in 2007.

As is shown in Table 7, a higher correlation between a country's government bond yield and VIX, the more severe the downward adjustment in intangible investment during the crisis, but tangible asset investment rate is not correlated with government bond safety, both in magnitude and statistical significance. Similarly, as is shown in Table 8, the higher the ratio of government debt as a percent of GDP, the more negative the intangible investment rate during the crisis. A one percent higher government debt implies 1.11% more downward adjustment in firms' intangible assets during crisis, but there is no significant impact on tangible asset adjustment. A one percent higher commercial real estate loan in domestic banking sector right before the financial crisis implies 5.9% more drop in intangible asset investment rate. A one percent higher NPL share in domestic banking sector is associated with 4.0% heavier decrease in intangible asset investment rate. A one percent higher Tier-1 capital as a share of total assets is associated with 8.1% less decrease in intangible asset investment rate.

In parallel with the intangible investment recovery and IP protection, in Figure 10, we found that firms' intangible asset investment rate recovery is negatively correlated with the "Gov Bond cov". Meanwhile, as is shown in Figure 11, the higher the pre-crisis non-performing loan ratio, the less likely the recovery in intangible asset investment rate during the post-crisis periods. Lastly, the higher the tier-1 capital adequacy ratio, the better the recovery situation it is in the intangible asset after the financial crisis.[28]

[28] Relatedly, previous literature documented that banks with weaker balance sheet conditions when entering the crisis cut their lending more significantly during the crisis (Ivashina and Scharfstein (2010), Puri, Rocholl, and Steffen (2011), Santos (2010)), and firms responded by cutting more employees and investments (Chodorow-Reich (2013), Ongena, Peydro, and Van Horen (2015)), Cingano, Manaresi, and Sette (2016).

5 Conclusion

The rise of intangible capital has attracted enormous attention in the past few decades. Outside of the U.S., the steady upward trend stopped at the global financial crisis. Specifically, the ratio of intangible capital to tangible capital reversed downward after the crisis. What explains this dynamics is the sharper decline of intangible investment during the crisis and much slower recovery afterwards relative to tangible investment. This paper provides the first evidence on firms' adjustment of investment portfolio in response to the crisis and long-lasting effects of GFC on the composition of productive capital outside of the U.S. As pointed out by Corrado, Haskel, Jona-Lasinio, and Iommi (2016), focusing on the U.S. firms can be misleading as they experienced a relative smaller decline in intangible investment.

Our explanation of the distinct dynamics of intangible and tangible investments focuses on their different means of financing. Tangible investment can be externally debt-financed. Therefore, it benefits from government intervention that aimed at restoring credit supply during and after the crisis. In contrast, intangible investment relies on firms' liquidity holdings that can only be rebuilt gradually via retained profits or through costly equity issuances. The slow recovery of intangible investment is due to a dynamic feedback loop that we formalize in a dynamic model of investment and liquidity management: the reduction of intangible investment hurts productivity growth, which in turn reduces future cash flows and slows down the rebuild of cash holdings; the lack of internal funds dampen intangible investment.

Our paper also relates intangible investment to the quality of liquid assets in a countries. The divergence in intangible and tangible investments during and after the crisis is most prominent among firms in countries with riskier government bonds. In contrast, intangible and tangible investments follow similar paths in countries with greater safety of liquid assets. The risk exposure of corporate liquidity holdings compromises the hedging value of holding liquid assets and amplifies the impact of crises.

Figure 1. Model Mechanism

In this figure, we illustrates the dynamic mechanism that amplifies the impact of crisis and generates persistent effects of shocks. We consider four channels of crisis propagation. First, the firm experiences negative cash-flow shocks. Second, the risk of the firm's liquidity holdings increases. Third, intangible capital becomes more illiquid. Fourth, tangible capital financing cost increases. The first channel triggers an intertemporal mechanism that is amplified by the second, third, and fourth channel. The key to the mechanism is that intangible capital and tangible capital differ in their means of financing. Intangible capital is financed by internal funds (cash holdings), while tangible capital is financed externally.

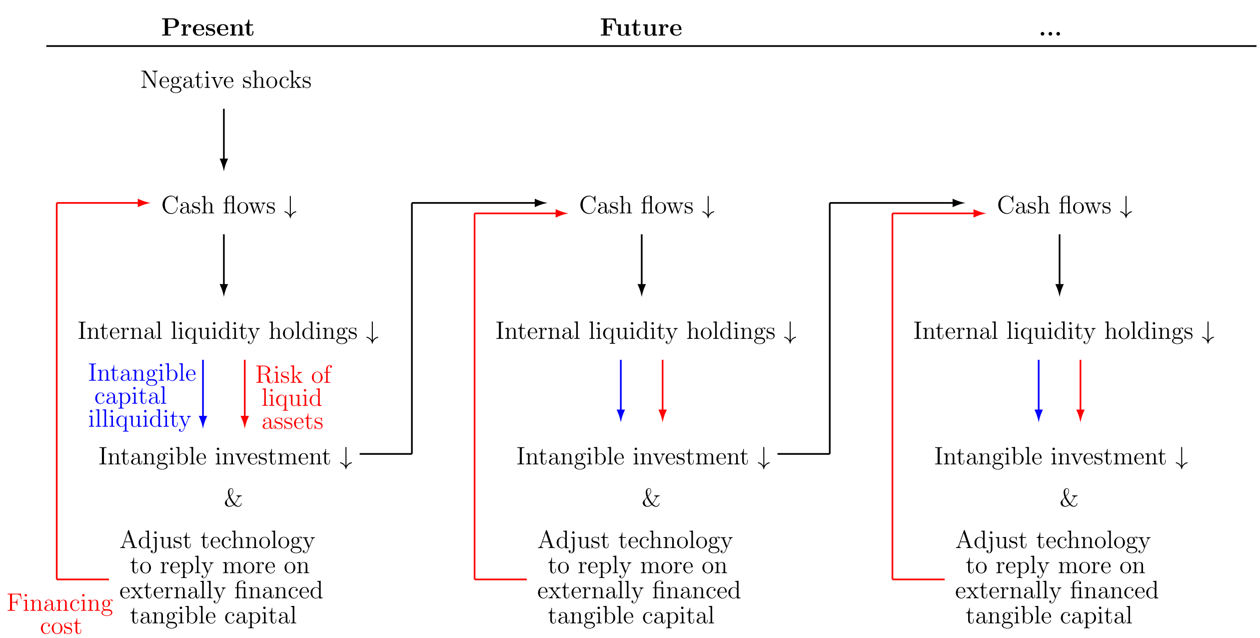


Figure 2. Model Solution.

In Panel A, B, C, D, E, and F, we report, respectively, the value function, $v(m)$, the marginal value of cash, $v'(m)$, the second derivative of value function, $v''(m)$, the optimal tangible-to-intangible capital ratio, K_t^T/K_t^I, tangible capital multiplier in the production function, a_t, and intangible investment per unit of capital, x_t. The parameters are for illustrative purposes: $\mu = 0.3$; $\sigma = 0.1$; $\theta = 0.5$; $\overline{a} = 2$; $\delta = 0.24$; $\omega = 0.01$; $phi = 0.5$; $r = 0.05$; $\gamma = 0.15$; $\lambda = 0.01$; $\xi_1 = 0.2$; $\xi_2 = 1.5$; $\zeta = 0.2$.

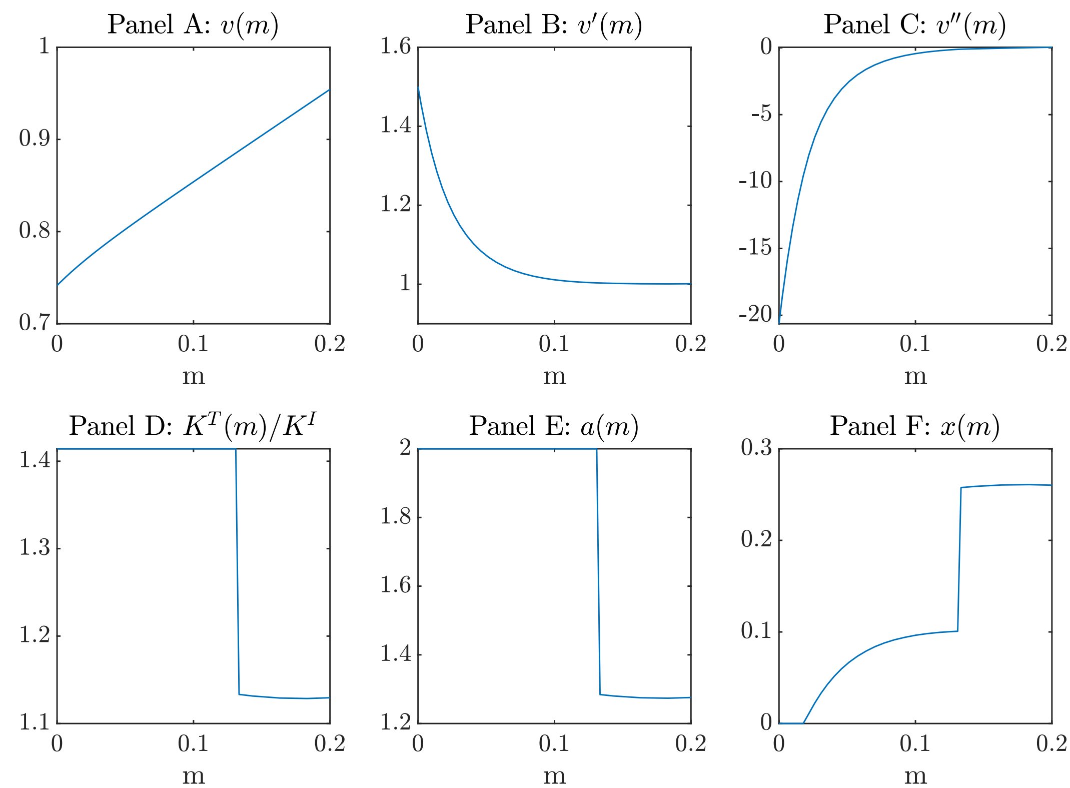


Figure 3. The Illiquidity of Intangible Capital

In Panel A, B, and C, we compare solutions under two proportional costs of equity issuance, χ_1, and report, respectively, tangible-to-intangible capital ratio, K_t^T/K_t^I, tangible capital multiplier in the production function, a_t, and intangible investment per unit of capital, x_t. In Panel C, D, and F, we compare solutions under a high and low pledgeability of intangible capital, η, and report, respectively, tangible-to-intangible capital ratio, K_t^T/K_t^I, tangible capital multiplier in the production function, a_t, and intangible investment per unit of capital, x_t. The rest of the parameters follow Figure 2.

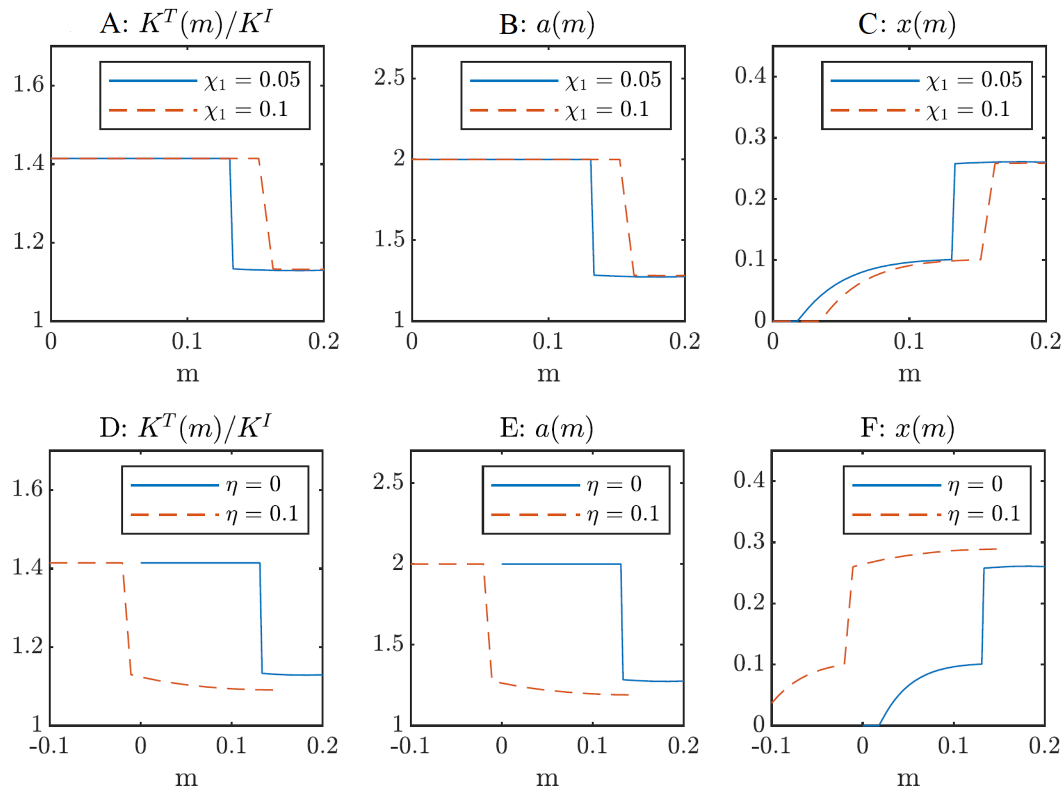


Figure 4. Tangible Capital Financing Cost and Cash Safety

In Panel A, B, and C, we compare solutions under two values of tangible capital financing costs, γ, and report, respectively, tangible-to-intangible capital ratio, K_t^T/K_t^I, tangible capital multiplier in the production function, a_t, and intangible investment per unit of capital, x_t. In Panel C, D, and F, we compare solutions under two risk exposures of cash holdings, ω, and report, respectively, tangible-to-intangible capital ratio, K_t^T/K_t^I, tangible capital multiplier in the production function, a_t, and intangible investment per unit of capital, x_t. The rest of the parameters follow Figure 2.

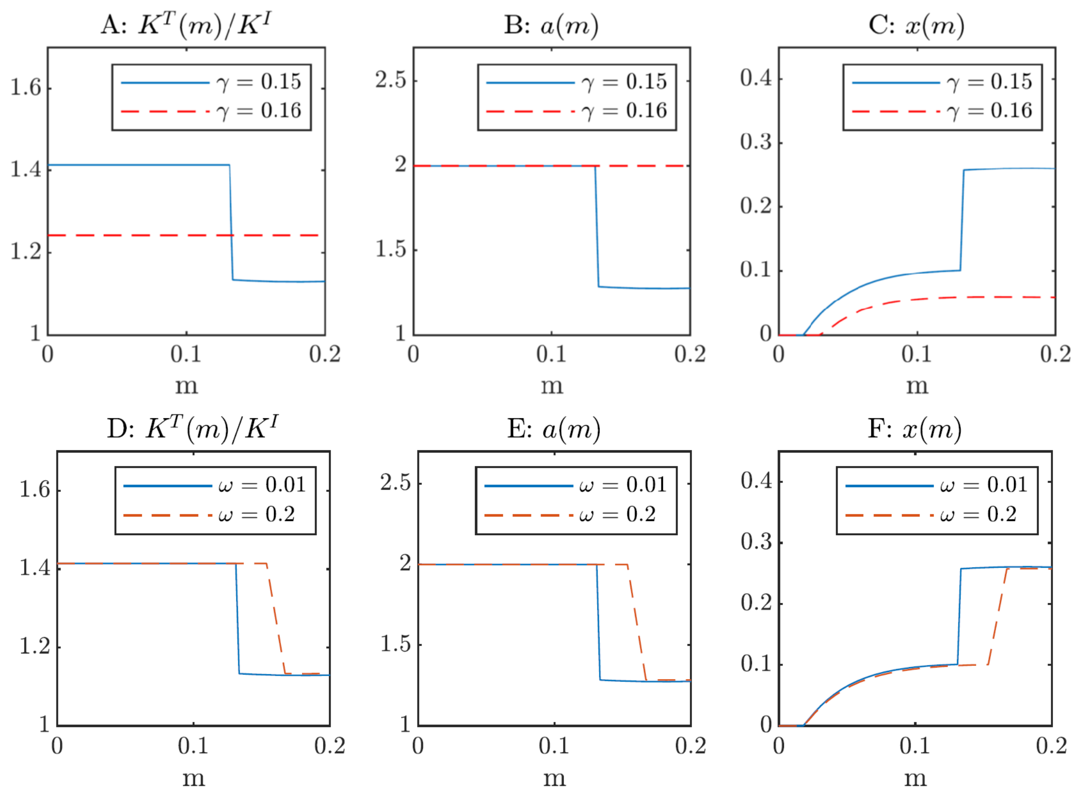


Figure 5. The Reversal of Intangible Capital-to-Tangible Capital Ratio

This figure shows the dynamics of firms' intangible asset as a share of tangible asset over time. The y-axis is the mean of firms' $\frac{\text{Intangible asset}}{\text{Tangible asset}}$ in a given year.

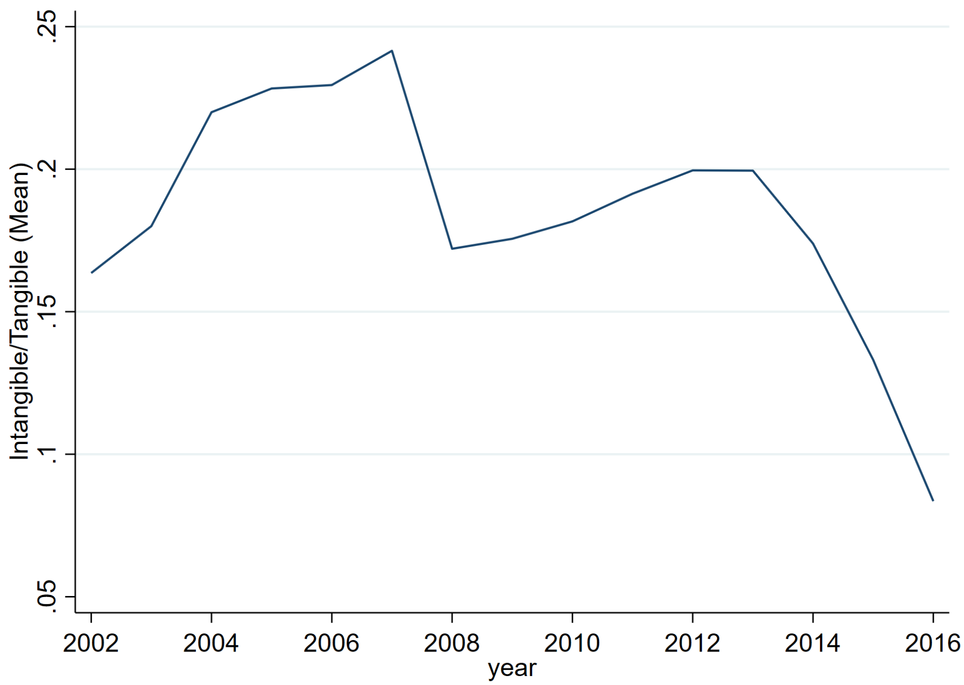


Figure 6. Intangible and Tangible Investment Dynamics (Time Series)

This figure shows the dynamics of firms' intangible asset investment rate by country group from 2002 to 2016. The y-axis is the average of intangible asset growth rate of firms in a specific country group in a given year. "Low IP" economies are defined as countries in the sample with below-median "IP-index 1", which is summarized in column (2) of Panel B in Table 1. "Low Safety" economies are defined as countries in the sample with above-median "Corr with VIX", which is summarized in column (5) of Panel B in Table 1.

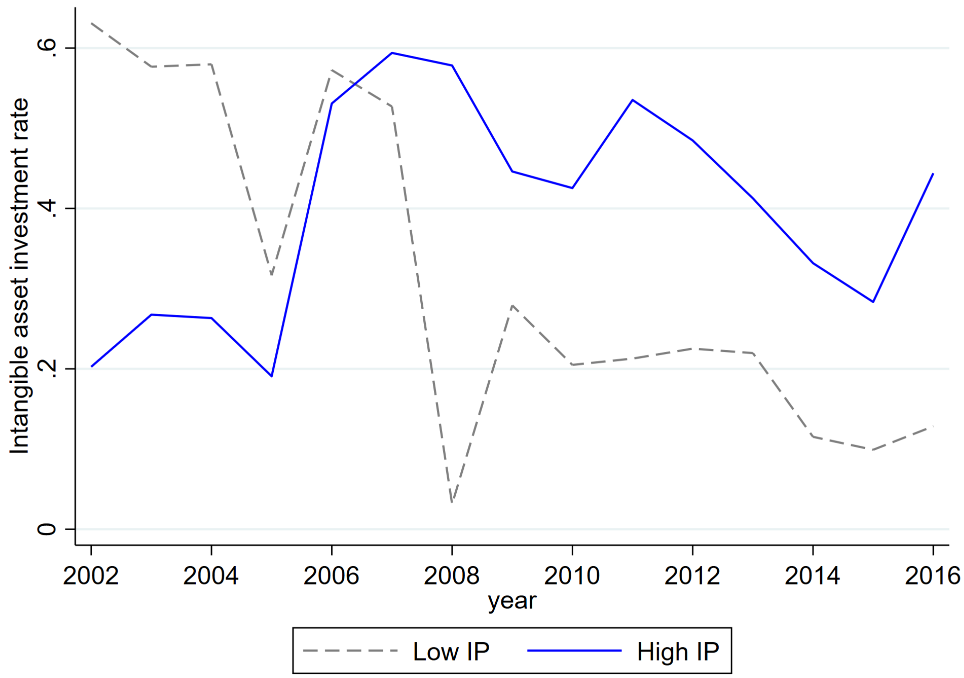


Figure 7. Intangible and Tangible Investment Dynamics (Time Coefficients)

This figure shows the coefficient plots of Equation 27, and is also written as follows:

$$\Delta y_{i,c,t} = \alpha_i + \mu_c + \sum_{j=2003,j\neq 2007}^{2018} \beta_j \mathbb{1}[\text{Year j} = t] + \pi \mathbf{X} + \epsilon_{i,c,t}$$

$\Delta y_{i,c,t}$ is either $\Delta \text{Intangible}_{i,c,t}$ or $\Delta \text{Tangible}_{i,c,t}$, where i refers to firm, c refers to country and t refers to year. β_j is a series of year-specific coefficients and $\mathbb{1}[\text{Year}j = t]$ is a series of year dummy. The year of 2007 is chosen as the base year. X is a vector of control variables including logarithm of employees, total debt scaled by assets, return on assets and tangibility. Firm and country fixed effects are included, standard errors are clustered at country-year level.

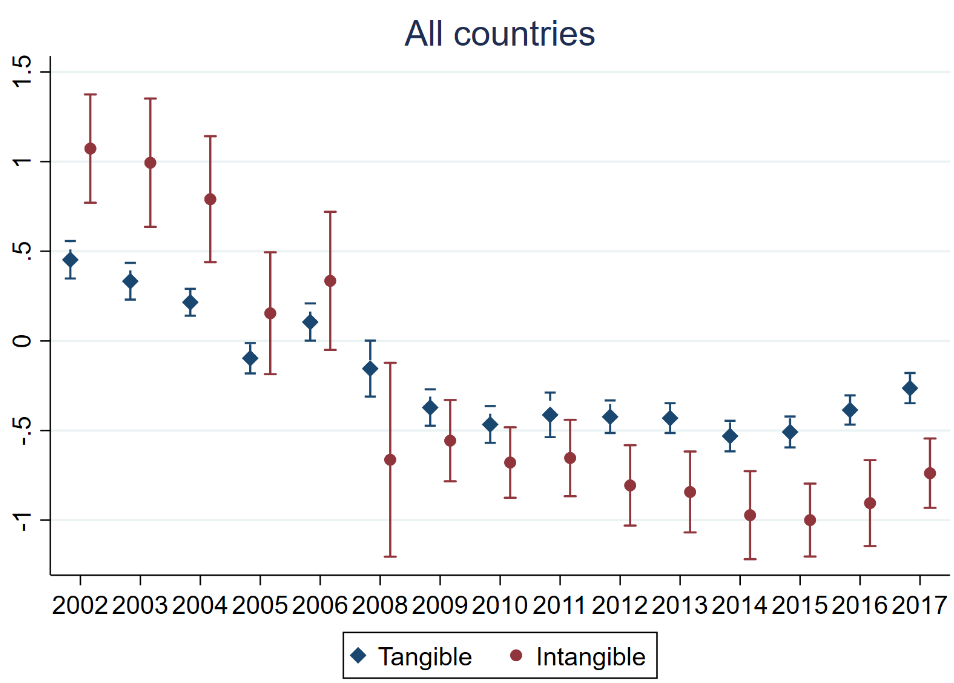


Figure 8. Intangible and Tangible Investment Dynamics by Country Groups

This figures below show the coefficient plots of Equation 27 for different groups of economies:

$$\Delta y_{i,c,t} = \alpha_i + \mu_c + \textstyle\sum_{j=2003, j\neq 2007}^{2018} \beta_j \mathbb{1}[\text{Year j} = t] + \pi \mathbf{X} + \epsilon_{i,c,t}$$

$\Delta y_{i,c,t}$ is either $\Delta\text{Intangible}_{i,c,t}$ or $\Delta\text{Tangible}_{i,c,t}$, where i refers to firm, c refers to country and t refers to year. β_j is a series of year-specific coefficients and $\mathbb{1}[\text{Year} j = t]$ is a series of year dummy. The year of 2007 is chosen as the base year. X is a vector of control variables including logarithm of employees, total debt scaled by assets, return on assets and tangibility. Firm and country fixed effects are included, standard errors are clustered at country-year level. "Low IP" is the group of countries whose IP protection score (IP-index 2) is below median; "Low Safety" is the group of countries with government bond yield correlation with VIX ("Corr with VIX") being above median. The summary statistics of "IP-index 2" and "Corr with VIX" are provided in Table 1.

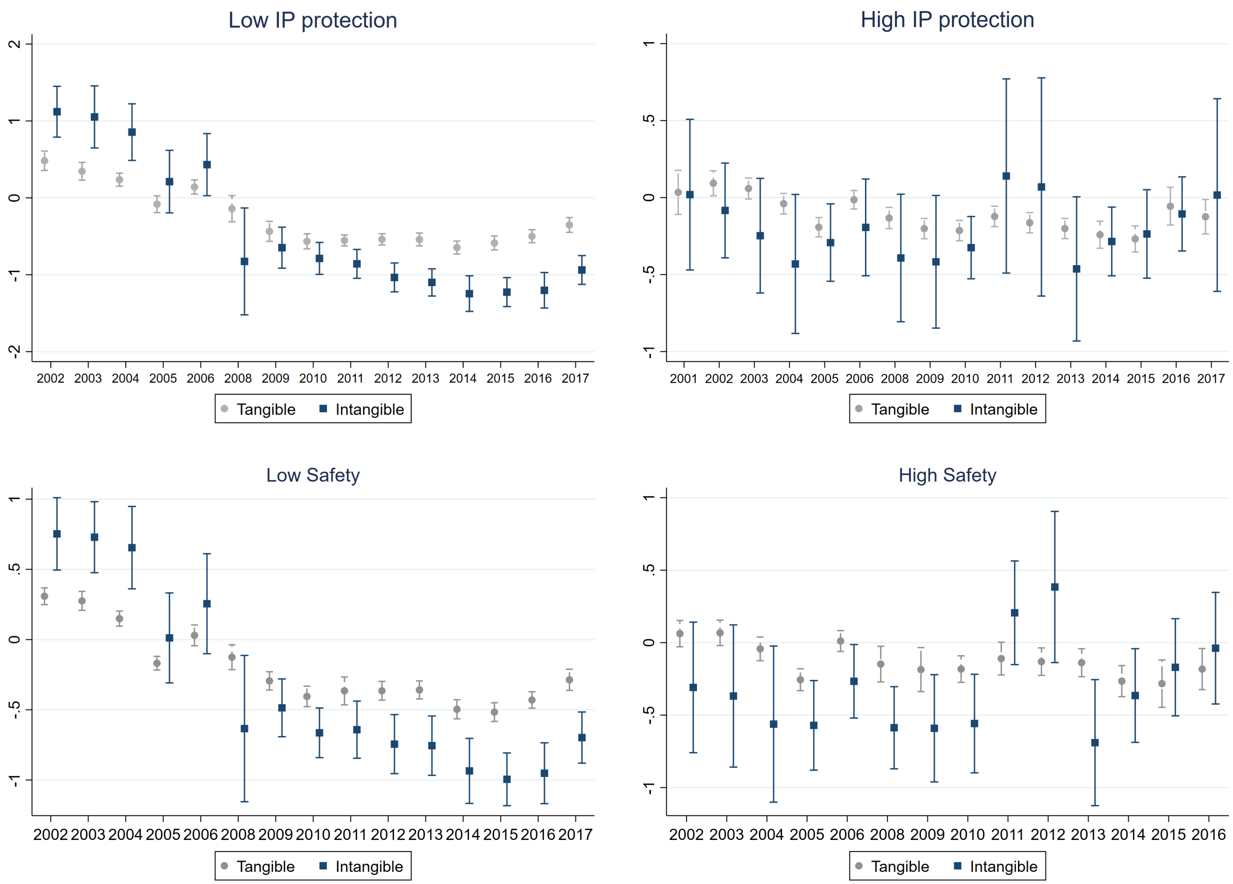


Table 1. Summary Statistics

The tables below show the summary statistics of firms' balance sheet variable during 2002-2018 and the summary of country-firm profile. In Panel A, "Tangible/Assets" is tangible fixed assets scaled by total assets, "Intangible/Assets" is intangible fixed assets scaled by total assets. "ΔIntangible" is $\frac{\text{Intangible}_t - \text{Intangible}_{t-1}}{\text{Intangible}_{t-1}}$, "ΔTangible" is $\frac{\text{Intangible}_t - \text{Tangible}_{t-1}}{\text{Tangible}_{t-1}}$. "ROA" is return on assets, "Tangibility" is tangible fixed assets scaled by total assets. "Debt/Assets" is total debt scaled by total assets. "ln(1+employees)" is logarithm of one plus total number of employees. "ln(1+assets) is logarithm of one plus dollar value of total assets. "Current liability/Assets" is current liability scaled by total assets. "Cash/Assets" is cash and cash equivalent assets scaled by total assets. "Revenue/Assets" is operating revenue scaled by total assets. "ΔCash/Assets" is $\frac{\text{Cash}_t - \text{Cash}_{t-1}}{\text{Assets}}$. "ΔRevenue/Assets" is $\frac{\text{Revenue}_t - \text{Revenue}_{t-1}}{\text{Assets}}$. "Profit/Emp" is dollar value of operating profits scaled by total number of employees. Panel B shows the number of firms in each country in the sample as well as two intellectual property protection index. "IP index-1" is the intellectual property index of a country in 2000 as constructed in Park (2008), "IP index-2" is the intellectual property index of a country in 2007 as provided by Property Rights Alliance. "Corr with VIX"/"Corr with FCI" are the correlation between 10-year government bond yield of a country and VIX or FCI up until 2007. The mathematical definition and explanation are provided in Section 3.3.

Panel A

	Mean	S.d.	P25	Median	p75
Tangible/Assets	0.222	0.270	0.100	0.100	0.346
Intangible/Assets	0.023	0.065	0.000	0.000	0.006
Δ Intangible	0.438	2.626	-0.096	-0.096	0.102
Δ Tangible	0.222	1.123	-0.037	-0.037	0.171
ROA	0.021	0.114	0.013	0.013	0.061
Tangibility	0.222	0.270	0.100	0.100	0.347
Debt/Assets	0.210	0.242	0.114	0.114	0.357
ln(1+empoyees)	2.887	1.435	2.773	2.773	3.738
ln(1+assets)	15.035	1.743	14.960	14.960	16.020
Current liability/Assets	0.472	0.363	0.440	0.440	0.731
Cash/Assets	0.130	0.182	0.047	0.047	0.176
ΔCash/Assets	0.016	0.129	0.000	0.000	0.035
Revenue/Assets	1.715	1.636	1.341	1.341	2.347
ΔRevenue/Assets	0.169	0.787	0.009	0.009	0.303
Profit/Emp	21.007	65.121	4.000	4.000	16.000

Panel B

Country	No. of firms	IP index-1	IP index-2	Corr with VIX	Corr with FCI
Belgium	13204	4.67	6.81	-0.21	-0.12
Czech Republic	7648	3.21	4.72	0.15	0.04
Denmark	2010	4.67	8.13	-0.09	-0.05
France	83274	4.67	6.67	-0.11	-0.13
Germany	61539	4.50	8.08	-0.20	-0.15
Hungary	6582	4.04	5.49	0.35	0.19
Ireland	6182	4.67	7.42	-0.12	-0.09
Italy	63785	4.67	5.67	0.16	-0.07
Japan	37045	4.67	7.50	-0.12	-0.19
South Korea	16041	4.13	5.82	-0.17	0.06
Netherlands	39523	4.67	8.24	-0.08	-0.14
Poland	9481	3.92	4.02	-0.01	0.07
Portugal	9077	4.08	6.12	-0.23	-0.09
Romania	8152	3.72	3.47	-	-
Slovak Republic	2294	2.76	6.31	0.32	0.18
Spain	87671	4.33	6.50	-0.01	-0.10
Sweden	24458	4.54	8.13	-0.20	-0.05
Turkey	2907	4.01	4.80	0.25	0.21
United Kingdom	65668	4.54	8.10	-0.16	-0.19

Table 2. Investments in the Crisis and Post-Crisis Performances

This table shows the regression results for the following regression specification:

$$\text{Performance}_{i,c,t} = \alpha_i + \mu_{c,t} + \beta \Delta y_{i,09-10} + \pi X + \epsilon_{i,c,t}$$

Performance$_{i,c,t}$ is either profit margin or profit per employee of firm i in country c in year t during the post-crisis period since 2010. Δy_{09-10} is the average investment rate of tangible or intangible asset during crisis of 2009 and 2010. Control variables include the logarithm of total assets in USD, return on assets and tangibility. Firm and country fixed effects are included. Standard errors are clustered at country-year level. Standard errors are in parentheses. ***, **, and * denote significance at the 1%, 5%, and 10% levels, respectively.

	Profit Margin		Profit per employee	
	(1)	(2)	(3)	(4)
ΔTangible$_{09-10}$	-10.93***		-159.9***	
	(2.113)		(36.98)	
ΔIntangible$_{09-10}$		-43.56***		-989.7***
		(10.74)		(329.5)
ln(1+Assets)	0.833***	0.831***	16.87***	16.83***
	(0.0971)	(0.0971)	(1.303)	(1.288)
Tangibility	1.057***	0.905***	-33.30***	-36.01***
	(0.306)	(0.308)	(4.094)	(4.603)
ROA	0.862***	0.861***	3.347***	3.338***
	(0.0252)	(0.0252)	(0.179)	(0.178)
Cash holding	2.336***	2.330***	-6.538	-6.726
	(0.368)	(0.369)	(4.199)	(4.215)
Country-Year FE	Y	Y	Y	Y
AdR-squared	0.309	0.309	0.147	0.146
N	1019570	1019793	813711	813862

Standard errors in parentheses

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table 3. Tangible and Intangible Investments in the Crisis

This table shows the regression results for the following regression specification:

$$\Delta y_{i,c,t} \quad = \alpha_i + \gamma_c + \beta \mathbb{1}[\text{Crisis}] + \pi X + \epsilon_{i,c,t}$$

$\Delta y_{i,c,t}$ is either tangible asset investment rate or intangible asset investment rate of firm i in country c in year t during 2002-2017. Control variables include the logarithm of total assets in USD, total debt scaled by total assets, return on assets and tangibility. Firm and country fixed effects are included. Standard errors are clustered at country-year level. Standard errors are in parentheses. ***, **, and * denote significance at the 1%, 5%, and 10% levels, respectively.

	ΔTangible	ΔIntangible	ΔTangible	ΔIntangible	ΔTangible	ΔIntangible
	(1)	(2)	(3)	(4)	(5)	(6)
$\mathbb{1}$[Crisis]	-0.081*	-0.957***	-0.068	-0.249***	-0.092**	-0.344***
	(0.042)	(0.344)	(0.045)	(0.166)	(0.037)	(0.129)
ln(1+Assets)			-0.004	0.162***	0.347***	0.513***
			(0.009)	(0.025)	(0.042)	(0.085)
Debt/Assets			0.237***	-0.123	0.194***	0.225
			(0.029)	(0.110)	(0.060)	(0.150)
ROA			0.006***	0.010***	0.006***	0.009***
			(0.000)	(0.002)	(0.001)	(0.002)
Tangibility			0.465***	-0.121*	2.865***	0.749***
			(0.037)	(0.072)	(0.168)	(0.255)
Firm FE	Y	Y	N	N	Y	Y
Country FE	Y	Y	N	N	Y	Y
Controls	N	N	Y	Y	Y	Y
AdR-squared	0.010	-0.053	0.001	0.001	0.028	0.015
N	3500209	2013744	2854742	1790933	2760040	1706779

Standard errors in parentheses

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table 4. Property Price and Intangible and Tangible Investments

This table shows the regression results for the following regression specification:

$$\Delta y_{i,c,t} \quad = \alpha_i + \gamma_c + \beta \Delta \text{Property Prices} + \pi X + \epsilon_{i,c,t}$$

$\Delta y_{i,c,t}$ is either tangible asset investment rate or intangible asset investment rate of firm i in country c in year t. Control variables include the logarithm of total assets in USD, total debt scaled by total assets, return on assets and tangibility. Firm and country fixed effects are included. Standard errors are clustered at country-year level. Standard errors are in parentheses. ***, **, and * denote significance at the 1%, 5%, and 10% levels, respectively.

	ΔTangible	ΔIntangible	ΔTangible	ΔIntangible	ΔTangible	ΔIntangible
	(1)	(2)	(3)	(4)	(5)	(6)
ΔProperty Prices	1.757**	7.224**	0.938***	3.222***	1.157***	2.375***
	(0.709)	(3.117)	(0.257)	(1.040)	(0.320)	(0.708)
ln(1+Assets)			0.009	0.168***	0.369***	0.721***
			(0.006)	(0.027)	(0.041)	(0.091)
Debt/Assets			0.205***	-0.183	0.148***	0.225
			(0.031)	(0.124)	(0.050)	(0.169)
ROA			0.004***	0.009***	0.004***	0.004***
			(0.000)	(0.002)	(0.001)	(0.001)
Tangibility			0.361***	-0.007	2.554***	1.098***
			(0.033)	(0.070)	(0.135)	(0.286)
Firm FE	Y	Y	N	N	Y	Y
Country FE	Y	Y	N	N	Y	Y
Controls	N	N	Y	Y	Y	Y
AdR-squared	-0.056	-0.054	0.001	0.002	-0.079	0.039
N	2655378	1594991	2150391	1421080	2084783	1349851

Standard errors in parentheses

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table 5. Financial Shock and Intangible and Tangible Investments: DID

This table shows the regression results for the following regression specification:

$$\Delta\bar{y}_{i,c,09-10} \quad = \alpha + \beta \text{Financial Shock}_c + \pi X + \epsilon_{i,c}$$

$\Delta\bar{y}_{i,c,09-10}$ is the change in average tangible/intangible asset investment rate during the 2009-2010, relative to the average tangible/intangible investment rate during 2007-2008. "Financial shock is the average CDS spread change of domestic banks in a country 30 days after the Leihman Brothers' collapse compared with 30 days before. Control variables include the logarithm of total assets in USD, total debt scaled by total assets, return on assets and tangibility. Firm and country fixed effects are included. Standard errors are clustered at country-year level. Standard errors are in parentheses. ***, **, and * denote significance at the 1%, 5%, and 10% levels, respectively.

	ΔTangible	ΔIntangible	ΔTangible	ΔIntangible
	(1)	(2)	(3)	(4)
Financial Shock	0.294	-0.583**	0.911	-0.472**
	(1.409)	(0.250)	(1.525)	(0.196)
ln(1+Assets)			0.002	-0.000
			(0.001)	(0.000)
Debt/Assets			0.018***	0.001
			(0.005)	(0.001)
ROA			0.001***	0.000***
			(0.000)	(0.000)
Tangibility			0.065***	0.000
			(0.018)	(0.001)
AdR-squared	0.000	0.002	0.025	0.003
N	824277	888791	581806	584412

Standard errors in parentheses

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table 6. IP Protection and Intangible and Tangible Investments

This table shows the regression results for the following regression specification:

$$\Delta y_{i,c,t} = \alpha_i + \beta \mathbb{1}[\text{Crisis}] \times \text{IP- index}_c + \pi X + \epsilon_{i,c,t}$$

$\Delta y_{i,c,t}$ is either tangible asset investment rate or intangible asset investment rate of firm i in country c in year t. $\mathbb{1}$[Crisis] is a dummy variable that equals to 1 for year 2009 and year 2010. Interaction terms are $\mathbb{1}$[Crisis] interacting with the two intellectual property indices defined in Table 1. Control variables include the logarithm of total assets in USD, return on assets and tangibility. Standard errors are clustered at country-year level. Standard errors are in parentheses. ***, **, and * denote significance at the 1%, 5%, and 10% levels, respectively.

	ΔTangible	ΔIntangible	ΔTangible	ΔIntangible
	(1)	(2)	(3)	(4)
$\mathbb{1}$[Crisis]×IP index-1	-0.040***	0.117***		
	(0.013)	(0.030)		
IP index-1	-0.045**	0.495***		
	(0.020)	(0.145)		
$\mathbb{1}$[Crisis]×IP index-2			-0.029***	0.116**
			(0.011)	(0.047)
IP index-2			-0.067***	0.196***
			(0.016)	(0.104)
$\mathbb{1}$[Crisis]	0.113	-0.429	0.052	-0.300
	(0.085)	(0.380)	(0.071)	(0.290)
ln(1+Assets)	-0.010*	0.184***	-0.002	0.144***
	(0.006)	(0.024)	(0.008)	(0.021)
Tangibility	0.375***	0.322**	0.388***	-0.083
	(0.037)	(0.135)	(0.032)	(0.080)
ROA	0.006***	0.009***	0.006***	0.009***
	(0.001)	(0.002)	(0.000)	(0.002)
AdR-squared	0.008	0.005	0.001	0.001
N	2027227	1351662	2884298	1804362

Standard errors in parentheses

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table 7. Asset Safety and Intangible and Tangible Investments

This table shows the regression results for the following regression specification:

$$\Delta y_{i,c,t} = \alpha_i + \beta \mathbb{1}[\text{Crisis}] \times \text{Safety}_c + \pi X + \epsilon_{i,c,t}$$

$\Delta y_{i,c,t}$ is either tangible asset investment rate or intangible asset investment rate of firm i in country c in year t. $\mathbb{1}$[Crisis] is a dummy variable that equals to 1 for year 2009 and year 2010. Interaction terms are $\mathbb{1}$[Crisis] interacting with the two measures of government bond safety defined in Table 1. Control variables include the logarithm of total assets in USD, return on assets and tangibility. Standard errors are clustered at country-year level. Standard errors are in parentheses. ***, **, and * denote significance at the 1%, 5%, and 10% levels, respectively.

	ΔTangible	ΔIntangible	ΔTangible	ΔIntangible
	(1)	(2)	(3)	(4)
$\mathbb{1}$[Crisis]	-0.0371	-0.378	-0.115*	-0.352**
	(0.0574)	(0.234)	(0.0662)	(0.163)
Gov bond corr VIX	0.0213	-2.695**		
	(0.136)	(1.112)		
$\mathbb{1}$[Crisis] × Gov bond corr FCI			-0.577	-0.980***
			(0.372)	(0.284)
Gov bond corr FCI			0.785***	-1.010
			(0.251)	(1.009)
$\mathbb{1}$[Crisis] ×Gov bond corr VIX	0.286	-1.226***		
	(0.261)	(0.396)		
ln(1+Assets)	0.000823	0.211***	0.00263	0.164***
	(0.00468)	(0.0304)	(0.00789)	(0.0265)
Tangibility	0.333***	0.245*	0.355***	-0.0900
	(0.0330)	(0.129)	(0.0294)	(0.0727)
ROA	0.00485***	0.00889***	0.00493***	0.0101***
	(0.000419)	(0.00160)	(0.000360)	(0.00202)
AdR-squared	0.00447	0.00346	0.000715	0.00104
N	1987394	1334050	2829150	1780574

Standard errors in parentheses

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table 8. Country Financial Soundness and Intangible and Tangible Investments

This table shows the regression results for the following regression specification:

$$\Delta y_{i,c,t} = \alpha_i + \beta \mathbb{1}[\text{Crisis}] \times \text{Financial Soundness}_c + \pi X + \epsilon_{i,c,t}$$

$\Delta y_{i,c,t}$ is either tangible asset investment rate or intangible asset investment rate of firm i in country c in year t during 2002-2017. $\mathbb{1}$[Crisis] is a dummy variable that equals to 1 for year 2009 and year 2010. Interaction terms are $\mathbb{1}$[Crisis] interacting with the multiple financial soundness indicators of a country in the pre-crisis year 2007. Control variables include the logarithm of total assets in USD, return on assets and tangibility. Standard errors are clustered at country-year level. Standard errors are in parentheses. ***, **, and * denote significance at the 1%, 5%, and 10% levels, respectively.

	ΔTangible	ΔIntangible	ΔTangible	ΔIntangible	ΔTangible	ΔIntangible	ΔTangible	ΔIntangible
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
$\mathbb{1}$[Crisis] × Gov debt	0.001	-0.011***						
	(0.002)	(0.003)						
Government Debt	-0.002**	-0.006***						
	(0.001)	(0.001)						
$\mathbb{1}$[Crisis] ×Tier 1 capital/Assets			-0.024	0.081**				
			(0.023)	(0.035)				
Tier 1 capital/Assets			0.018	0.188***				
			(0.020)	(0.070)				
$\mathbb{1}$[Crisis] ×real estate loan/Total loan					-0.020	-0.059**		
					(0.021)	(0.026)		
Commercial real estate loan/Total loan					0.032***	-0.184***		
					(0.006)	(0.052)		
$\mathbb{1}$[Crisis] ×NPL/Total loan							-0.027	-0.040**
							(0.022)	(0.018)
NPL/Total loan							-0.001	0.018
							(0.014)	(0.030)
$\mathbb{1}$[Crisis]	-0.125	-1.300***	-0.033	-0.497*	0.021	-0.087	-0.029	-0.429*
	(0.211)	(0.328)	(0.077)	(0.269)	(0.096)	(0.442)	(0.075)	(0.258)
ln(1+Assets)	-0.030***	-0.003	-0.010	0.164***	0.016	0.156***	-0.009	0.175***
	(0.006)	(0.013)	(0.009)	(0.027)	(0.011)	(0.045)	(0.009)	(0.029)
Tangibility	0.289***	-0.165***	0.412***	-0.014	0.360***	0.110	0.422***	0.113
	(0.030)	(0.050)	(0.035)	(0.064)	(0.058)	(0.138)	(0.036)	(0.081)
ROA	0.006***	0.008***	0.006***	0.009***	0.005***	0.024***	0.006***	0.010***
	(0.001)	(0.001)	(0.000)	(0.002)	(0.000)	(0.004)	(0.000)	(0.002)
R-squared	0.007	0.010	0.001	0.001	0.002	0.002	0.001	0.001
N	1093151	687643	2553358	1529805	1009386	643952	2553358	1529805

Standard errors in parentheses

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table 9. Pre-crisis Cash Holdings and Intangible Investment

This table shows the regression results for the following regression specification:

$$\Delta\text{Intangible}_{i,\text{post}} = \mu_c + \beta\text{Cash/Assets}_{i,\text{pre-crisis}} + \pi X + \epsilon$$

$\Delta\text{Intangible}_{i,\text{post}}$ is the average post-crisis intangible asset investment rate during the 2009-2010. $\text{Cash/Assets}_{i,\text{pre-crisis}}$ is the average pre-crisis cash holding as a proportion of total assets during 2007-2008. Control variables include the logarithm of total assets, total debt scaled by total assets, return on assets and tangibility. Country fixed effects are included. Standard errors are clustered at country level. Standard errors are in parentheses. ***, **, and * denote significance at the 1%, 5%, and 10% levels, respectively.

	Δ Intangible				
	(1)	(2)	(3)	(4)	(5)
Cash/Assets	0.295***	0.793***	0.057	0.437***	-0.154
	(0.072)	(0.078)	(0.113)	(0.044)	(0.773)
ROA	0.006***	0.009***	0.004**	0.005***	0.015*
	(0.001)	(0.001)	(0.002)	(0.001)	(0.008)
Tangibility	0.011	0.127***	-0.174*	0.105***	-0.816*
	(0.045)	(0.033)	(0.096)	(0.026)	(0.461)
ln(1+Assets)	0.071***	0.095***	0.051***	0.083***	0.010
	(0.007)	(0.006)	(0.012)	(0.004)	(0.063)
Country FE	Y	Y	Y	Y	Y
Country Group	All	Low IP	High IP	Low Safety	High Safety
AdR-squared	0.044	0.015	0.050	0.017	0.021
N	173643	88585	85058	125357	13885

Standard errors in parentheses

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table 10. Cash Holdings in the Crisis

This table shows the regression results for the following regression specification:

$$\text{Cash/Assets}_{i,c,t} \text{ OR Revenue/Assets}_{i,c,t} \quad = \quad \alpha_i + \mu_{c,t} + \beta \mathbb{1}[\text{Crisis}] + \pi X + \epsilon_{i,c,t}$$

The left-hand side variables are cash holding scaled by total assets, change in cash holding scaled by total assets and operating revenue scaled by total assets. $\mathbb{1}$[Crisis] is a dummy variable that equals to 1 for years 2009-2010. Control variables include the logarithm of total employees, total debt scaled by total assets, return on assets and tangibility. Firm and country fixed effects are included. Standard errors are clustered at country-year level. Standard errors are in parentheses. ***, **, and * denote significance at the 1%, 5%, and 10% levels, respectively.

	Cash/Assets			Δ Cash/Assets			OP Revenue/Assets		
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
$\mathbb{1}$[Crisis]	-0.00837**	-0.0134***	-0.00333	-0.00122	-0.00640***	0.00478	-0.0735**	-0.158***	0.0358
	(0.00332)	(0.00363)	(0.00183)	(0.00509)	(0.00177)	(0.00964)	(0.0280)	(0.0396)	(0.0776)
ROA	0.00129***	0.00118**	0.00139***	0.00208***	0.00178***	0.00238***	0.0232***	0.0312***	0.0162***
	(0.000201)	(0.000355)	(0.000188)	(0.000247)	(0.000428)	(0.000231)	(0.00405)	(0.00605)	(0.00172)
Tangibility	-0.190***	-0.144***	-0.250***	-0.134***	-0.126***	-0.151*	-0.241	-0.499	0.0114
	(0.0391)	(0.0260)	(0.0659)	(0.0375)	(0.0328)	(0.0691)	(0.184)	(0.292)	(0.154)
ln(1+employees)	0.00879*	0.000280	0.0201**	0.0166**	0.00303**	0.0297***	0.319***	0.190***	0.397***
	(0.00486)	(0.00214)	(0.00606)	(0.00714)	(0.000936)	(0.00731)	(0.0901)	(0.0158)	(0.103)
Debt/Assets	-0.208***	-0.150***	-0.322***	-0.159***	-0.124**	-0.233***	1.372***	0.995***	2.016***
	(0.0472)	(0.0378)	(0.0598)	(0.0388)	(0.0384)	(0.0561)	(0.318)	(0.274)	(0.438)
Firm FE	Y	Y	Y	Y	Y	Y	Y	Y	Y
Country FE	Y	Y	Y	Y	Y	Y	Y	Y	Y
Country Group	All	Low IP	High IP	All	Low IP	High IP	All	Low IP	High IP
AdR-squared	0.723	0.617	0.750	0.0240	0.0428	0.0145	0.536	0.492	0.625
N	2351066	1152619	1198447	1993991	983847	1010144	2006719	1029618	977101

Standard errors in parentheses

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table 11. Post-Crisis Cash Build-up and Intangible Investment

This table shows the regression results for the following regression specification:

$$\text{Ave.}\Delta\text{CashAssets}_{i,c,\text{post}} \text{ OR } \Delta\text{RevenueAssets}_{i,c,\text{post}} = \alpha_i + \mu_c + \beta\Delta\text{Intangible}_{i,c,09-10} + \pi X + \epsilon_{i,c,t}$$

The left-hand side variables the average changes in cash holding of firm i scaled by total assets, or changes in revenue of firm i scaled by total assets during the post-crisis periods. $\Delta\text{Intangible}_{\text{09-10}}$ is the average intangible asset investment rate of firm i during the 2009-2010 recession period. Control variables include the logarithm of total employees, total debt scaled by total assets, return on assets and tangibility. Country fixed effects are included. Standard errors are clustered at country level. Standard errors are in parentheses. ***, **, and * denote significance at the 1%, 5%, and 10% levels, respectively.

	ΔCash/Assets$_{post}$	Δ Revenue/Assets$_{post}$
	(1)	(2)
Δ Intangible$_{post}$	0.0453***	1.225***
	(0.0146)	(0.224)
ROA	0.00125***	0.0114***
	(0.000230)	(0.00260)
Tangibility	-0.0268	-0.0440
	(0.0168)	(0.0868)
Debt/Assets	-0.0172*	0.314*
	(0.00983)	(0.166)
ln(1+employees)	-0.0000915	-0.0429
	(0.000784)	(0.0373)
Country FE	Y	Y
AdR-squared	0.0844	0.0913
N	244016	240254

Standard errors in parentheses

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table 12. Leverage in the Crisis

This table shows the regression of firm leverage and financial crisis:

$$\text{Debt/Cash or long-term debt/cash}_{i,c,t} = \alpha_i + \beta \mathbb{1}[\text{Crisis}] + \pi X + \epsilon_{i,c,t}$$

Debt/Cash$_{i,c,t}$ is total debt scaled by cash holding of firm i in country c in year t, Long-term debt/Cash$_{i,c,t}$ is the long-term debt scaled by cash holding of firm i in country c in year t. $\mathbb{1}$[Crisis] is a dummy variable that equals to 1 for year 2009 and year 2010. Control variables include the logarithm of total assets in USD, return on assets and tangibility. Firm and country fixed effects are included. Standard errors are clustered at country-year level. Standard errors are in parentheses. ***, **, and * denote significance at the 1%, 5%, and 10% levels, respectively.

	Debt/Cash	Long-term debt/Cash
	(1)	(2)
$\mathbb{1}$[Crisis]	28.022***	60.734**
	(6.398)	(30.235)
ln(1+Assets)	13.270***	6.401***
	(1.165)	(1.801)
Tangibility	-28.643***	39.990***
	(3.523)	(8.392)
ROA	-0.443***	-0.601***
	(0.031)	(0.061)
Firm FE	Y	Y
Country FE	Y	Y
AdR-squared	0.383	0.441
N	3700958	3217917

Standard errors in parentheses

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Figure 9. Intangible Investment Recovery and IP Protection

This two figures below show the relationship between recovery in firms' intangible asset investment rate and the country's intellectual property protection. Recovery of intangible asset investment rate is defined as $Ave.\Delta\text{Ingangible}_{11-16} - Ave.\Delta\text{Intangible}_{02-07}$. "Patent Rights" is the IP-index 1 and "IP-index(2007)" is the IP-index 2. Summary statistics of both indices are provided in Table 1.

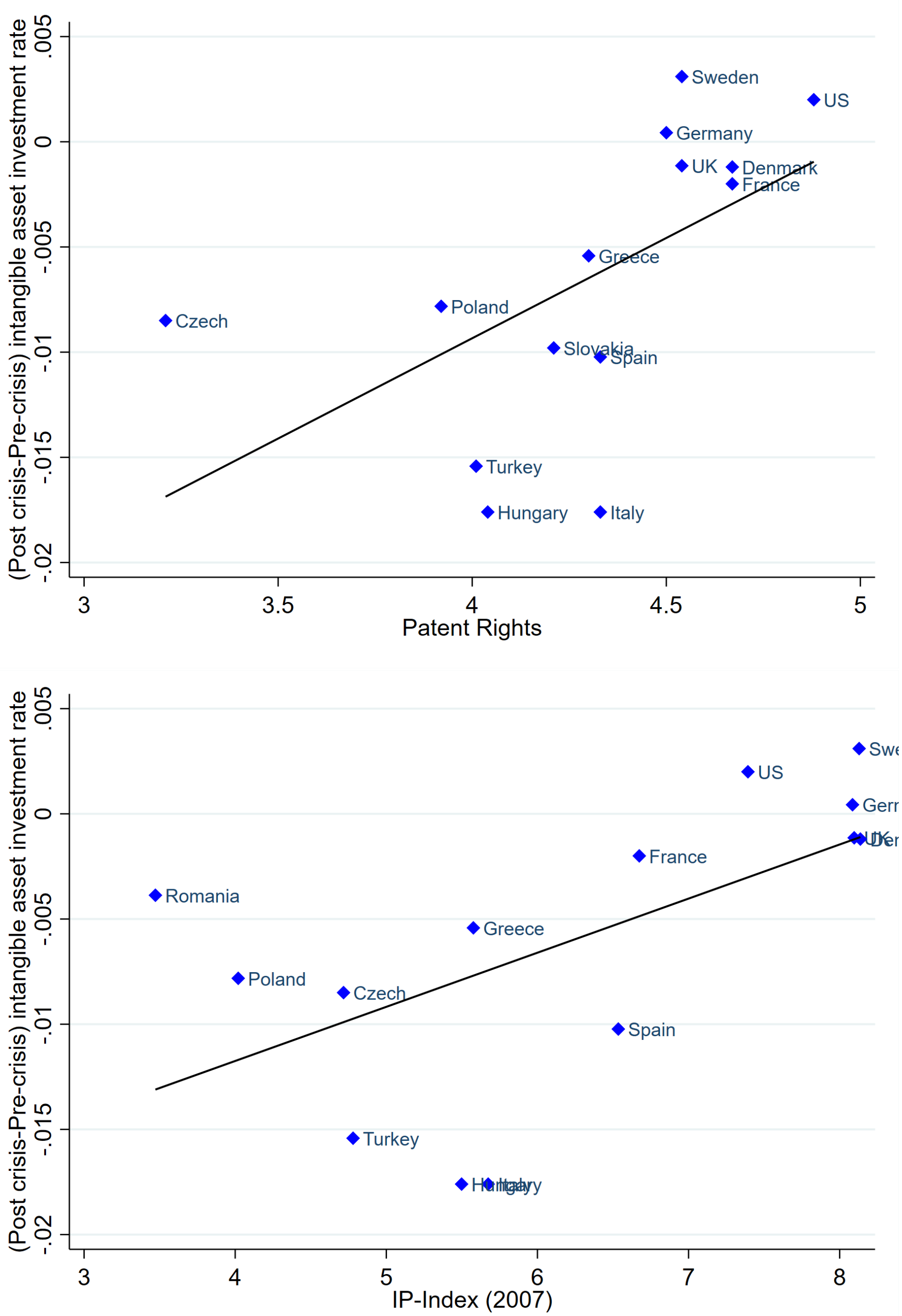
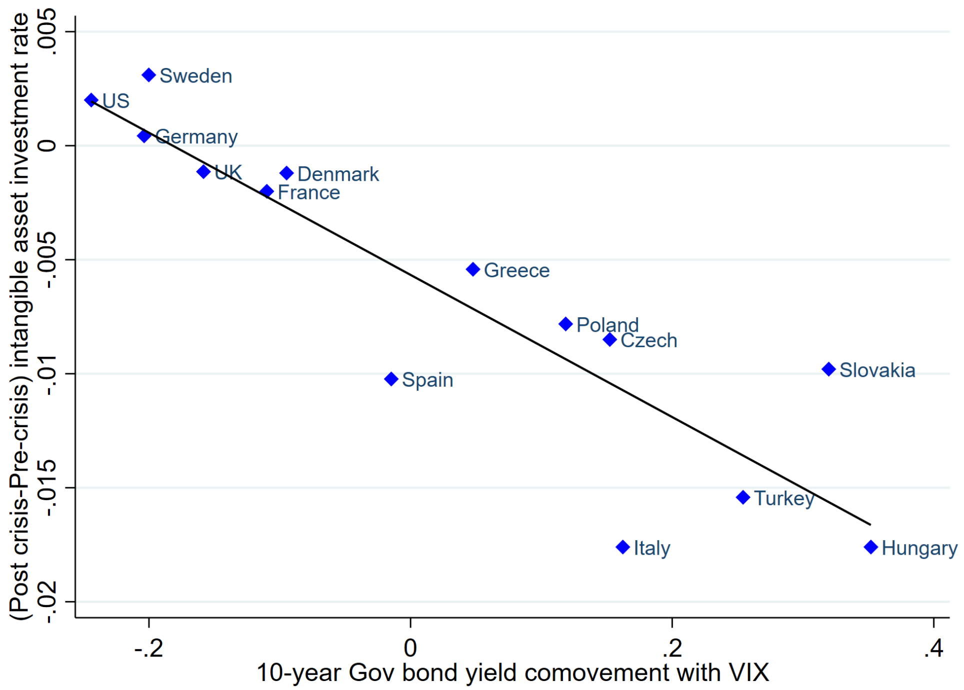


Figure 10. Intangible Investment Recovery and Asset safety

This two figures below show the relationship between recovery in firms' intangible asset investment rate and the government bond safety. Recovery of intangible asset investment rate is defined as $Ave.\Delta\text{Ingangible}_{11-16} - Ave.\Delta\text{Intangible}_{02-07}$. Government bond safety is either measured as the correlation between 10-year government bond yield and VIX or correlation between 10-year government bond yield and Financial Condition Index. Summary statistics of the measurements are provided in Table 1.



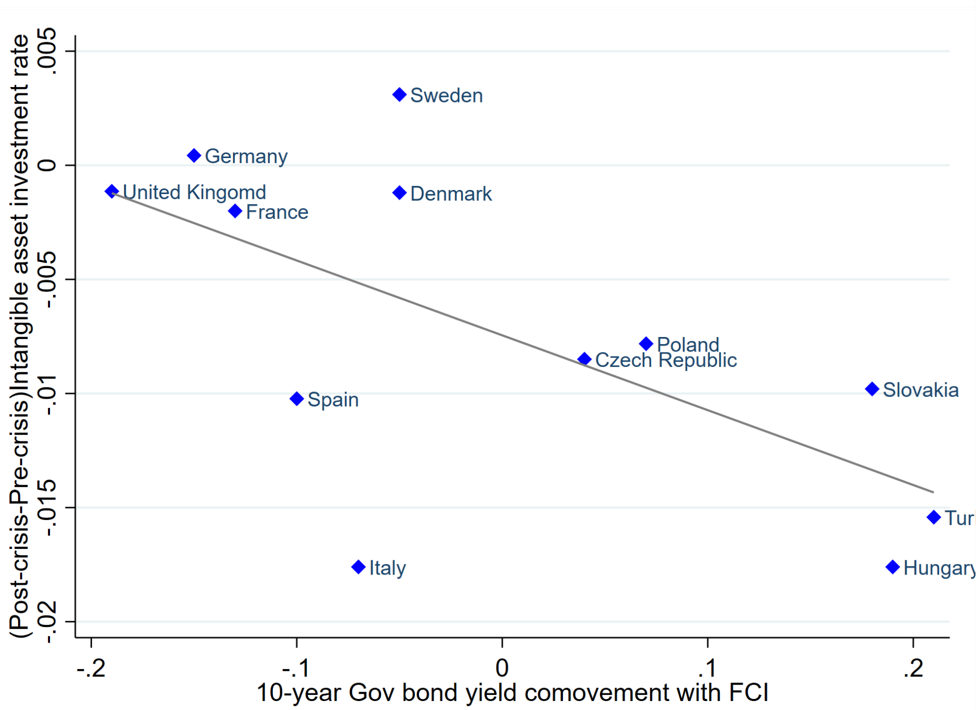
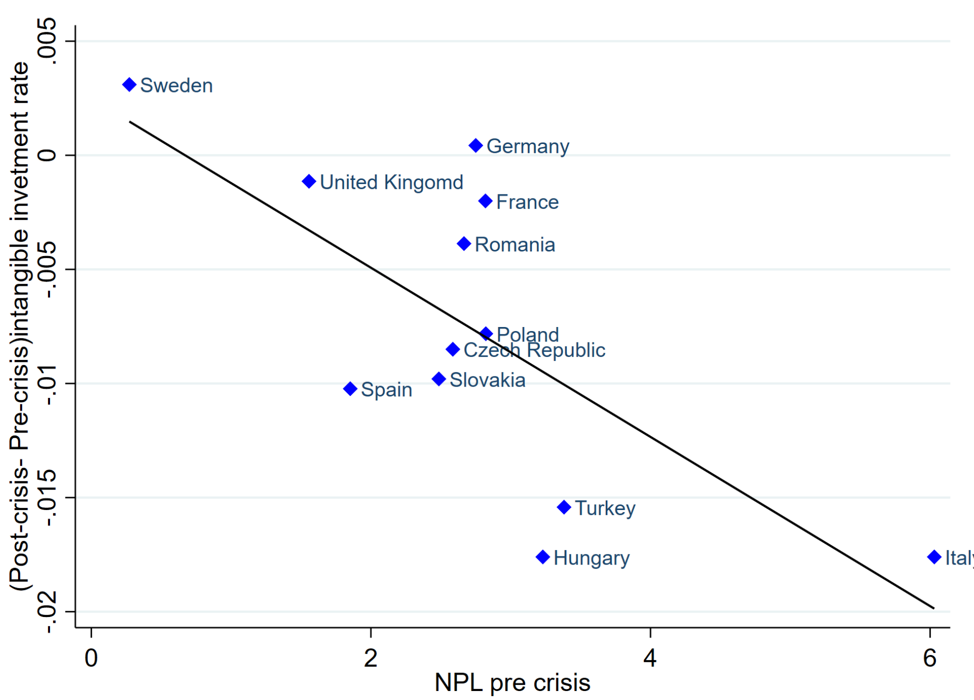
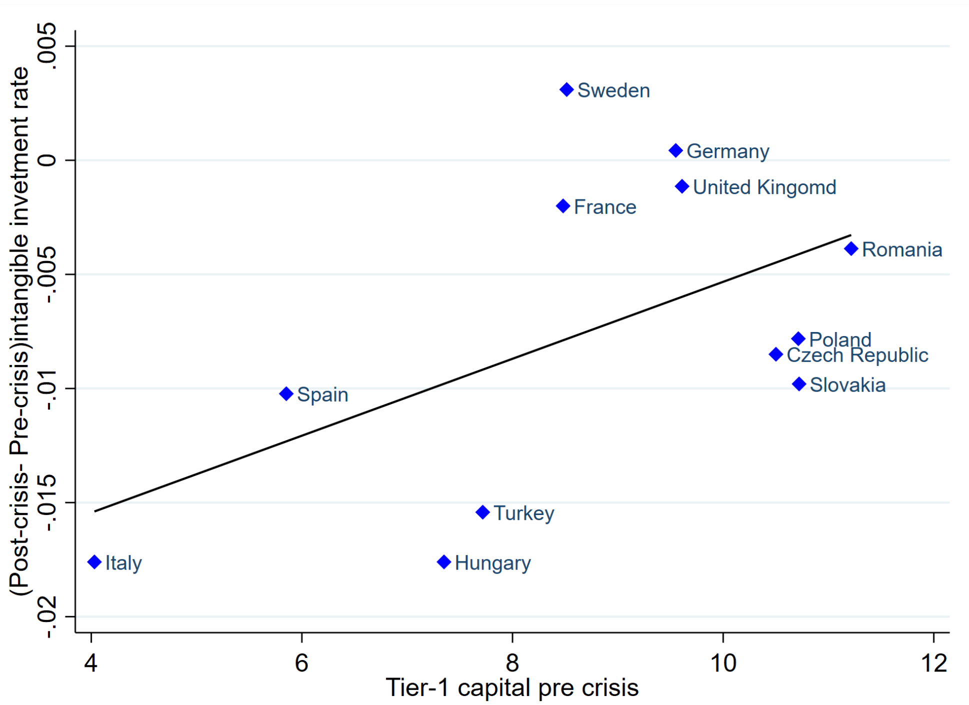


Figure 11. Intangible Investment Recovery and Financial Soundness

This two figures below show the relationship between recovery in firms' intangible asset investment rate and the pre-crisis financial soundness. Recovery of intangible asset investment rate is defined as $Ave.\Delta\text{Ingangible}_{11-16} - Ave.\Delta\text{Intangible}_{02-07}$. The X-axis of the upper figure is the domestic banking sector's non-performing loan as a share of total loan in 2007 and the X-axis of the bottom figure is the domestic banking sector's Tier-1 capital ratio in 2007.





Appendix

Table A1. Intangible and Tangible Investment Dynamics Over Time: by Country Group (IP Protection)

This table shows the over-time dynamics of firms' tangible and intangible asset investment rate in "High IP protection" economies and "Low IP protection" economies. The regression specification and the coefficients plot are displayed in the notes and the upper two sub-figures of Figure 8. ***, **, and * denote significance at the 1%, 5%, and 10% levels, respectively.

	Low Patent		High Patent	
	ΔTangible	ΔIntangible	ΔTangible	ΔIntangible
	(1)	(2)	(3)	(4)
2002	0.488***	1.125***	0.118***	-0.014
	(0.059)	(0.167)	(0.041)	(0.157)
2003	0.346***	1.054***	0.073**	-0.204
	(0.058)	(0.204)	(0.034)	(0.189)
2004	0.238***	0.856***	-0.029	-0.401*
	(0.041)	(0.187)	(0.033)	(0.230)
2005	-0.083	0.210	-0.189***	-0.276**
	(0.054)	(0.205)	(0.032)	(0.126)
2006	0.141***	0.431**	-0.013	-0.188
	(0.046)	(0.204)	(0.031)	(0.159)
2008	-0.142	-0.828**	-0.134***	-0.394*
	(0.086)	(0.350)	(0.035)	(0.210)
2009	-0.437***	-0.651***	-0.204***	-0.419*
	(0.065)	(0.134)	(0.033)	(0.218)
2010	-0.569***	-0.792***	-0.217***	-0.328***
	(0.049)	(0.104)	(0.033)	(0.101)
2011	-0.558***	-0.863***	-0.125***	0.137
	(0.035)	(0.094)	(0.034)	(0.318)
2012	-0.544***	-1.040***	-0.167***	0.065
	(0.036)	(0.093)	(0.033)	(0.357)
2013	-0.546***	-1.106***	-0.205***	-0.468*
	(0.041)	(0.088)	(0.033)	(0.236)
2014	-0.653***	-1.253***	-0.245***	-0.289**
	(0.042)	(0.115)	(0.044)	(0.111)
2015	-0.594***	-1.235***	-0.273***	-0.240*
	(0.045)	(0.093)	(0.043)	(0.144)
2016	-0.506***	-1.213***	-0.061	-0.113
	(0.041)	(0.115)	(0.062)	(0.120)
2017	-0.358***	-0.949***	-0.129**	0.008
	(0.049)	(0.094)	(0.057)	(0.315)
Firm FE	Y	Y	Y	Y
Country FE	Y	Y	Y	Y
Control	Y	Y	Y	Y
AdR-squared	0.128	-0.034	0.060	0.031
N	1347918	861623	1365213	809798

Standard errors in parentheses

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table A2. Intangible and Tangible Investment Dynamics Over Time: by Country Group (Asset Safety)

This table shows the over-time dynamics of firms' tangible and intangible asset investment rate in "High asset safety" economies and "Low asset safety" economies. The regression specification and the coefficients plot are displayed in the notes and the bottom two sub-figures of Figure 8. ***, **, and * denote significance at the 1%, 5%, and 10% levels, respectively.

	Low Safety		High Safety	
	ΔTangible	ΔIntangible	ΔTangible	ΔIntangible
	(1)	(2)	(3)	(4)
2002	0.346***	0.784***	0.153***	-0.066
	(0.032)	(0.109)	(0.036)	(0.177)
2003	0.281***	0.698***	0.121***	-0.254
	(0.037)	(0.111)	(0.032)	(0.211)
2004	0.144***	0.578***	-0.023	-0.500*
	(0.028)	(0.122)	(0.031)	(0.246)
2005	-0.158***	0.043	-0.229***	-0.427***
	(0.026)	(0.136)	(0.026)	(0.130)
2006	0.058	0.242	0.055**	-0.177
	(0.048)	(0.155)	(0.026)	(0.107)
2008	-0.085	-0.603**	-0.179***	-0.487***
	(0.064)	(0.253)	(0.041)	(0.126)
2009	-0.342***	-0.474***	-0.241***	-0.467***
	(0.047)	(0.086)	(0.057)	(0.155)
2010	-0.430***	-0.576***	-0.205***	-0.375***
	(0.052)	(0.078)	(0.026)	(0.134)
2011	-0.366***	-0.526***	-0.093**	0.427
	(0.067)	(0.095)	(0.044)	(0.275)
2012	-0.360***	-0.605***	-0.134***	0.363
	(0.045)	(0.103)	(0.039)	(0.364)
2013	-0.355***	-0.614***	-0.145***	-0.400**
	(0.039)	(0.100)	(0.035)	(0.188)
2014	-0.456***	-0.732***	-0.240***	-0.407**
	(0.039)	(0.105)	(0.035)	(0.191)
2015	-0.420***	-0.722***	-0.191***	-0.133
	(0.034)	(0.085)	(0.057)	(0.204)
2016	-0.311***	-0.661***	-0.092*	0.159
	(0.036)	(0.087)	(0.047)	(0.240)
2017	-0.173***	-0.441***	0.031	0.249
	(0.032)	(0.089)	(0.047)	(0.259)
Firm FE	Y	Y	Y	Y
Country-year	Y	Y	Y	Y
Control	Y	Y	Y	Y
AdR-squared	0.117	0.028	0.155	0.015
N	1176417	845055	181973	75877

Standard errors in parentheses

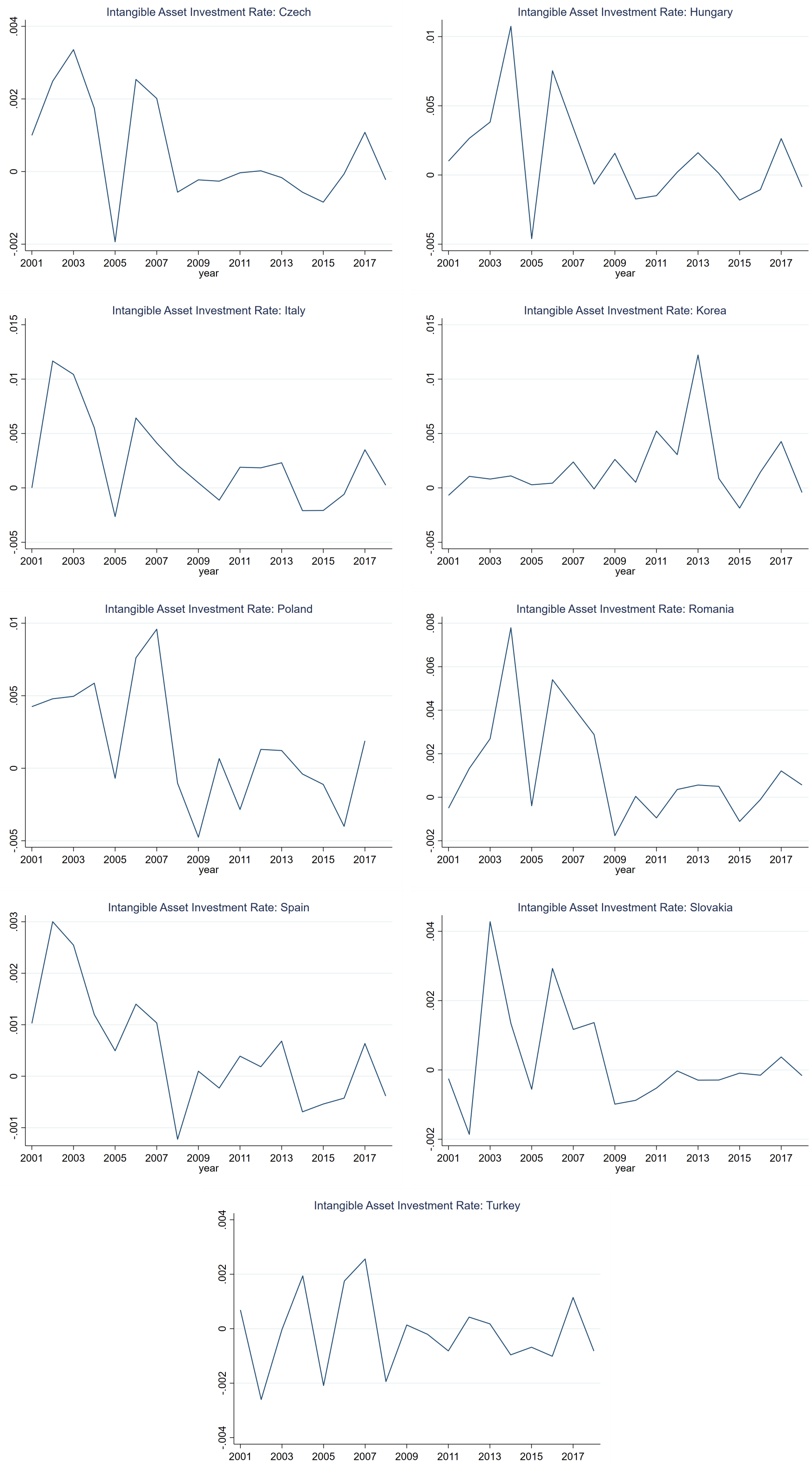
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Figure A1. Country-level Trend: I

This two figures below show the over-time dynamics of intangible asset growth in total asset. The Y-axis is the weighted average of $\frac{\text{Intangible}_t - \text{Intangible}_{t\text{-}1}}{\text{Total Assets}}$ (weighted by the firms' total asset in that year) of all firms in a country in a given year.

Figure A2. Country-level Trend: II

This two figures below show the over-time dynamics of intangible asset growth in total asset. The Y-axis is the weighted average of $\frac{\text{Intangible}_t - \text{Intangible}_{t\text{-}1}}{\text{Total Assets}}$ (weighted by the firms' total asset in that year) of all firms in a country in a given year.



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