

The Financing of Ideas and the Great Deviation*

Job Market Paper

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Abstract

Why did the Great Recession lead to such a slow recovery? I build a model where heterogeneous firms invest in physical and in intangible capital, and can default on their debt. In case of default, intangible assets tend to be harder to seize by external investors. Hence, financing intangible capital faces higher costs than financing physical capital. This differential is exacerbated in a financial crisis, when default is more likely and aggregate risk bears a higher premium. The resulting fall in intangible investment amplifies the crisis, and gradual intangible capital spillovers to other firms contribute to its persistence. Using a rich panel dataset of Spanish manufacturing firms, I estimate the model by matching firm-level moments regarding physical and intangible investment and financing. The model captures the extent and components of the Great Recession, as incumbent intangible investment falls and firm exit rates surge. A standard model without endogenous intangible investment would miss half of the 2008-2013 GDP fall in Spanish manufacturing. Targeted fiscal policy could speed up the recovery: transfers to young firms relax the borrowing constraints of the firms with higher returns to investment and mitigate the fall in GDP.

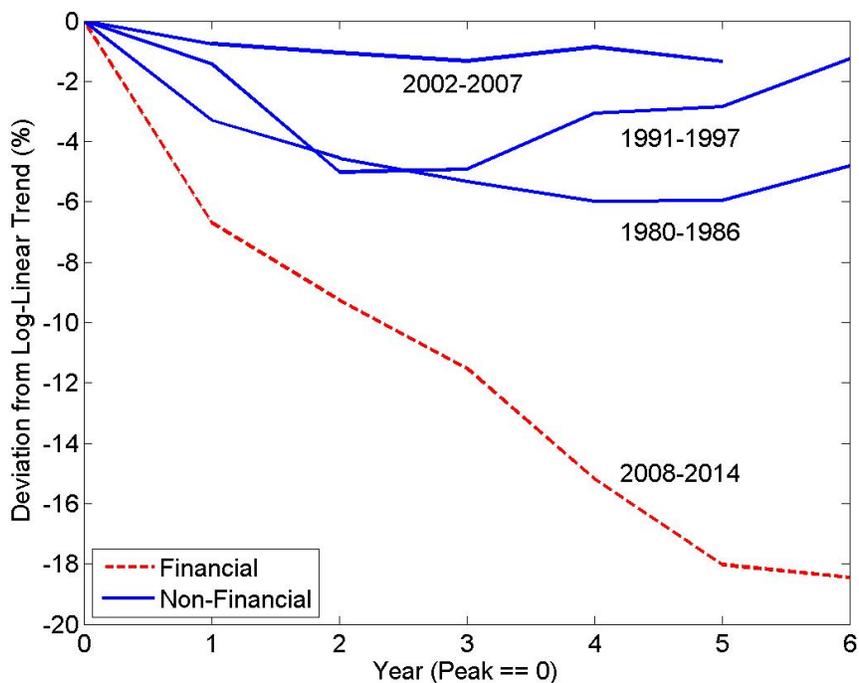
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1 Introduction

The 2007-2008 Global Financial Crisis has been followed by a large contraction in GDP and a particularly slow recovery in many developed economies, especially in the European periphery. Figure 1 illustrates these facts for Spain, comparing the deviation of real GDP per capita from trend after the peak in recent financial and non-financial recessions. I classify a recession as financial if it is accompanied by an atypical increase in the equity premium in financial markets. Figure 1 shows that the Great Recession has turned into a “Great Deviation” of output from trend.

Figure 1: Real GDP per Capita in Recent Recessions, Spain



This paper presents a model that explains why the response of the real economy can be larger and more persistent after a financial shock than after other types of shocks. The mechanism is based on the interaction between investment in intangible capital and financial constraints. Financial shocks make financing intangibles disproportionately more costly, and the consequent fall in intangible capital accumulation generates a prolonged deviation in output. I estimate the model with panel data on Spanish manufacturing firms and find that modeling intangible investment accounts for more than half of the fall in value added between 2008 and 2013. The paper also delivers quantitative recommendations for fiscal policy based on firm characteristics.

I model the corporate sector in a small open economy. Heterogeneous firms invest in physical (or tangible) capital and in intangible capital. Intangible investment includes all expenditures in non-physical assets aimed at increasing the productivity of a firm. Thus, it captures the formation of both technological and organizational capital. Firms finance their investments with internal equity and debt—the most common channels in Europe. Yet, they have limited commitment and can default on their debt obligations. The corporate sector is subject to financial and non-financial aggregate shocks. Both types of shocks feature a fall in foreign income, which reduces the demand for domestic firms. But financial shocks also feature an increase in the price of aggregate risk in global financial markets, which makes financing risky firm debt more expensive. This is consistent with the evidence that the risk premium rises in financial crises, whereas the risk-free rate is barely affected. As in previous macroeconomic models, financial frictions amplify both types of aggregate shocks. However, the novel result in my model is that shocks which are financial in nature lead to additional amplification and persistence.

The amplification mechanism is related to the financial properties of intangible capital. I estimate that intangible assets are harder to pledge as collateral than tangible assets. Therefore, in case of default, creditors expect lower recovery rates for intangible-capital intensive firms. Moreover, all firms are more likely to default in bad states of the world. Given these two equilibrium results, the debt of intangible-capital-intensive firms carries more aggregate risk, i.e., its repayment rates covary more with the aggregate state. Hence, financing investment in intangible capital always tends to be more costly than financing tangible investments. Yet, this differential widens when a financial shock hits the economy, as creditors discount aggregate risk more heavily. Consequently, intangible investment falls disproportionately more after a financial shock. The rise in financing costs also causes an increase in firm default and exit rates, especially for intangible-intensive firms, which entails efficiency losses. Thus, both the intensive and extensive margin propagate the GDP decline.

Indeed, the Spanish firm-level data confirms that the Great Recession came together with a particularly large fall in the debt issuances and investment rates of intangible-capital-intensive firms and industries, a considerable deterioration in several intangible investment and productivity measures, and a surge in firm exit rates. None of these facts can be replicated by a standard model without endogenous intangible investment.

The properties of intangible capital also lead to two channels of persistence. First, I estimate that investment adjustment costs are higher for intangible capital. This implies that entrants replacing exited firms take more time to reach the mature level of intangible capital than that of tangible capital. Second, my model allows for gradual spillovers of intangible capital to other firms in the economy. Such spillovers can take the form of diffusion

of knowledge about technological and organizational processes, new products, or domestic and foreign market conditions. Individual firms perceive spillovers of their own intangible capital as private depreciation, but public intangible capital, which accumulates with firms' spillovers, does not depreciate. It is therefore a slow-moving variable that contributes to generate low-frequency fluctuations. As a result, any shock that affects intangibles disproportionately more, such as a financial shock, also causes more persistence.

The quantitative part of this paper estimates the model using a high-quality representative panel of Spanish manufacturing firms from 1990 to 2013, the Survey on Business Strategies (*Encuesta Sobre Estrategias Empresariales*). This dataset is unique in that it features very detailed information on firms' tangible and intangible investment expenditures, together with complete balance-sheet information on assets and liabilities, including the stock of tangible and intangible assets. Intangible investment is disaggregated into R&D, marketing and advertising, technology imports and training of workers, with the first two categories accounting for the largest share. The dataset covers small and medium enterprises, which represent a large share of the market in Europe, and an even larger share of investment and job creation. I complement this sample with information on the entire manufacturing firm population from the Firm Public Registry (*Directorio Central de Empresas*).

The model parameters are estimated by indirect inference, matching key firm-level moments regarding cross-sectional and within-firm patterns of investment and financing. Targeted moments include the tangible and intangible investment rates as a function of firm characteristics and their within-firm volatility, the average leverage ratio across firms, firm life-cycle growth, and aggregate entry and exit rates. In the model, firm heterogeneity is due to the presence of persistent firm-idiosyncratic shocks to the private depreciation of intangible capital. I infer that intangible assets are less collateralizable from the empirical observation that intangible-intensive firms tend to issue less debt. I also estimate that intangible capital has higher adjustment costs, as the within-firm volatility of intangible investment rates is lower, and that it has a higher private depreciation rate, as intangible investment rates remain high for mature firms. The private depreciation rate of intangible capital disciplines the intensity of the spillover channel.

Importantly, the model approximates the empirical size-weighted leverage distribution across firms. Considering the endogenous response of intangible investment allows for large and persistent effects of financial shocks without assuming unrealistically high levels of external-financing dependence for firms.

Next, I compare model-simulated aggregate data against the evolution of the macro time series in the Spanish manufacturing sector. The model takes the observed dynamics of aggregate prices as given. State prices in financial markets and foreign income shocks

are directly estimated with data on the expected equity premium and GDP in the rest of the European Union. Therefore, the comparison with the Spanish macro data serves as an overidentifying check of the model. The simulated model can fit both the extent and the components of the Great Deviation that followed the Great Recession. Specifically, the main drivers of amplification seem to be the new channels described in this paper: lower intangible investment rates by incumbents and higher firm exit rates, together with the fall in employment due to the rigid behavior of wages. In contrast, a standard model of heterogeneous firms and collateral constraints, but no endogenous intangible investment, would miss 58 percent of the observed GDP fall from 2008 to 2013. The spillover channel does not significantly amplify the initial impact of the Great Recession, but it is important for persistence as it almost doubles the predicted deviation of GDP from trend by 2018.

The need to speed up the recovery is at the center of the policy debate in Europe. With this goal in mind, the European Commission is currently starting to implement a policy of subsidized credit to risky investments, the so-called Juncker Plan. This paper proposes an alternative policy that could be more effective in increasing aggregate investment at no public cost: a budget-neutral scheme of transfers based on firm age. Such a policy mitigates the consequences of a financial shock because it relaxes the borrowing constraints of younger firms, which tend to have higher returns to investment in tangible and especially intangible capital, moving the economy closer to the first-best allocation. If implemented unanticipatedly in 2009, this policy could have avoided 15 percent of the 2008-2013 GDP fall, according to the model. Conditioning transfers on firm size is less efficient than conditioning on age, as an important fraction of small firms are not financially constrained. The implementation details of the Juncker Plan are yet to be finalized. However, in a framework with endogenous borrowing constraints, subsidized credit fails to increase the debt capacity of a firm and crowds out private credit. Thus, the current European policy also seems to be dominated by well-targeted outright transfers.

The rest of the paper is organized as follows. Section 2 highlights the main contributions to the literature. Section 3 lays down the model, solves for the equilibrium and discusses the theoretical mechanism. Section 4 describes the aggregate and firm-level data. The estimation strategy and results are presented in Section 5. Section 6 contains the quantitative macroeconomic results and the policy analysis. Section 7 concludes.

2 Related Literature

This paper is motivated by the empirical literature on the macroeconomic consequences of financial crises. Muir (2014) documents that periods of financial turmoil are associated with

increases in spreads in financial markets, and [Gilchrist and Zakrajšek \(2012\)](#) and [Krishnamurthy et al. \(2015\)](#) show that these increases tend to predict persistent declines in output. Another side of the empirical literature classifies recessions as financial if they come together with episodes of bank restructuring or default. [Reinhart and Rogoff \(2009\)](#) document the persistence of financial recessions across countries and over time, while [Jorda et al. \(2013\)](#) show that financial recessions tend to last longer than non-financial recessions in advanced countries, even conditioning on the magnitude of the fall in output. On the other hand, [Bordo and Haubrich \(2012\)](#) and [Romer and Romer \(2015\)](#) point out that the size of financial recessions reported in previous papers may hinge on the definition of the sample and the recession period.

Starting with [Bernanke and Gertler \(1989\)](#), there has been an ample body of research modeling the impact of financial frictions on the economic cycle. Quantitative papers in this literature include [Bernanke et al. \(1999\)](#), [Mendoza \(2010\)](#), [Gertler and Karadi \(2011\)](#), [Gertler and Kiyotaki \(2013\)](#) and [Boissay et al. \(2015\)](#). One common feature of the quantitative analysis in these papers is that the agents that own the productive technology tend to rely more on external financing than what is typically observed in the data. This assumption is necessary for these models to replicate the empirical depth and persistence of financial recessions. In practice, as shown in [Shourideh and Zetlin-Jones \(2014\)](#), most firms seem to have enough internal funding to cover all their investment needs. Since my paper considers the response of an additional investment margin, intangible capital, which is disproportionately affected by financial shocks, it can explain the aggregate consequences of financial shocks while still fitting the distribution of external financing across firms.

A series of papers have considered the effects of financial shocks on aggregate productivity due to misallocation across heterogeneous firms, following on the observation by [Hsieh and Klenow \(2009\)](#) that firm-level returns to capital are highly heterogeneous. Recent contributions to these literature include [Buera et al. \(2011\)](#), [Khan and Thomas \(2011\)](#), [Gilchrist et al. \(2013\)](#), [Khan et al. \(2014\)](#), [Midrigan and Xu \(2014\)](#), [Buera and Moll \(2015\)](#) and [Gopinath et al. \(2015\)](#). However, these papers do not study the endogenous decision of a firm to invest in increasing its productivity. The effects on aggregate productivity that they obtain are caused by compositional changes after exogenous shocks.

Another branch of the literature, stemming from the work of [King and Levine \(1993\)](#) and [Rajan and Zingales \(1998\)](#), has focused on the link between financing and innovation (which is a form of intangible investment) from both the empirical and theoretical point of view. [Aghion et al. \(2010\)](#) develop a model with two-period firms where the fact that investment in innovation has a longer time horizon can explain why financial recessions are more persistent. Allowing for a lower private depreciation rate of intangibles would amplify the persistence

of crises in my model. Yet, both the studies on intangibles by [Corrado et al. \(2012\)](#) and my own estimates show significantly higher depreciation rates for all categories of intangible capital, including scientific R&D, than for physical capital. Thus, I focus on the spillovers of intangible capital to other firms, which decouple (high) private depreciation rates from (low) social depreciation rates, as well as on the financial properties of intangibles. [Garcia-Macia \(2013\)](#), [Guerrón-Quintana and Jinnai \(2014\)](#) and [Queraltó \(2015\)](#) build upon the medium-run business cycle model of [Comin and Gertler \(2006\)](#), which adds business cycle fluctuations to an endogenous growth model, to calibrate the aggregate role of endogenous innovation after financial shocks in recent recessions. In a similar framework adding New-Keynesian elements, [Bianchi and Kung \(2014\)](#), [Anzoategui et al. \(2015\)](#) and [Benigno and Fornaro \(2015\)](#) describe the interaction between endogenous innovation and nominal rigidities or liquidity traps. However, none of these papers analyzes firm heterogeneity, which is an important dimension due to the non-linear effects of collateral constraints. [Ates and Saffie \(2014\)](#) and [Schmitz \(2015\)](#) do include firm heterogeneity in a model with creative destruction and aggregate financial shocks, but they do not consider the collateralizability of different types of capital nor its effects on incumbent firms' incentives to invest and default. Finally, [Kerr and Nanda \(2014\)](#) provide a thorough summary of the latest developments in the field from the microeconomic perspective.

To the best of my knowledge, my paper is the first to analyze the response of incumbent intangible investment to financial shocks in a dynamic framework with endogenous default. In the data, incumbent intangible investment is also sensitive to financial conditions (see [Figures 8 and 9](#)), and it accounts for the largest share of total intangible investment (see [Garcia-Macia et al. \(2015\)](#) for the contribution of incumbents in the U.S.). Moreover, contrary to what simpler innovation models would predict, entry and exit rates are by no means coupled. Both in Spain and in the U.S., the Great Recession brought a surge in exit rates, with a much less obvious (inexistent in Spain) fall in entry rates (see [Figure 10](#)). Another contribution of this paper to the literature on endogenous productivity is modeling financial shocks as an increase in the price of aggregate risk, as opposed to the risk-free rate or the compensation for default risk. This distinction turns out to be crucial to explain the propagation of financial shocks through the channels related to intangibles and would be missed by a linearized model.

The empirical method in this paper, structural estimation of a heterogeneous-firm model by the simulated method of moments, is similar to the one in [Hennessy and Whited \(2007\)](#), [Bloom \(2009\)](#) and [Acemoglu et al. \(2013\)](#). The work which is methodologically closer is [Eisfeldt and Papanikolaou \(2013\)](#), which estimates a structural model where firms can invest in tangible and organizational capital, and shows that firms with a larger proportion of

measured organizational capital yield a significantly larger equity premium. Nevertheless, [Eisfeldt and Papanikolaou \(2013\)](#) do not study the effects of aggregate shocks nor debt financing. Furthermore, no papers have tried to estimate the relationship between financial constraints and intangible investment in a structural framework with a sample representative of the whole firm population. From the early work on the measurement of intangible assets of [Hall \(2001\)](#), which infers the value of intangibles from stock market valuations, to the studies of [Atkeson and Kehoe \(2005\)](#), [McGrattan and Prescott \(2005\)](#) and [Corrado et al. \(2009\)](#), which use data from national accounts, the focus has been on either publicly listed firms or aggregate data, rather than on smaller firms. Yet, individual information on non-listed firms is crucial to study financial constraints and the extensive entry/exit margin.

There is a series of reduced-form corporate finance studies that corroborate some of the my model's predictions. [Benmelech and Bergman \(2009\)](#) show that asset collateralizability decreases loan spreads and increases lending volumes to firms within the airline industry. With a sample of listed firms, [Falato et al. \(2013\)](#) provide evidence that investment in intangible assets is correlated with own-resource accumulation, which suggests the presence of stricter external financing constraints for those assets. Using an earlier version of the the dataset analyzed in this paper (ESEE), [Garicano and Steinwender \(2013\)](#) show with a diff-and-diff strategy that in the Great Recession domestically-owned firms cut long-run investment by a larger proportion than subsidiaries of multinational firms. Similarly, [Aghion et al. \(2012\)](#) document that French firms which are more credit constrained tend to have a more procyclical R&D expenditures pattern. [Goodridge et al. \(2013\)](#) and [Barnett et al. \(2014\)](#) analyze the striking decline in productivity after the Great Recession in the U.K.

3 Model

I develop a corporate-sector model with heterogeneous firms that can invest in physical capital as well as in intangible capital. Firms use these two factors, together with labor, to produce a monopolistically competitive variety. Private intangible capital diffuses to other firms at a random firm-idiosyncratic rate, which is the source of firm heterogeneity. Investments are financed by internal equity and defaultable debt. Firms maximize shareholder value taking aggregate prices as given. The corporate sector is subject to aggregate shocks to revenues and state prices. The model focuses on short and medium-run fluctuations, abstracting from the determinants of long-run growth. This framework should be relevant for any open economy where intangible investment has a significant role and debt financing is prevalent, as is the case for most European and advanced Asian economies.

3.1 Agents and Maximization Problem

3.1.1 General Framework

This is a model of firms operating in a small open economy. Each firm produces one differentiated variety in monopolistic competition. The total number of varieties that can be produced in a country is constant. Global aggregate output Y_t^w is defined as a CES composite of the N^w final good varieties that can be produced in the whole world:

$$(1) \quad Y_t^w = \left(\sum_{j=0}^{N^w} (y_t^j)^{\frac{\sigma-1}{\sigma}} dj \right)^{\frac{\sigma}{\sigma-1}},$$

where σ is the elasticity of substitution across varieties and y_t^j is the value added output of each variety in the global economy. Throughout the paper, variables labeled in small letters are those defined at the firm level, whereas variables in capital letters are defined at the aggregate level.

Real global income D_t is exogenous and equal to a deterministic component, growing at rate $g \geq 0$, multiplied by a stochastic component. As discussed below, variables in this model fluctuate around a balanced growth path (BGP) growing at rate g , so all variables with a trend can be normalized to the deterministic component of global income.

Given a level of global income, world consumers maximize the aggregate output composite Y_t^w choosing the quantity of each variety y_t^j that they purchase in each period, and taking individual prices p_t^j as given. From the demand function of consumers, we obtain that the revenue for an individual firm as a function of its output y_t^j is given by

$$(2) \quad p_t^j y_t^j = (D_t)^{\frac{1}{\sigma}} (y_t^j)^{\frac{\sigma-1}{\sigma}}.$$

For the purposes of the model, shocks to global income D_t matter insofar as they affect the revenue function of domestic firms. A positive shock to global income raises revenues both because of the direct increase in the price of domestic varieties, given by the term $(D_t)^{\frac{1}{\sigma}}$, and because of the positive endogenous response in the quantity produced, given by $(y_t^j)^{\frac{\sigma-1}{\sigma}}$.

The Spanish manufacturing sector consists of a collection of firms operating in this environment, i.e., selling to global consumers, and taking aggregate prices and shocks from abroad as given. The maximum number of varieties that can be produced in the domestic economy is fixed to $N \ll N^W$.

3.1.2 Production Technology

Henceforth, I will avoid time and firm indexes whenever they are not strictly necessary. Each individual firm can use labor l , physical or tangible capital k and intangible capital to produce output. I denote the private intangible stock of the firm by a and the publicly available stock of intangible capital by A . Production requires the payment of a fixed cost T every period. The production function

$$(3) \quad y = A^{1-\alpha-\beta} a^\beta k^\alpha l^{1-\alpha}$$

is assumed to be Cobb-Douglas with $\alpha, \beta \in (0, 1)$ and $\alpha + \beta < 1$. Note that this specification features constant returns to scale in physical capital and labor, which is consistent with the usual replication argument formulated in the Neoclassical Growth Model, and increasing returns to scale once we take into account investment in private intangible capital. The underlying assumption is that intangible capital is not consumed as a firm opens an additional production unit. I also assume that the decreasing returns generated by the revenue function in (2) dominate the private increasing returns in the production function in (3), i.e., $(1 + \beta) \left(\frac{\sigma-1}{\sigma} \right) < 1$. This ensures that the optimal firm size from the private point of view is a real number. The exponent on A is such that the exponents on all the reproducible stocks of capital (k , a and A) sum up to one. This means that the production function simplifies to the AK Growth Model from the point of view of a social planner that takes into account the externalities in intangible investment and employs a fixed labor supply. Appendix A provides the analytical steady-state solution to the firm's production problem in the absence of financial constraints and adjustment costs.

Labor contracts last one period and pay a wage W . Firms can invest in physical capital and private intangible capital. The accumulation function for physical capital includes a standard adjustment cost function $\phi_k(\cdot)$:

$$(4) \quad k' = \left(k + i_k - \phi_k \left(\frac{i_k}{k} \right) k \right) (1 - \delta_k),$$

where k' denotes physical capital in the next period, δ_k is the depreciation rate of physical capital and i_k is the amount of the consumption good invested in physical capital accumulation.

The timing convention that depreciation affects current investment facilitates comparability with the accumulation of private intangible capital. The difference in the accumulation

function of intangibles is the addition of random depreciation shocks z' :

$$(5) \quad a' = \left(a + i_a - \phi_a \left(\frac{i_a}{a} \right) a \right) (1 - \delta_a z'),$$

where a' denotes private intangible capital in the next period, δ_a is the average depreciation rate of intangible capital and i_a is the amount of the consumption good invested in intangible capital accumulation.

The adjustment cost function takes a quadratic form

$$(6) \quad \phi_x \left(\frac{i_x}{x} \right) = \eta_x \left(\frac{\left(\frac{i_x}{x} \right) - (\delta_x / 1 - \delta_x)}{1 + (\delta_x / 1 - \delta_x) - \eta_x} \right)^2,$$

where $x = \{k, a\}$ indexes the two types of capital and η_x is a parameter. This parametrization ensures that the cost for a firm that maintains its level of type- x capital constant is zero. The adjustment cost captures the fact that capital formation may be firm-specific up to a certain degree. Negative investment rates, i.e., transformation of capital into consumption goods, are possible as long as there is enough capital to divest, i.e., $x + i_x - \phi_x \left(\frac{i_x}{x} \right) x \geq 0$.

The shock z' is an exogenous firm-idiosyncratic random variable which evolves according to a log-normal AR(1) process bounded above by $1/\delta_a$,

$$(7) \quad \log(z') = \min \left\{ \rho \log(z) + \nu, \log \left(\frac{1}{\delta_a} \right) \right\}, \quad \nu \sim N(0, \theta), \quad \rho \in [0, 1),$$

and the process is normalized to have a mean equal to one. The current realization z' is not known when the firm makes its investment, hiring and production decisions. The value of z can be interpreted as the inverse of the creativity of a firm. Firms with lower values of z expect lower depreciation for their intangible investments in the future. Presumably, more creative or advanced knowledge takes more time to depreciate and is harder to imitate by competitors, providing a longer-lasting competitive advantage to the owner.

The accounting or private depreciation rate of intangible capital $\delta_a z'$ does not only include technological depreciation, but also spillovers to other firms. A fraction $\kappa \in (0, 1]$ of a firm's private depreciation of intangible capital diffuses to the rest of firms in the economy every period, while the remaining fraction $1 - \kappa$ is technological depreciation.¹ Both forms of accounting depreciation, diffusion and technological depreciation, imply the loss of a firm's

¹Citations of patents registered by other firms or geographical clustering of innovative firms are two visible consequences of the presence of intangible capital spillovers. Bloom et al. (2013) show evidence that, in the U.S., the social return to firm R&D is two to three times the private return.

competitive advantage over the depreciated stock of intangible capital.

Consistent with the interpretation of private depreciation of intangible capital partly as spillovers to the rest of firms, the accumulation function for the public stock of intangible capital is

$$(8) \quad A' = \left(\frac{F - A}{A} \right) \kappa \delta_a \bar{a} + A,$$

where A' denotes public intangible capital in the next period, F is the world technology frontier and \bar{a} is the average of the term $\left(a + i_a - \phi_a \left(\frac{i_a}{a} \right) a \right) z'$ across firms. Public intangible capital A accumulates with the average diffusion flows of private intangible capital $\kappa \delta_a \bar{a}$, and is not subject to technological depreciation. Yet, to keep the model stationary, the term $\left(\frac{F - A}{A} \right)$ introduces a force for mean reversion to the global technological frontier F , which grows exogenously at rate g . Section 3.3 discusses the implications for the equilibrium of the assumptions regarding the spillover process.

3.1.3 Exit and Entry

Firm exit and entry are endogenous. Firms can decide to liquidate production and exit by divesting all their capital stocks. From equations (4), (5) and (6), the fraction of capital x lost in adjustment/divestment costs when a firm liquidates production is η_x , since in that case $i_x = -(1 - \eta_x)x$.²

There are as many potential entrants as potential varieties in the domestic economy N , but entrants can only grab varieties of exited firms. Each potential entrant is endowed with initial debt $b_0 < 0$ (positive equity) and decides whether to pay the entry cost $-\gamma b_0 > 0$ after observing its initial realization of the idiosyncratic shock z_0 , which is drawn from the stationary distribution of z . If there are less idle varieties than potential entrants willing to enter, I assume that entrants with lower values of z_0 have priority. If a potential entrant decides to enter, it can use its initial equity net of the entry cost to invest in the two types of capital k and a and start production. Otherwise, it enjoys the outside value b_0 .³

3.1.4 Firm Financing

Once a firm has entered, it can finance investments internally with accumulated profits, and it can also issue a defaultable one-period bond b at a price q^b . Bonds are traded in a

²This result assumes that liquidation is immediate, and so depreciation does not kick in.

³I assume that the depreciation rate of initial (age-zero) tangible and intangible investment is equal to δ_k and $z_0 \delta_a$ respectively, and that initial investment is subject to the same proportional adjustment costs as a liquidating firm: η_k and η_a .

competitive market where investors can observe all the current characteristics of each firm, as well as the aggregate state.

Bond contracts are structured as follows. Firms receive a quantity $q^b b'$ of the consumption good in the current period and must repay b' in the following period if they want to avoid liquidation. The price q^b can depend on the aggregate and firm idiosyncratic states, as well as on the current actions of the firm, which are observable. Firms also have the option to default and liquidate production.⁴ From the amount of assets remaining after divestment costs, the maximum that debtholders can recover is a fraction ψ_k of tangible assets and a fraction ψ_a of intangible assets. The rest is captured by the owners. Formally, in case of liquidation, the amount recovered by debtholders is

$$\min \{ \bar{b}, b \},$$

where the upper bound is

$$(9) \quad \bar{b} \equiv (1 - \eta_k) (1 - \psi_k) k + (1 - \eta_a) (1 - \psi_a) a,$$

and the remaining amount captured by owners is

$$(10) \quad (1 - \eta_k) k + (1 - \eta_a) a - \min \{ \bar{b}, b \}.$$

The relevant assumption for the main theoretical mechanism to operate, which is confirmed by my estimation results, is that $\psi_k > \psi_a$, i.e. physical capital is easier to seize by debtholders in case of default than intangible capital.

Firms can also save in a risk free-bond (setting $b < 0$), which returns a net risk-free rate R_f and bears no divestment cost. I assume that there is no conflict of interests between managers and owners or shareholders. Owners can trade equity in a competitive stock market, but the cost of new equity issuances is prohibitive.

3.1.5 Aggregate Shocks

Since the ultimate goal of this model is to understand the effects of different types of shocks, I consider three possible aggregate states: normal, non-financial shock and financial shock.

⁴For simplicity, I assume that default inevitably leads to liquidation, even if in some cases debt restructuring could be Pareto improving due to the presence of real liquidation costs. I proceed thusly since 95 percent of companies that start insolvency procedures in Spain end up in liquidation, according to a report by Pricewaterhouse Coopers. A law change aimed at making renegotiation easier was introduced in March 2015.

Formally, the aggregate state can take the values $M_t = \{M^n, M^c, M^f\}$ and it evolves over time as a Markov Chain with transition matrix Π_M . The aggregate state determines three aggregate variables: global income $D(M)$, wages $W(M)$ and the equity premium $R_e(M)$ in global financial markets. Both financial and non-financial shocks feature lower global income than a normal state, which reduces the revenues of domestic firms. The qualitative difference between the two types of shocks is that in a financial shock state the equity premium is larger than in the other two states: $R_e(M^n) = R_e(M^c) < R_e(M^f)$.⁵ Section 3.2.2 explains how the equity premium affects firm financing. Real wages are roughly acyclical in Spanish manufacturing, so I normalize the level of wages (relative to the BGP) to $W(M^n) = W(M^c) = W(M^f) = 1$. Wage rigidity contributes to generate large employment flows. Appendix I computes the aggregate results under flexible wages. Section 4.1 describes in detail the estimation of the exogenous variables Π_M , $D(M)$, $W(M)$ and $R_e(M)$, as well as the risk-free rate R_f , with aggregate European Union (E.U.) data.

3.1.6 Asset Pricing

The possibility for firms to trade equity implies that all agents are perfectly diversified against idiosyncratic risk, and therefore only price aggregate risk.⁶ Hence, we can define a unique matrix of state prices S for all agents, where each entry in S indicates the price of next period's state M' , conditional on the current state M . The vector $S(M)$ can be used to price any asset in the economy at aggregate state M . Section 4.1.1 shows how we can infer the matrix of state prices directly from the data on the risk-free rate R_f , equity premium $R_e(M)$ and realized market returns x_m . This model-free approach avoids specifying a utility function and is consistent with different underlying asset-pricing models that explain why the equity premium is higher in financial recessions. Changes in S over time could reflect changes in beliefs about the next period's distribution of consumption across aggregate states or in risk preferences.⁷

3.1.7 Dynamic Firm Problem

To recap, the state variables in the firm's problem are physical capital k , private intangible capital a , public intangible capital A , the stock of debt b , the idiosyncratic shock z , the

⁵Muir (2014) provides empirical support for this qualitative assumption, as it shows that the expected equity premium increases in financial crises, but not in other types of crises.

⁶In this model, the fall in aggregate investment in response to a financial shock is mainly due to the contraction in the supply of credit to firms, so assuming that agents were also subject to acyclical idiosyncratic risk would not have a first-order effect on the aggregate cyclical results.

⁷Kozłowski et al. (2015) is an example of a general equilibrium model where persistent changes in beliefs explain higher risk premiums after the Great Recession.

aggregate shock M , and whether each variety is being produced or not.

The value of an incumbent firm for its owners

$$(11) \quad V(k, a, A, b, z, M) = \max \{ \mathcal{C}(k, a, A, b, z, M), \mathcal{L}(k, a, b) \}$$

is the maximum between the continuation and liquidation values.

The continuation value \mathcal{C} is the optimum of the following problem. Firms choose investments in the two assets i_k and i_a , labor l and debt issuances b' to maximize dividends d plus the next period's discounted value,

$$(12) \quad \mathcal{C} = \max_{\{i_k, i_a, l, b'\}} d + \sum_{M'} S(M, M') \mathbb{E}[V(k', a', A', b', z', M')],$$

subject to i) the no-equity-issuance condition

$$(13) \quad d \geq 0,$$

equivalent to requiring non-negative dividends, and ii) the laws of motion for capital stocks in equations (4), (5) and (8), and the evolution for the idiosyncratic shock in equation (7). Note that next period's value is discounted with the vector of state prices S in each future state M' , which is a function of the current state M . The expectation operator $\mathbb{E}[\cdot]$ is taken over the probability distribution of the idiosyncratic shock z .

Dividends are equal to net profits v plus debt issuances minus debt repayment

$$(14) \quad d = v + q^b b' - b.$$

Net profits are defined as revenues minus labor costs, investment expenditures and the fixed production cost

$$(15) \quad v \equiv (D(M))^{\frac{1}{\sigma}} y^{\frac{\sigma-1}{\sigma}} - W(M)l - i_k - i_a - T.$$

Output y is determined by the production function in equation (3).

The liquidation value is equal to the amount captured by owners in case of liquidation

$$(16) \quad \mathcal{L} = (1 - \eta_k)k + (1 - \eta_a)a - \min \{ \bar{b}, b \}.$$

If there is no default, i.e. if the maximum collateralizable amount \bar{b} is larger than outstanding debt b , the owners recover the post-liquidation value of assets after repaying b (or after cashing in b if $b < 0$). If instead $\bar{b} < b$, the owners only repay \bar{b} and can run away with a fraction of the post-liquidation value of assets, as explained in Section 3.1.4.

Assuming that entrants do not find it profitable to invest any amount in risk-free bonds, which will be the case in the equilibrium of the estimated model, the value for entrant firms is given by the solution to the following problem:

$$(17) \quad \max_{k_0, a_0} V(k_0, a_0, A, 0, z_0, M)$$

subject to no debt issuances in period zero

$$(18) \quad \frac{k_0}{1 - \delta_k} + \frac{a_0}{1 - z_0 \delta_a} = -b_0.$$

This is, firms have zero financial assets in their first period of life and then start issuing debt.

3.2 Equilibrium

3.2.1 Definition

A competitive equilibrium is defined by a debt price q^b , quantities $\{k, a, A, b, i_k, i_a, l\}$, and a decision $\{\mathcal{C}, \mathcal{L}\}$, for each period of the lifetime of each firm, as well as the number of varieties produced in each period, such that: i) firms maximize their value given the idiosyncratic shock z , global income $D(M)$, the vector of state prices $S(M)$, wages $W(M)$, the public stock of intangibles A and the no-equity-issuance condition; ii) investors price bonds competitively given $S(M)$; and iii) the laws of motion for k , a and A in equations (4), (5) and (8) are satisfied.

Note that the only endogenous aggregate variable is A . Financial markets are globally integrated, and labor can flow in and out of unemployment or other sectors in the economy. Given the small open economy assumption that the Spanish manufacturing sector does not affect global prices or wages, I do not need to impose market clearing conditions.

Appendix B lists the steps for the numerical computation of the equilibrium.

3.2.2 Characterization

Labor The optimality condition for labor is purely static. Optimal labor can be solved for analytically from the firm first order condition

$$(19) \quad l = \left[\frac{(\sigma - 1)(1 - \alpha)}{\sigma W} D^{\frac{1}{\sigma}} \left(A^{1-\alpha-\beta} a^\beta k^\alpha \right)^{\frac{\sigma-1}{\sigma}} \right]^{\frac{\sigma}{\sigma - (\sigma-1)(1-\alpha)}}.$$

Debt issuances and debt prices Let us now consider the intertemporal optimality conditions. A useful feature of the equilibrium is that it is never strictly optimal for a firm to pay out any positive dividends. Firm owners have the same pricing function as external investors and can always accumulate risk-free bonds in the firm, which is a costless way to reduce the probability of facing high external financing costs in the future. Hence, in equilibrium $d = 0$, so we can use the definition of dividends in equation (14) to obtain an expression for debt issuances

$$(20) \quad b' = [q^b]^{-1} (b - v).$$

Given the optimal labor choice, debt issuances b' are pinned down by investment in the two types of assets i_k and i_a , which determines the equilibrium price of a firm's debt q^b and net profits v .

From investors optimality, the equilibrium price of debt is given by

$$(21) \quad q^b = \sum_{M'} S(M, M') \mathbb{E}[\mathcal{R}(k', a', A', b', z', M')],$$

where the repayment rate is

$$(22) \quad \mathcal{R} = \begin{cases} 1 & \text{if } \mathcal{C} \geq \mathcal{L} \\ \min\left(\frac{\bar{b}}{b}, 1\right) & \text{if } \mathcal{C} < \mathcal{L} \end{cases}.$$

This is, the repayment rate \mathcal{R} is equal to one if the firm does not exit (liquidate production), and equal to the maximum amount that debtholders can seize from the firm's assets divided by total outstanding debt otherwise.

Therefore, debt prices for each firm are determined by two components. First, the expected repayment rate in the next period. Second, the covariance of the repayment rate with the aggregate state, through the state prices S . The first component would also be present

in a model with risk-neutral agents. The importance of the second component is increasing in the price of aggregate risk in global markets R_e .

The gross interest rate is the inverse of the debt price $(q^b)^{-1}$. To provide intuition on the relationship between the equity premium R_e and the cost of financing, it is useful to express the equilibrium interest rate in the state-price beta formulation (see Duffie (2010))⁸. The gross interest rate is given by

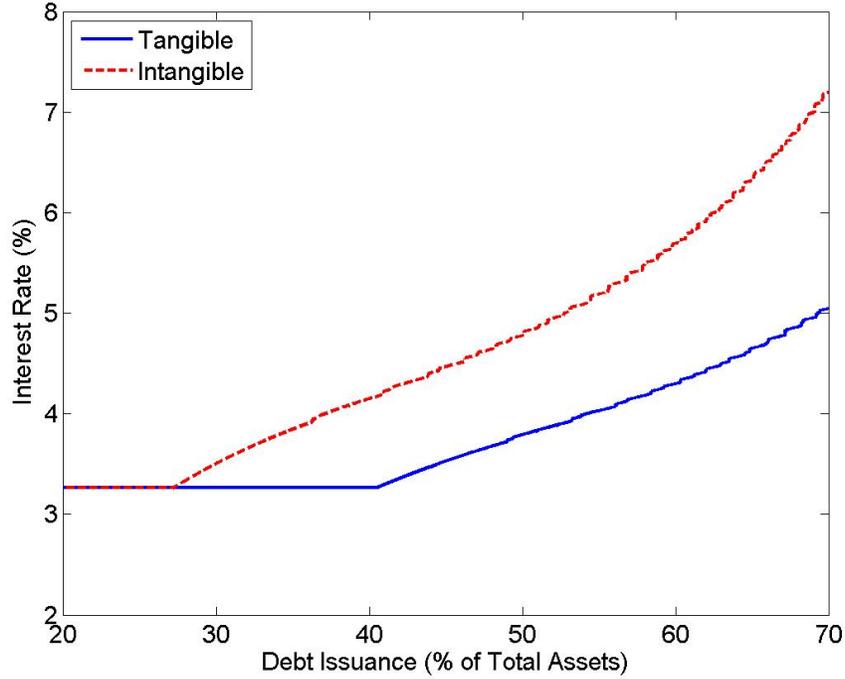
$$(23) \quad \frac{1}{q^b} = \frac{1}{\mathbb{E}[\mathcal{R}(M')]} \left(1 + R_f + R_e(M) \frac{\text{cov}(\mathcal{R}(M'), x_m(M, M'))}{\text{var}(x_m(M, M'))} \right),$$

where x_m is the matrix of expected returns of the global equity market for each current and future state (see Section 4.1.1 for the mapping between x_m and data observables), and the covariance and variance are taken over the future states M' . The equilibrium interest rate is equal to the risk-free rate plus the equity premium times the market beta of the firm's debt, all divided by expected repayment $\mathbb{E}[\mathcal{R}(M')]$. The market beta is defined as the covariance of the repayment rates with the return of the equity market, divided by the variance of the latter. Equation (23) illustrates why intangible investment tends to be more costly to finance in a financial shock state. Equilibrium interest rates are higher when repayment rates are low and covary more with the aggregate state, which is the case for the debt of intangible-intensive firms, and when the equity premium $R_e(M)$ is high, i.e. in a financial shock. From this equation we can also see that shocks to the equity premium would be irrelevant in the absence of real aggregate shocks. In that case, the returns of firm debt and equity would be independent of the aggregate state, and so the market beta of these assets would be zero.

It is also illustrative to analyze the behavior of the interest rate as a function of debt issuances. Figure 2 plots the inverse loan supply function for two firms that start with zero outstanding debt, an average level of tangible and intangible capital, $z = 1$, in a normal state ($M = M^n$). In the current period, I impose that one of the firms only invests in tangible capital and the other one only in intangible capital. The amounts invested are kept fixed for each firm. The figure shows that for the two firms, the net interest rate is increasing in the amount of debt issuances b' . For values of b' below \bar{b}' , the probability of default is zero and thus the inverse loan supply curve is perfectly flat. As b' grows, the default probability increases and the repayment rate becomes more correlated with the aggregate state, so the interest rate goes up. However, the supply curve for the firm investing in intangibles is shifted up. For any given amount of debt issuances, as soon as creditors expect a nonzero default

⁸This derivation is not necessary to compute the numerical equilibrium, so it is only included for illustration purposes.

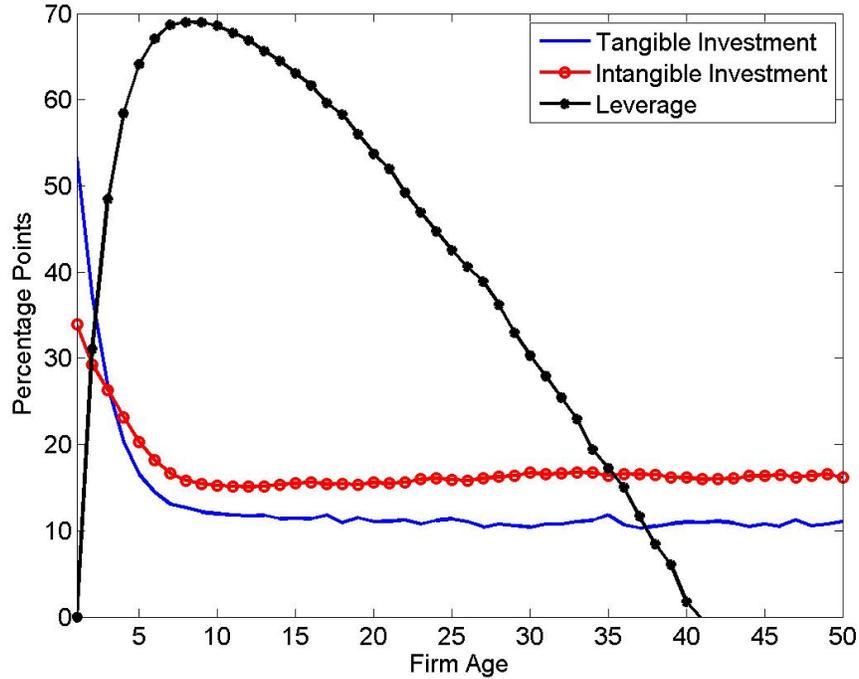
Figure 2: Inverse Loan Supply Curve to Firms



probability, that firm has to pay a higher interest rate. This is due to a lower repayment rate in case of default and higher aggregate risk, as shown in equation (23). In a financial shock state, both curves will shift up, but the one for the firm investing in intangibles will do so in a greater proportion, due to the higher exposure to aggregate risk.

Investment in physical and intangible capital The equilibrium values for investments in physical capital i_k and in intangible capital i_a are obtained by numerical maximization, as explained in Appendix B. However, we can gain some intuition by looking at the firm life-cycle pattern. Figure 3 shows average tangible and intangible investment rates as a percentage of tangible and intangible capital respectively (i_k/k and i_a/a), as well as the leverage ratio, defined as debt over total assets $\left(\frac{b}{k+a}\right)^+$, as a function of a firm's age. Firms start small and with no debt. To reach their optimal mature size, they invest at high rates when they are young, issuing bonds to finance investment expenditure. This progressively increases the leverage ratio until the firm is large enough to start financing internally and begins to deleverage. As they age, firms end up accumulating positive financial assets (negative debt), which makes default no longer an option and reduces their incentives to exit. Mature firms feature intangible investment rates higher than tangible investment rates because the private depreciation rate of intangible capital is larger (see estimated parameters in Table 2). However, the relationship flips for younger firms. This is due to both the more stringent

Figure 3: Firm Life Cycle



Notes: In this Figure, tangible and intangible investment are rates to tangible and intangible capital respectively. Leverage is debt over total assets.

financial constraints and higher adjustment costs affecting intangible investment. The data on the firm life cycle in Appendix E features the same qualitative pattern.

Another interesting comparative static is the dependence of investment rates on the outstanding leverage of a firm. When leverage is very high, external financing becomes expensive and firms have to reduce their investment rates, particularly on intangible capital, as implied by Figure 2. This is the force that dominates on the aggregate. However, investment rates are not monotonically decreasing on the leverage of a firm. For a region around moderate leverage levels, higher leverage can induce higher investment rates due to the real option provided by the possibility for owners to default and capture part of the firm’s assets.

Exit and entry By assumption, default leads to exit (liquidation), but exit can also occur in the absence of default. Given the process specified for the idiosyncratic shock z , all firms have a positive probability to lose all their stock of private intangible in each period, which leads to firm exit endogenously. Since investment costs tend to infinity when a tends to zero, and the production function is Cobb-Douglas, firms that have lost all their intangibles do not find it optimal to continue producing. Even if a is positive, for a bad enough idiosyncratic shock, firms may find it optimal to exit in the absence of default due to the presence of the fixed production cost T .

The only dimension of heterogeneity among entrants is the initial value of the intangible capital depreciation shock z_0 , which is informative about future shocks due to its autocorrelation. This implies that in each period there will be a threshold z_0 above which potential entrants decide not to enter. Since entrants face higher adjustment and external financing costs, they will tend to have lower values of z (higher creativity) than the average firm.

The maximum number of varieties that *can* be produced, both in the domestic and in the world economy, is fixed, so long-run growth is not driven by variety creation. However, the *actual* number of varieties produced will fluctuate over the business cycle, according to the accumulated difference between entry and exit flows. Adverse aggregate shocks, which typically entail higher exit rates, may be followed by a series of periods with a lower number of varieties produced in equilibrium.

3.3 Discussion of Assumptions

The assumptions in the model are tailored to capture the behavior of the corporate sector in a European country. To fix ideas, I take the example of the Spanish manufacturing sector, which I will use for estimation.

General framework The Spanish manufacturing sector—like most in Europe—consists of firms with a high degree of openness: 61 percent of the firms in the data export their products (35 percent correcting for sample representativity), and many firms are financed by foreign banks or are owned by foreign groups. Hence, it is appropriate to consider a small open economy model. The main trading partner and source of financing for Spanish manufacturing firms is the rest of the E.U. Thus, we can think of the E.U. as the “rest of the world” in the language of the model.

Intangible depreciation shocks and spillovers One of the original elements in this model is the introduction of private intangible capital depreciation shocks z that can take the form of spillovers. Let us first consider the effects of these shocks for the incumbent firm. The idiosyncratic shock serves two purposes in the model. First, it generates a cross section of firm tangibility ratios in the economy. Firms with lower values of z expect lower depreciation for their intangible investments in the future, and thus optimally become intensive in intangible capital. Second, it leads to realistic default rates in equilibrium. The assumption that z' is not known when firms invest increases the average probability of endogenous default (when z' becomes unexpectedly high), and avoids extreme investment patterns at the firm level that would otherwise arise due to linearity in the depreciation term (see equation (5)). In

this sense, we can think of intangible depreciation shocks as a proxy for creative (or rather imitative) destruction.

Let us now focus on the role of idiosyncratic shocks as spillovers to other firms. I allow for a fraction κ of the depreciated intangible capital to diffuse to other firms. For example, knowledge about a more efficient production process or about best marketing practices can spill over and be adopted by other firms, but the value of an advertising campaign may simply depreciate over time. The fraction that spills over determines the BGP level of A . However, as long as κ is strictly positive, the value of κ does not have any effect on the cyclical behavior of the economy. Given the Cobb-Douglas form of the production function and the normalization of the frontier level F (discussed below), only relative changes over time in \bar{a} matter. Since the focus of this paper are the fluctuations of the domestic economy with respect to the trend, henceforth I will assume that $\kappa = 1$ in the baseline model. The quantitative analysis in Section 6 also considers the alternative case without spillovers within the domestic economy, assuming that A grows exogenously at constant rate g .

In the accumulation function for public intangible capital in equation (8), I assume that diffusion of knowledge within the domestic economy is faster the further away the country is from the technological frontier. This avoids the possibility of divergent paths for the growth rates of the domestic and the global economy, which would be at odds with the high degree of convergence observed across developed economies, particularly within the E.U. In this model, fundamental parameters only affect the output level of a country with respect to the frontier, through their impact on the level of the aggregate private intangible capital stock, but not its long-run output growth rate. All the stock variables in the model grow at rate g in the long run. I normalize F so that in the BGP $\frac{F-A}{A} = 1$, and thus $A = \frac{\kappa\delta_a\bar{a}}{g} < F$ for any parametrization with $g > 0$. Note that irrespective of the parameters, the public stock of knowledge A never reaches the global frontier F , so we can think of F as the level of theoretical research that no firm has implemented in production yet. If for some reason domestic diffusion flows were interrupted, A would gradually drift away from the frontier, so the effective (post-normalization) social depreciation rate of public intangible capital is g . In the data, g is much smaller than the average private depreciation rate of intangibles δ_a , and also smaller than the depreciation rate of tangibles δ_k .

Financing channels The model rules out equity issuances, which means that all external financing must come via debt. This is consistent with the financial properties of firms in Europe, where the main channel for external financing are bank loans and, to a lesser extent, corporate bonds. Due to stringent regulation, private equity financing is fairly underdeveloped, especially in comparison to the U.S., and the value-added share of publicly listed firms

is also quite limited (less than 14 percent in the Spanish sample).

3.4 Amplification and Persistence of Financial Shocks

We are now ready to analyze how this model generates additional amplification and persistence of the GDP deviation after a financial shock, compared to a non-financial shock. First I will describe the theoretical channels, and then I will show how they modify the transition dynamics after a one-period shock compared to a benchmark model with exogenous intangible investment.

3.4.1 Channels

The channels for amplification and persistence are related to the particularities of intangible capital modeled in this paper. First, intangible assets are less collateralizable. This means that intangible-intensive-firm bonds are subject to more aggregate risk and thus financing intangible investment is more costly when a financial shock hits. Second, positive spillovers of intangible capital lower the social depreciation rate of intangibles, so any shock affecting this capital stock disproportionately generates more persistent effects. Third, higher adjustment costs for intangible investment imply that the intangible capital destroyed by exiting firms takes longer to be rebuilt. I proceed to describe each of these three channels in detail.

Financial constraints In general, all firms have higher expected default rates in shock states. However, the repayment rates to creditors of firms whose balance sheet is more intensive in intangible assets feature a higher covariance with the aggregate state. This is because intangibles are less collateralizable, as modeled in the assumption that $\psi_k > \psi_a$, so expected repayment rates of intangible-intensive firms are comparatively low in shock states. Since firm actions are observable and q^b is firm-specific, firms take into account the effect that their investment decisions have on the current price of their debt issuances. Hence, intangible investment is proportionally more reduced in financial shock states, when the discount on aggregate covariance is higher, than in non-financial shock states. In addition, the higher price of aggregate risk in a financial shock also leads to an increase in default and exit rates, especially for intangible-intensive firms, as it becomes harder to refinance outstanding debts. Since in this model entrants do not automatically replace exiters, the consequent fall in the number of varieties produced further deepens the GDP fall in financial shock states. Therefore, financial constraints on intangibles provide amplification through both the intensive (investment) and the extensive (exit) margin. In turn, these two margins create the following two channels for persistence.

Gradual spillovers and social depreciation In any model with capital accumulation, persistence after aggregate shocks is larger when capital depreciation rates are low, as stocks take longer to recover. Here, as discussed in Section 3.3, gradual spillovers from firms to the public stock of intangible capital imply a lower social depreciation rate for intangibles. Thus, financial shocks propagate over time because increases in the price of aggregate risk affect investment in the capital stock with lower social depreciation disproportionately more.

Adjustment costs and life-cycle growth From the estimation results (discussed in detail in Table 2), I obtain that investment in intangible capital has higher adjustment costs, i.e., $\eta_a > \eta_k$. We have seen how financial shocks lead to higher default and exit rates. Exiters are eventually replaced by entrants, which start small. Since adjustment costs are higher for intangibles, entrants take more time to reach the optimal level of intangible capital than that of tangible capital. The combination of higher exit rates and adjustment costs for intangible-intensive firms implies that the aggregate stock of intangibles also takes longer to recover on the extensive margin. As a result, this last channel adds to the persistence of financial shocks.

My model does not produce a persistent response after financial shocks simply because there is an increase in average interest rates, but because the discount on aggregate risk rises and intangible-intensive firms carry more aggregate risk. An increase in the risk-free rate would have very similar effects to a non-financial shock, or more generally to any shock reducing firm profits. It would affect investment in tangibles and in intangibles in the same way and it would not generate the qualitative result that financial shocks are more persistent.

The literature on balance sheet constraints emphasizes how financial frictions can amplify any shock affecting firms' net worth through the financial accelerator channel (see [Bernanke et al. \(1999\)](#)). This mechanism is also present in my model. However, a novel result here is that shocks of different nature lead to qualitatively different responses of the real economy.

3.4.2 Benchmark Model: Exogenous Intangible Investment

I compare my endogenous intangible investment model against a standard model in the literature of collateral constraints with exogenous idiosyncratic productivity shocks, [Midrigan and Xu \(2014\)](#), which builds on the model of [Kiyotaki and Moore \(1997\)](#). The benchmark model has no endogenous intangible investment, no spillovers and no default in equilibrium. The goal of this exercise is to show that without the channels emphasized in this paper we cannot replicate the same degree of amplification and persistence after financial shocks, nor

the qualitative difference between the two types of shocks.⁹

In particular, in the benchmark model, intangible investment i_a is fixed at the same level for all firms, costs no resources and has no adjustment costs. The level of i_a is chosen to replicate the level of private intangible capital in the full model. I also suppress spillovers, fixing the (post-normalization) public stock of intangibles to $A = 1$. The idiosyncratic intangible depreciation shock z is maintained, so it enters as an exogenous productivity shock. Moreover, there is no default in equilibrium, i.e., only debt contracts with $q_b = \frac{1}{1+R_f}$ can be signed. These assumptions eliminate the endogenous response of intangible investment to financial shocks, the surge in default and exit rates and the forces that translate these responses into persistence: spillovers and adjustment costs.

In order to give the benchmark model a fair chance in fitting the data, I reestimate the fixed production cost T , the entry cost γ and the initial level of equity $-b_0$ as if the benchmark model was the true data-generating process. Reestimation of these parameters is necessary to fit the empirical average exit and entry rates and the relative size of entrants. Appendix H contains the estimated parameters for the benchmark model.

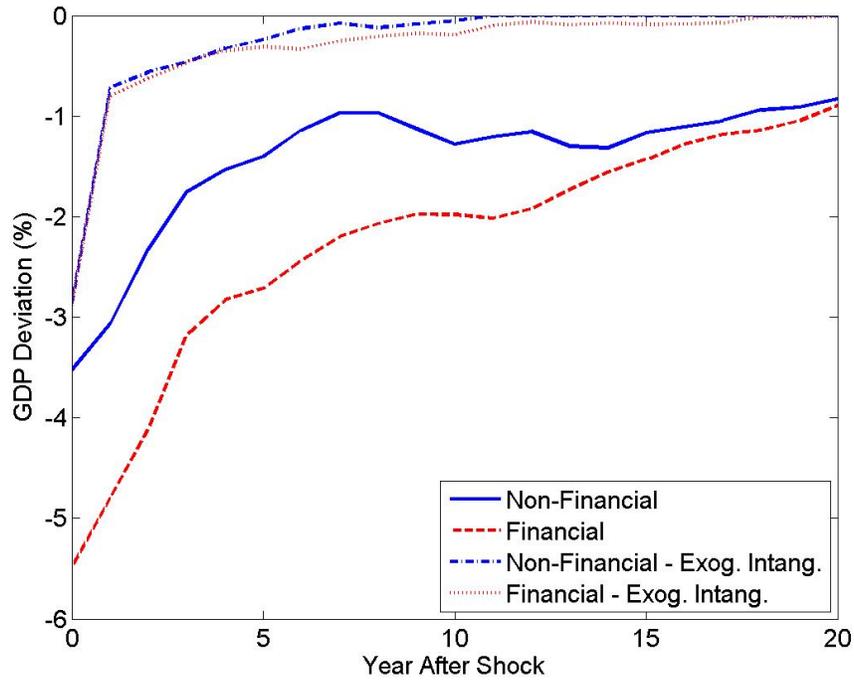
3.4.3 Transition Dynamics

Figure 4 plots the transition dynamics after a one period non-financial and financial shock, both for the full and the benchmark (exogenous intangible investment) models. This is, I compute the evolution of aggregate value added in the two models for the following sequences of realizations for the aggregate state M : $\{M^c, M^n, M^n, \dots\}$ and $\{M^f, M^n, M^n, \dots\}$. I repeat this process 100 times and plot the average across repetitions. Computing transition dynamics after a one-period shock highlights the internal propagation in the model, without adding persistence exogenously through the path of the aggregate shock. For comparability, in Figure 4 global income D experiences an exogenous 5 percent reduction for both the financial and non-financial shocks. On top of that, the financial shock features an increase in the equity premium R_e from 4 to 14 percent. These values correspond to the empirical average global-income fall in shocks of the two types and to the average equity premium increase in a financial shock. Section 5 covers the estimation of model parameters. At this point, the goal is simply to understand the qualitative properties of the model.

Let us first compare the transition dynamics after the two shocks in the full model. The change in the state prices associated with a financial shock generates both a larger impact in the period when the shock hits and a slower recovery when the aggregate state goes

⁹Note that comparing to a model of physical capital accumulation alone, the simple addition of another stock of reproducible capital generates more persistence after any aggregate shock. However, this force by itself does not explain the additional persistence of financial shocks, as intangible capital has a higher depreciation rate and thus less persistent dynamics in the absence of adjustment costs and spillovers.

Figure 4: Transition Dynamics After a One-Period Shock



In this Figure, global income is reduced by 5 percent in the two types of shocks.

back to normal. Even a decade after the shock, the economy remains substantially more depressed if the shock was financial. In contrast, in the benchmark model the two types of shocks produce very similar transition dynamics. The benchmark model not only predicts shallower recessions, but more importantly it also generates an almost immediate recovery to the trend after shocks. The tiny differential in the persistence of financial shocks appears as firm owners discount aggregate risk in equity returns more heavily, but the rest of channels are shut down. This is not a surprising result for a standard open economy model with realistic levels of firm external financing. Hence, the properties of intangibles modeled here generate more amplification and persistence after any shock, and also qualitative differences for different types of shocks.

4 Data

Let us proceed to the quantitative part of the paper. This section describes the data used to identify aggregate shock processes and structural parameters of the model. The aggregate shocks are estimated with E.U. data and are interpreted as exogenous to the Spanish manufacturing sector. The estimation of the rest of model parameters is based on firm-level Spanish manufacturing data.

4.1 Aggregate Shocks

Table 1 contains the results for the aggregate shocks, as well as the matrix of transition probabilities for M and the matrix of state prices S . I estimate the exogenous aggregate shock process with data from the E.U. The Spanish manufacturing sector, which accounts for about one fifth of total Spanish value added, is not large enough to significantly alter E.U. averages. The only aggregate variable which is computed with data from the Spanish manufacturing sector are wages, as the European labor market is not *de facto* integrated.

The first step is to classify each of the years spanned by the firm-level dataset (1990-2013) into one of the three possible aggregate states: normal, non-financial shock and financial shock. The variable used to estimate the global income shock is real GDP in the E.U. excluding Spain.¹⁰ Normal years are defined as those with GDP growth weakly higher than the period's average, 2 percent. The rest are “shock” years. Due to the asymmetry in business cycle fluctuations, there are more normal years than shock years. To classify shock years into financial and non-financial, I use the expected equity premium in the E.U. stock market. A year is classified as a financial shock if in any of the years in the same shock sequence the expected equity premium was higher than 10 percent.¹¹ According to this classification algorithm, non-financial shock periods are 1981-1983, 1992-1994 and 2003-2004.¹² The only financial shock is the Great Recession, 2009-2013. For the period of analysis, the classification based on the expected equity premium is perfectly coincident with the one in [Reinhart and Rogoff \(2009\)](#), which is based on the existence of systemic bank default or debt restructuring episodes.

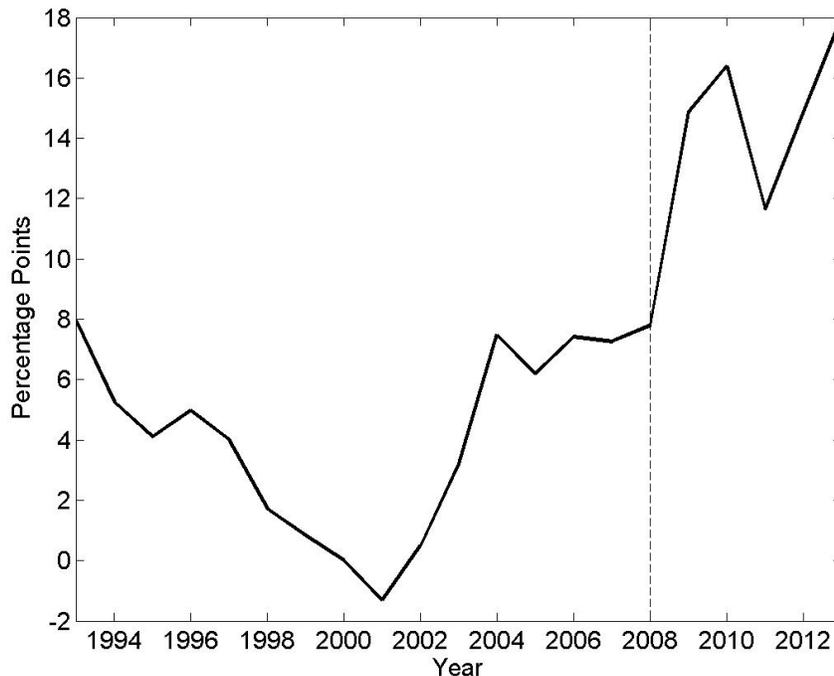
The expected equity premium is computed a la [Cochrane \(1999\)](#), with a regression of realized returns on the one-year-lagged dividend-price ratio. Figure 5 shows the time series of the expected equity premium. The Great Recession is accompanied by a large and persistent increase in expected returns, while the years of the dot-com boom coincide with very low expected returns. Figure 6 shows how the increase in the price of aggregate risk translated into higher real interest rates for the debt of Spanish non-financial firms, both for corporate

¹⁰Exports account for 29 percent of Spanish manufacturing sales. An alternative method to estimate aggregate income shocks would be to also include the fall in Spanish internal demand, although that would compromise the exogeneity of the shock. The alternative would yield only slightly larger shocks: 0.97 and 0.89 in a non-financial and financial crisis respectively.

¹¹E.U. real GDP data is from the International Monetary Fund, World Economic Outlook Database (October 2014). I use data for the period 1981-2013 (instead of 1990-2013) to increase precision of the transition probabilities matrix. To estimate the risk-free rate and the equity premium, I use data on German federal-security nominal rates from the Bundesbank, German inflation data from the World Bank and equity returns data from the STOXX Europe Total Market Index (TMI).

¹²Given that stock market data is only available since 1992, I follow [Reinhart and Rogoff \(2009\)](#) to classify the 1981-1983 crisis as non-financial.

Figure 5: Expected Equity Premium



Sample: European Total Market Index. Source: Stoxx.

bonds and for corporate bank loans of less than EUR 1M.¹³

Once the value of M for each year is determined, I estimate the mapping between M and global income $D(M)$, the equity premium $R_e(M)$ and wages $W(M)$, as well as the transition function Π_M . $D(M)$, expressed in relative terms to the BGP, is obtained as the average level of real GDP relative to the 1980-2013 trend for each value of M . Given normalization to the BGP, $D(M^n) = 1$. Global income falls by 2 percent in a non-financial shock and by 8 percent in a financial shock. The real risk-free rate R_f is set as a constant, since it is not significantly correlated with the aggregate state.¹⁴ The estimated value is 3.3 percent. $R_e(M)$ is obtained as the average expected equity premium in financial shock periods and in the rest of periods. On average, it increases from 4 to 14 percent when the economy enters a financial shock state. $W(M)$ seems to be roughly acyclical, probably due to regulation-driven wage rigidities in the Spanish labor market.¹⁵

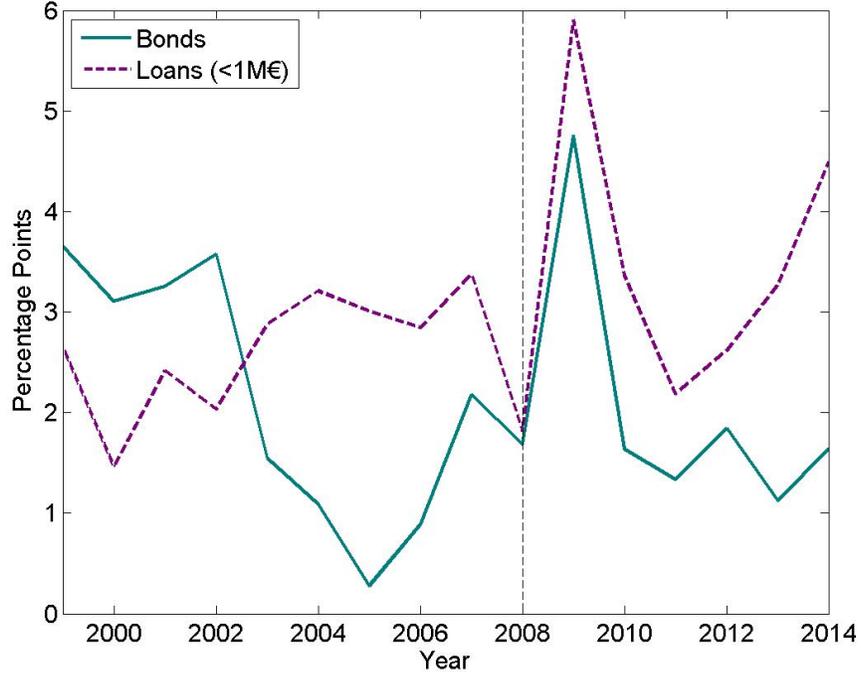
To estimate the transition matrix Π_M , I proceed in two stages due to the limitation of years of data available. Conditional on being in the normal state, I estimate the transition probabilities from my sample of realizations for M . For shock states, I also estimate the probability of reverting to the normal state directly from the data, but I assume that the

¹³Corporate bond rates are obtained from Dealogic and bank loan rates from the ECB MIR statistics.

¹⁴The average risk-free rate varies by less than 1 percentual point across aggregate states.

¹⁵Wages for the manufacturing sector are obtained from the Spanish National Statistics Institute.

Figure 6: Debt Real Interest Rates



Sample: Spanish non-financial firms. Source: Dealogic (bonds) and ECB Statistical Data Warehouse (loans).

Table 1: Aggregate Shocks

(a) Global Income, Equity Premium and Wage

	normal	non-finan. shock	financial shock
global income	1	0.98	0.92
equity premium	4.0%	4.0%	13.9%
wage	1	1	1

(b) Transition Matrix Π_M

	normal'	non-finan. shock'	financial shock'
normal	0.84	0.11	0.05
non-finan. shock	0.38	0.38	0.24
financial shock	0.14	0.53	0.33

(c) State Prices S

	normal'	non-finan. shock'	financial shock'
normal	0.33	0.04	0.60
non-finan. shock	0.18	0.19	0.60
financial shock	0.02	0.09	0.85

Notes: In Sub-Tables b and c, rows indicate the current state M and columns indicate next period's state M' .

probability to transition to the other type of shock is equal to the unconditional frequency of that shock state, divided by the unconditional probability of both shock states. Admittedly, this is not ideal, as my classification algorithm does not allow for transitions between the two shock states. However, imposing no transitions between shock states in the estimation of the transition matrix would be inconsistent with the presence of strictly positive state prices for each future state of the world. In any case, the transition matrix is only necessary to simulate random time series for M . The behavior of agents is solely determined by the vector of state prices in each current state.

4.1.1 State Prices

To infer state prices from the empirical values of R_f , $R_e(M)$ and the realized market-returns, for each current state M I use the theorem in financial economics that, under no arbitrage, there exists a vector of positive state prices (see Duffie (2010)). This method requires information on the payoff matrix and prices of as many independent assets as states are to be estimated. From the data I can only construct the payoff matrix for two assets, the risk-free bond and the market security.¹⁶ Hence, I will first estimate state prices for a financial shock state and for the two other states (normal and non-financial shock) combined. I denote this reduced 2-by-2 matrix of state prices by \bar{S} . The price of the risk free-security is given by $\frac{1}{1+R_f}$, and the price of the market security by $\frac{1}{1+R_f+R_e(M)}$. The payoff of the risk-free security, by definition, is 1 in each state of the world. For the market security, I assume that the payoff is $1 + m$ in states without a financial shock and $1 - m$ in a financial shock state. The parameter m is chosen such that the variance of $\{1 + m, 1 - m\}$ is equal to the variance of the empirical realized market returns. State prices for these two states are then given by

$$(24) \quad \bar{S} = \begin{pmatrix} 1 & 1 \\ 1 + m & 1 - m \end{pmatrix}^{-1} \begin{pmatrix} \frac{1}{1+R_f} & \frac{1}{1+R_f} \\ \frac{1}{1+R_f+R_e(M^n)} & \frac{1}{1+R_f+R_e(M^f)} \end{pmatrix}.$$

Matrix rows correspond to the current state and columns to next period's state. The next step is to obtain an approximated 3-by-3 matrix of state prices S for the three states. To do that, I multiply the state prices in the states without a financial shock by the unconditional probability that each of the two states (normal and non-financial shock) occurs:

¹⁶I do not use information on defaultable debt returns to infer state prices because I do not have data on the recovery rates for debtholders in case of default during the relevant period.

$$(25) \quad S = \left(\begin{array}{ccc} \frac{\pi_1}{\pi_1 + \pi_2} \bar{S}_1 & \frac{\pi_2}{\pi_1 + \pi_2} \bar{S}_1 & \bar{S}_2 \end{array} \right),$$

where $\pi = \iota' \Pi_M$ and ι is a 3-by-1 vector of ones.¹⁷ ¹⁸ Table 1c shows the estimated values of S . For each current state in the matrix rows, the state prices in the matrix columns sum up to the price of a risk-free bond $\frac{1}{1+R_f}$. Their composition varies according to the equity premium. If the economy is currently in a financial shock, the financial shock state next period has a higher state price. Since the financial shock state is associated with a low equity payoff, a high price attached to that state in the next period is consistent with a higher equity premium in equilibrium.

4.2 Firm-Level Data

I estimate the rest of model parameters with firm-level data from the Survey on Business Strategies (ESEE in Spanish) and from the Public Registry of Firms (DIRCE in Spanish).¹⁹ This dataset is a high-quality panel of 1,800 Spanish manufacturing firms from 1990 to 2013 which was designed to understand firm strategic behavior. It surveys the whole population of firms with more than 200 employees, including foreign company subsidiaries, and a representative sample of firms between 10 and 200 employees.²⁰ The sample represents around 35 percent of value added in Spanish manufacturing, and it includes small and medium enterprises, which account for a large share of the market in Europe, and an even larger share of investment and job creation, but are frequently left out of empirical corporate finance studies.

This dataset is unique in that it features very detailed information on firms' tangible and intangible investment expenditures, together with financial (complete balance sheet) information and employment. In particular, it contains both the book value of the stock of intangible assets and the flow of investment in intangibles.²¹ To construct intangible invest-

¹⁷The matrix of expected market returns is $x_m = (1 + R_f) \iota' + R_e \iota' + m \iota \begin{pmatrix} 1 & 1 & -1 \end{pmatrix}$.

¹⁸This approximation is consistent with the literature on the macroeconomic implications of disaster risk (e.g. [Gourio \(2012\)](#)), which shows that the price of aggregate risk is driven by the valuation of extremely bad events.

¹⁹ESEE is property of Fundacion SEPI, a government entity related to the Ministry of Industry. Annual reports are available at Fundacion SEPI's website. [Fariñas and Jaumandreu \(1995\)](#) provide a more detailed description of the survey methods and goals. Earlier versions of this data have been used in other publications on firm-level innovation, including [Guadalupe et al. \(2012\)](#) and [Doraszelski and Jaumandreu \(2013\)](#).

²⁰The employment share of firms with less than 10 employees is only 12 percent of the Spanish manufacturing sector.

²¹Spanish accounting law (Royal Decree 1514/2007), which is in accordance with International Financial Reporting Standards, specifies that the book value of intangible assets is imputed at the cost of purchase or internal development of the asset, and depreciation is specific to the properties of each asset.

ment for each firm, I follow the approach by [Corrado et al. \(2009\)](#) and include all investments in non-physical assets aimed at increasing the productivity of the firm. Intangible investment is the sum of four different accounting entries: R&D expenditures, marketing and advertising, workers training and technology imports. The first two entries account for almost all intangible investment, and they both predict future productivity growth.²² It is important to consider intangible investments beyond R&D also because many small or young firms find it too costly to complete R&D paperwork, and instead may classify innovation-related expenditures as other intangible investments (e.g. marketing and advertising).²³ In the data, firms with zero R&D spending still report significant amounts of product and process innovations.

It is certainly not the case that all categories of intangible investment generate positive spillovers to other firms. For example, marketing can have positive externalities when domestic firms enter in foreign markets and by doing so increase the demand for other domestic firms, but it can also involve capturing the demand for other firms. However, as discussed in [Section 3.3](#), as long as the fraction of private intangible capital which spills over to the pool of public intangible capital is positive, the value of that fraction has no effect on the cyclical results of the model. Only relative changes over time in the stock of private intangible capital matter. Of course, the results do change if there are no spillovers at all. [Section 6](#) also analyzes this alternative scenario.

I complement ESEE with data from the Public Registry of Firms, publicly available for recent years at the National Statistics Institute (INE) website. DIRCE has much less variables than ESEE, but it includes the whole population of manufacturing firms, which is helpful to compute firm representativity weights for ESEE and aggregate entry and exit rates.

[Appendix C](#) provides a list of all the variables used for structural estimation, their summary statistics, and the bounds to winsorize outliers. After eliminating outliers, the remaining number of firm-year observations from 1992 to 2013 is 23,380.²⁴ Each firm-year observation is weighted by its representativity. Firm representativity weights are constructed from DIRCE by sector of activity (20 categories in manufacturing) and employment size category (1-19, 20-49, 50-99, 100-199 and 200+ employees).

Before delving into the estimation method, it is informative to analyze the evolution

²²With an earlier version of the same dataset, [Doraszelski and Jaumandreu \(2013\)](#) show that R&D predicts productivity growth, and I find that one-year-lagged marketing and advertising rates are even more correlated with TFP growth than R&D rates.

²³Reporting R&D is particularly complicated due to the existence of R&D tax credits, which raise the bar for accounting standards.

²⁴The two years previous to 1992 are lost due to the lagged nature of some variables and lack of consistent definitions in 1990.

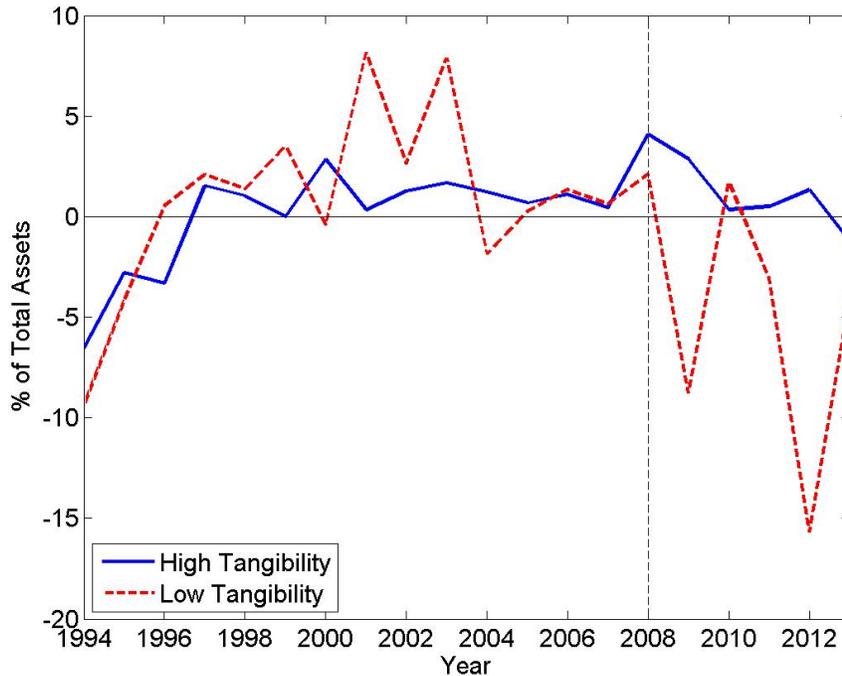
of some key aggregate variables around the Great Recession. To be clear, I will not use the aggregate time series to estimate the parameters in the model. The estimation method described in Section 5 relies uniquely on within-firm and cross-sectional moments. Then, Section 6 compares the macroeconomic results of the estimated model to the aggregate data. The following analysis is meant only as suggestive evidence of the qualitative relationships implied by the model.

Figure 7 displays aggregate debt issuances as a percentage of total assets ($\frac{b'-b}{k+a}$) for firms with lower and higher than average tangibility. The terms in parentheses are the model-equivalent definitions. Tangibility is defined as physical capital divided by total fixed assets ($\frac{k}{k+a}$). Average tangibility is 57 percent, which leaves a 43 percent share of intangible assets in total fixed assets. We can see that low-tangibility firms drastically reduced their debt issuances after the Great Recession, and also that they featured high debt issuances during the dot-com boom years. High-tangibility firms have a much more stable pattern of external financing flows. Average leverage (debt over total assets) weighted by value added is 21 percent, so the observed changes in debt issuances are economically significant. As we have seen in Figures 6 and 5, the fall in debt issuances coincided with an increase in the interest rates for debt and the equity premium. Hence, this pattern would suggest a fall in the supply of credit to firms, rather than in the demand. There are no substantial differences in the size, age or legal form of the two groups of firms plotted in Figure 7, and the pattern is robust to excluding non-exporters.

Moreover, the total investment rate ($\frac{i_k+i_a}{k+a}$) of low-tangibility firms dropped by a third in the period 2009-2013 compared to the previous average, which is twice the collapse for the rest of firms. This pattern is also observable across industries. Appendix D shows that intangible-intensive industries were the ones that reduced their average investment rates more in this period.

Figure 8 shows aggregate investment by all firms in the two types of capital as a percentage of fixed assets ($\frac{i_k}{k+a}$ and $\frac{i_a}{k+a}$ respectively). Both tangible and intangible investment have comparable magnitudes, and they both dropped after the Great Recession. In general, tangible investment seems more volatile. Although at first glance this last fact may seem at odds with the theory, it is also replicated by the quantitative model (see Figure 14). Since I estimate a higher private depreciation rate and a higher adjustment cost for intangible capital (see parameters in Table 2), intangible investment displays smoother time series. What the theory predicts is that the negative effect of financial shocks on investment rates compared to non-financial shocks is higher for intangible capital. More generally, Figure 8 makes apparent that intangible investment is a variable that fluctuates with the cycle, so it

Figure 7: Debt Issuances by Firm Tangibility



Sample: Spanish manufacturing firms. Source: ESEE. Tangibility = Tangible Assets / Total Fixed Assets.

is important to include it in business cycle models.²⁵ In Figure 9 I show that this pattern is shared by all the categories of intangible investment. Even though they have very different levels, they all feature a sharp decrease in the Great Recession. Consistent with the decline in intangible investment, in the ESEE sample aggregate total factor productivity (TFP) fell by 5 percentage points between 2008 and 2013. That fall came on top of the prolonged slow decline experienced during the late 1990s and early 2000s.²⁶

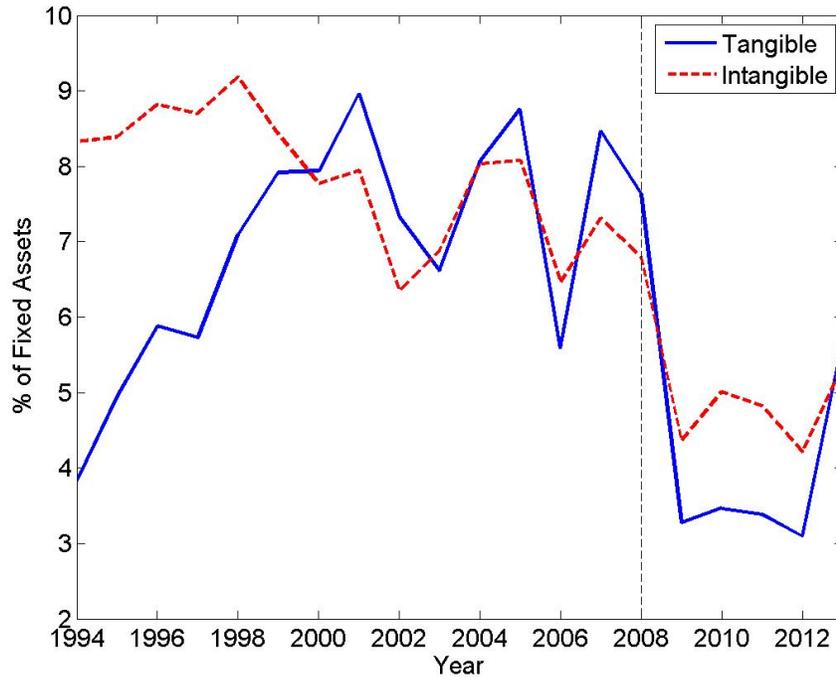
Finally, Figure 10 shows the evolution of aggregate entry and exit rates. Entry rates show a downward trend over the entire period for which data is available, but, if anything, they moderate their steady fall in the Great Recession. The Great Deviation cannot be explained by a fall in entry rates. On the contrary, exit rates start from very low levels and suffer a dramatic increase in 2009. As of 2014, they remain abnormally high.²⁷

²⁵Barlevy (2007) documents the procyclicality of R&D in the U.S.

²⁶Gopinath et al. (2015) obtain a slightly larger TFP fall with an overlapping sample of Spanish manufacturing firms from Amadeus and assuming $\alpha + \beta = 1/3$.

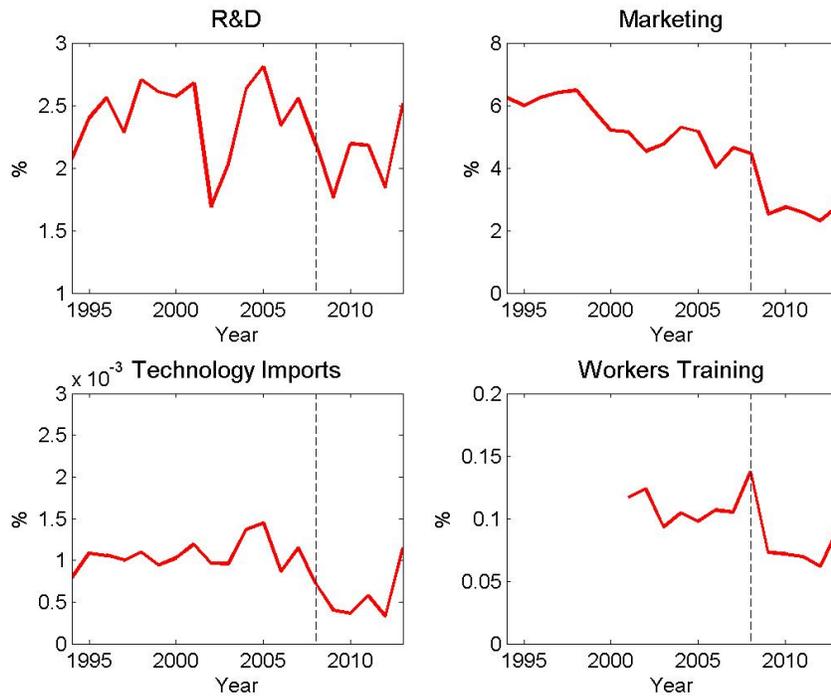
²⁷Indeed, Bentolila et al. (2013) document that the majority of job losses in Spain were due to firm closures rather than downsizing. Decker et al. (2014) report a similar qualitative pattern in U.S. entry and exit rates, although the U.S. rise in exit rates is not so persistent.

Figure 8: Investment Rates



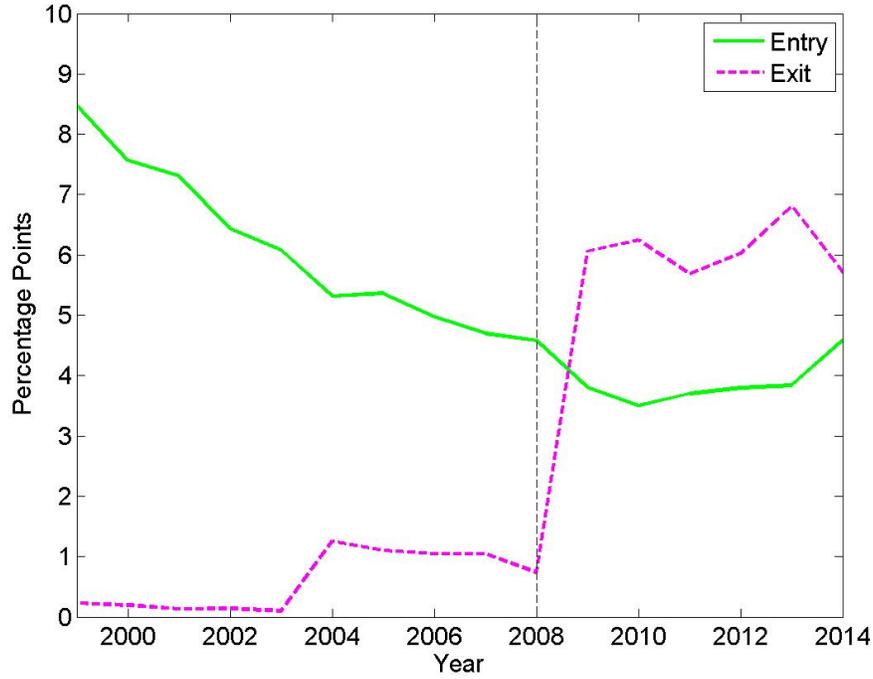
Sample: Spanish manufacturing firms. Source: ESEE. Intangible investment = R&D + Marketing + Technology Imports + Workers Training.

Figure 9: Intangible Investment Decomposition



Sample: Spanish manufacturing firms. Source: ESEE.

Figure 10: Entry and Exit Rates



Sample: Spanish manufacturing firms. Source: Public Registry.

5 Estimation

I use firm-level data to estimate the structural parameters of the model by the Simulated Method of Moments (SMM).²⁸ In the model, heterogeneity across firms is caused by different current and past realizations of the idiosyncratic intangible depreciation shock z . I compare model-simulated and actual data for the same time period, feeding into the model the empirical history of aggregate shocks estimated in Section 4.1 and keeping the draws of idiosyncratic shocks constant across iterations. The model is overidentified, so I minimize the squared distance in the moments weighted by the estimated optimal GMM matrix (see Appendix G for details).

The estimation of the model only uses cross-sectional and within-firm moments. As an additional overidentifying check, Section 6 compares the model to the aggregate time series to judge the validity and importance of the mechanisms presented in this paper.

5.1 Identification and Results

Table 2 lists the parameters in the model, their estimated values, their standard errors, and the moments targeted for estimation. Since the model is overidentified, all the moments

²⁸Smith (2008) provides a simple and general description of SMM.

Table 2: Firm-Level Parameters

concept	label	value	s.e.	target(s)
physical capital share	α	0.17	0.01	labor costs / value added
intangible share	β	0.21	0.01	tangible / fixed assets
depreciation tangibles	δ_k	0.08	0.02	$\frac{i_k}{k}$ mature firms
depreciation intangibles	δ_a	0.14	0.01	$\frac{i_a}{a}$ mature firms
fixed cost	T	0.27	0.02	average entry and exit rates
entry cost	γ	0.11	0.06	average entry-exit gap
recovery creditor tang.	ψ_k	0.60	0.05	leverage, debt issuance tang., slope $(\frac{i_k}{a+k}, \frac{b}{a+k})$
recovery creditor intan.	ψ_a	0.15	0.02	leverage, debt issuance intan., slope $(\frac{i_a}{a+k}, \frac{b}{a+k})$
adj. cost tangibles	η_k	0.09	0.01	within std. dev. $\frac{i_k}{a+k}$
adj. cost intangibles	η_a	0.20	0.02	within std. dev. $\frac{i_a}{a+k}$
autocorr. shock	ρ	0.08	0.01	autocorr. $\frac{i_a}{a+k}$
std. dev. shock	θ	1.00	0.05	corr. $\frac{i_a}{a}$ and growth in a
entrants net debt	b_0	-1.24	0.03	relative employment entrants
elasticity of subs. varieties	σ	4	-	calibrated

See Appendix G for the computation of the standard errors.

depend on multiple parameters. Yet, for intuition, in the table I align the parameters with the moment(s) that most directly identify each of them. Appendix F contains the Jacobian matrix, i.e., the elasticity of each moment with respect to local changes in each parameter. Table 3 reports the comparison between data and simulated moments. Appendix G explains the details of the computation of moment and parameter standard errors.

I proceed to discuss the intuition for the identification of the parameters. This analysis is supported by the theory as well as by the qualitative relationships observed in the Jacobian. The exponents in the production function α and β are identified respectively by the value-added-weighted average labor share and the average tangibility weighted by firm fixed assets. A larger α reduces the labor share and a larger β reduces tangibility. Intangible capital has a slightly larger exponent (21 percent) than tangible capital (17 percent), but this is compensated by the higher depreciation rate for intangibles. These results imply that the exponent on the public stock of intangibles $1 - \alpha - \beta$, which governs the contribution of the spillover channel, is 0.62, an arguably high value. Section 6 also considers the case where A has constant growth, i.e., that there are no intangible capital spillovers. The depreciation rates of tangible and intangible capital δ_k and δ_a are estimated by matching the average investment rates of mature (older than 10 years) firms, which tend to invest as much as needed to replace their depreciated capital stock, weighted by tangible and intangible assets respectively. The private depreciation rate of intangibles is larger (14 vs 8 percent for tangibles), consistent with the results in Corrado et al. (2012). The fixed production cost

T is expressed as a fraction of the frictionless steady-state operating profits ($py - Wl$) of a firm with constant $z = 1$, and is estimated to 27 percent to match the average annual entry and exit rates, which are increasing in T . Actual entry and exit rates fluctuate over time according to the history of realizations of the aggregate state. The entry cost γ is identified by the average absolute gap between entry and exit rates. If $\gamma = 0$, all exiting-firm varieties would be filled by entrants immediately and entry rates would be equal to exit rates in every period. Higher values of γ increase the threshold for entry. The entry cost γ is estimated to be 11 percent of the initial equity of entrants $-b_0$.

The parameters which directly relate to the financial constraints in my model are the fractions that debtholders can recover from each type of asset in case of firm default, ψ_k and ψ_a , and the adjustment cost parameters, η_k and η_a , which determine how much value is lost after liquidation. The estimated creditor recovery rates are 60 percent of the tangible assets left after liquidation and only 15 percent of the intangibles.²⁹ The remaining fractions are captured by owners. The recovery rates are identified by the value-added-weighted average leverage ratios (outstanding debt over total assets), the average debt issuance over total assets for firms with higher than average and lower than average tangibility, and the slope coefficient of tangible and intangible investment rates with respect to the firm's current leverage. Higher observed leverage ratios indicate that firms ability to commit is larger, and so will lead to the inference that recovery rates for creditors are higher.³⁰ To distinguish the recovery rates for the two types of assets, I look at average debt issuances by tangibility, weighted by total assets. In the data, higher-than-average tangibility firms issue positive debt on average, while the opposite is true for low-tangibility firms. Hence, the estimation algorithm infers that tangible assets are more collateralizable. The slope coefficient of tangible and intangible investment rates is obtained from a firm-level regression of these two variables on all the states of the firm which are observable in the data: the log of fixed assets, tangibility, leverage, firm's age and lagged investment rates. Appendix E reports the results of these two regressions. Lower recovery rates for each type of assets make the respective investment rates more sensitive to debt. The adjustment costs are such that upon liquidation firms lose 9 percent of the value of tangible assets and 20 percent of the value of intangibles, reflecting the fact that intangible capital is more firm-specific. These are identified by the within-firm volatility of positive investment rates in the two types of capital, which is decreasing in

²⁹Altman and Kishore (1996) report that the percentage of the face value of corporate bonds (not of a firm's assets) that is recovered by bondholders in case of default ranges from 30 to 70 percent across industries. Regarding the difference between asset types, the lack of collateralizability of intangibles is consistent with the evidence in Falato et al. (2013), who show empirically that firms with more tangibility also have higher levels of leverage, whereas firms with more intangibles use internal financing preferentially.

³⁰Yet, as commented in Section 3.2.2, the relationship is not monotonic. This is seen in the inverted sign of the local elasticity in Table 7.

adjustment costs. I only look at positive values because sales of intangible assets (which are infrequent) are not reported in the ESEE survey.

The parameters that govern the idiosyncratic shock process z are its autocorrelation ρ and the standard deviation θ of its error term. I identify the autocorrelation by matching the firm-level regression coefficient of the current intangible investment rate to the lagged intangible investment rate. The more autocorrelated is the depreciation shock, the more likely a firm is to have autocorrelated intangible investment rates. The standard deviation is identified by the correlation between intangible investment rates and the evolution of the stock of intangibles, relative to the same moment for tangible capital. Since the shock z , which is observed after the firms decision to invest, determines the relationship between intangible investment expenditure and formation of intangible capital, the more volatile is z the weaker the correlation will be.

Finally, the exogenous initial (negative) debt of entrants b_0 , expressed as a fraction of frictionless steady-state operating profits of a firm with constant $z = 1$, is set to match the life-cycle growth in employment by age ($\text{age} \leq 5$ vs $\text{age} > 5$). Due to investment adjustment costs and financial frictions, it takes time for entrants to accumulate the “mature” optimal level of tangible and intangible capital if they start with few initial internal resources.

The only parameter which I cannot estimate with the data is the elasticity of substitution across varieties σ , as I do not have information on firm total costs to compute markups. I use the estimate from [Broda and Weinstein \(2006\)](#) for three-digit categories of US imports and set σ equal to 4.

5.2 Goodness of Fit

Table 3 includes the values of all the moments targeted, in the real data and in the simulated data, as well as the moment standard errors in the data. We can see that the fit of the model is accurate with respect to the majority of moments, but not all of them, as the estimation is overidentified. The entry-exit gap is too low in the model, as the data features extremely low exit rates before the Great Recession (see [Figure 10](#)). The model has trouble in fitting the high within-firm volatility in the data. Lower adjustment costs or a higher standard deviation of the idiosyncratic shock would help in this dimension, but they would generate an excessive average leverage ratio. However, investment volatility is likely to be exaggerated by measurement error in the data. Relatedly, average value-added-weighted leverage is a bit too high in the model, as firm size is more disperse in the data and very large firms tend to have lower leverage ratios.

Targeting average leverage is particularly important when analyzing financial frictions,

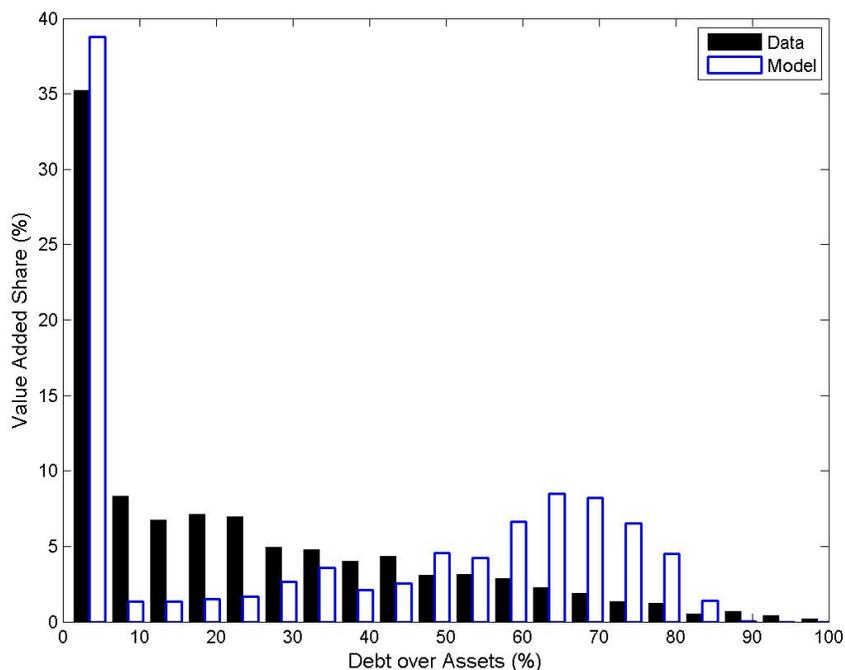
Table 3: Moments Fit

moment	data	s.e.	model
labor costs / value added	62.3	1.9	62.1
tangible / fixed assets	57.2	4.4	57.6
average $\frac{i_k}{k}$ mature firms	10.0	0.5	11.2
average $\frac{i_a}{a}$ mature firms	16.2	4.0	16.0
average entry and exit rates	4.0	0.9	4.3
average entry-exit gap	4.3	1.2	1.0
within std. dev. $\frac{i_k}{a+k}$	18.0	0.4	5.3
within std. dev. $\frac{i_a}{a+k}$	11.5	0.5	3.4
corr. $\frac{i_a}{a}$ and growth in a	0.22	0.09	0.24
relative employment entrants	57.1	2.2	62.3
debt issuance high tangibility	0.6	0.3	1.3
debt issuance low tangibility	-1.7	1.4	-1.0
slope coeff. $\frac{i_k}{a+k}$ on $\frac{b}{a+k}$ *	-0.06	0.02	-0.01
slope coeff. $\frac{i_a}{a+k}$ on $\frac{b}{a+k}$ *	-0.01	0.01	-0.02
autocorr. $\frac{i_a}{a+k}$ *	0.25	0.04	0.21
average leverage	21.1	0.8	33.6

*Coefficients from a regression of $\frac{i_x}{a+k}$ on log assets, tangibility, leverage, age and lagged investment rates, where $x = \{k, a\}$.

The regression includes firm and year FE. All regression coefficients are reported in Table 6.

Figure 11: Leverage Distribution



Sample: Spanish manufacturing firms. Source: ESEE.

and is a step above most of the quantitative macro literature, which often assumes unrealistically high leverage ratios for a representative firm. Although the shape of the distribution is not targeted, Figure 11 shows the whole leverage distribution, weighted by the value added share of each bin. We see that more than 35 percent of the firms in the data, weighting by their value-added contribution, have a leverage ratio below 5 percent, and the contribution of firms with leverage ratios above 50 percent is very modest. Hence, the room for restrictions in external financing to affect aggregate investment is limited. My model shows how financial constraints can generate persistent effects even if only a small fraction of firms are affected by them. The fit in the distribution is not perfect, as the model produces a bimodal leverage distribution, with some apparent bunching around the endogenous borrowing constraint of each firm. We do not observe this pattern in the data, but the presence of firm heterogeneity and endogenous default in equilibrium allow the model to still produce a relatively flat distribution of leverage values, compared to what simpler models of borrowing constraints would predict.

6 Macroeconomic Analysis

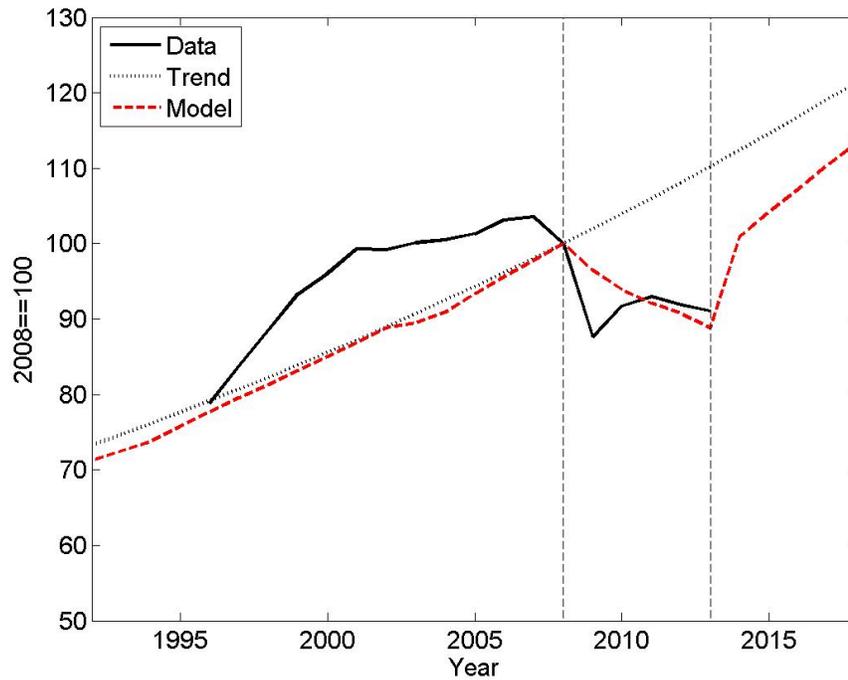
Once the model is estimated, it can be used to examine the role of endogenous intangible investment in explaining the extent and the components of the “Great Deviation” that followed the Great Recession, as well as to conduct policy analysis.

6.1 The Great Deviation

Figure 12 compares the evolution of Spanish manufacturing GDP (aggregate value added) in the data and in the model for the period of analysis. I feed into the model the series of European aggregate shocks estimated in Section 4.1. The period plotted encompasses a non-financial recession (2003-2004) and a financial recession (2009-2013), marked with vertical dashed lines. The model is able to fit the extent of the GDP fall between 2008 and 2013, but it does not wholly capture the boom around the late 1990s and early 2000s. Figure 12 also plots the evolution of GDP predicted by the model for the period 2014-2018, assuming that the aggregate state went back to normal in 2014, and the exponential long-run trend, normalized to 100 in 2008. It is apparent that the economy remains depressed with respect to the trend for multiple years after the end of the financial shock, leading to a Great Deviation.

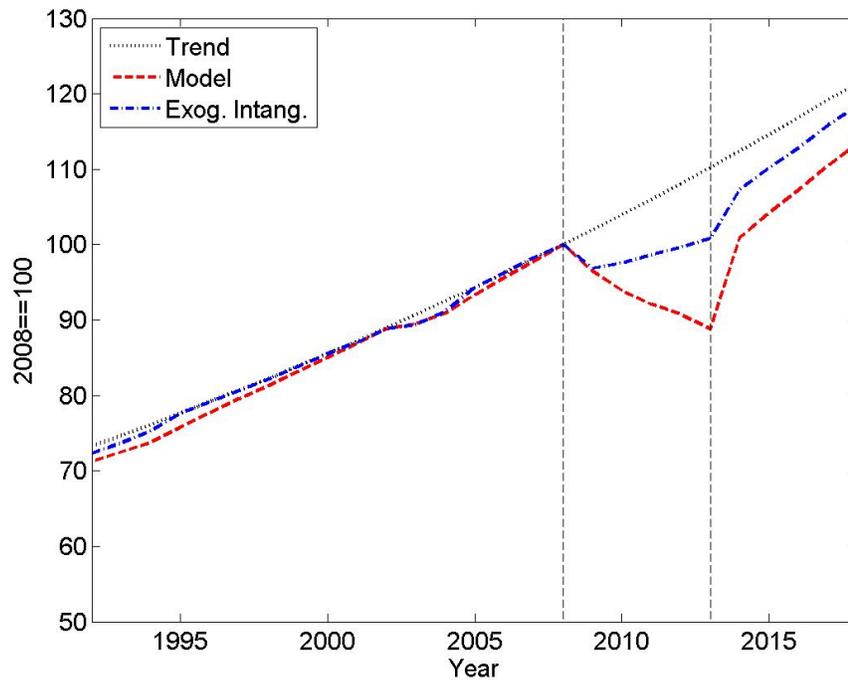
In order to show that endogenous intangible investment is necessary to fit the deviation in the data, Figure 13 compares the full model to the benchmark model presented in Section 3.4.2. The benchmark model without endogenous intangible investment can neither capture

Figure 12: Aggregate Value Added vs Data



Sample: Spanish manufacturing firms. Source: INE.

Figure 13: Aggregate Value Added vs Benchmark Model



the extent of the Great Recession nor generate substantial persistence after the financial shock expires. It only explains 42 percent of the 2008-2013 deviation, while the remaining 58 percent is accounted for by endogenous intangible investment and the associated propagation channels. To shed light on the reasons behind the discrepancy between models, I proceed to analyze the components of the Great Deviation.

6.2 Components

Table 4 decomposes the GDP change with respect to trend for the periods 2008-13 and 2008-18. This allows us to distinguish between channels of amplification (while the economy is hit by a financial shock) and persistence (after the aggregate state goes back to normal). The table presents the decomposition in terms of production factors and in terms of entrants, incumbents and exiters. It includes the results for the full model with all the channels, for a model without intangible capital spillovers ($A = 1$), and for the benchmark model with exogenous intangible investment.

Let us start analyzing the decomposition by production factors. GDP, which is defined as aggregate value added by domestic firms, can be decomposed as follows:

$$(26) \quad \sum_{j=1}^N p^j y^j = D^{\frac{1}{\sigma}} E \left(A^{1-\alpha-\beta} a^\beta k^\alpha l^{1-\alpha} \right)^{\frac{\sigma-1}{\sigma}}.$$

Here, all variables without the superscript j denote aggregates. For example, a is the sum of private intangible capital in the economy. Time subscripts are omitted. The variable E denotes allocative efficiency and is obtained as a residual, as in the Olley-Pakes decomposition (see [Olley and Pakes \(1996\)](#)).

The first row in Table 4 gives the contribution of the exogenous global income shock D , i.e., the change in GDP if domestic producers did not react to the aggregate shock. Obviously, this is the same for all models. Across the table rows, labor is the variable that accounts for the largest GDP changes. This is not surprising due to the presence of one-period labor contracts in the model, the magnitude of the labor share and wage rigidity. Appendix I shows that under flexible wages GDP falls less, although the relative contribution of each production factor is similar. Comparing the first two columns, we can see that the stocks of capital have more persistent dynamics (recover more slowly), and that the contribution of intangible capital to the recession is larger than that of tangible capital. Public intangible capital is the most persistent component, as its fall is larger for the whole decade than for the crisis period. It keeps destroying GDP even when the aggregate state goes back to normal. Since the model features firm heterogeneity and frictions to reallocate capital across firms

Table 4: GDP Change Decomposition

decomposition	full model		no spillovers		exog. intang. inv.	
	2008-13	2008-18	2008-13	2008-18	2008-13	2008-18
global income	-2.0	0.0	-2.0	0.0	-2.0	0.0
physical cap.	-2.1	-1.0	-2.1	-0.7	-1.4	-0.9
priv. intan. cap.	-2.6	-1.3	-2.7	-1.0	0.0	0.1
publ. intan. cap.	-0.2	-0.4	0.0	0.0	0.0	0.0
labor	-13.4	-4.3	-13.3	-2.8	-5.5	-1.6
alloc. efficiency	-1.3	0.0	-1.4	0.0	0.0	-0.1
entrants	-3.4	5.4	-3.4	5.5	0.6	1.4
incumbents	-11.9	-4.2	-11.3	-2.3	-8.6	-1.9
exitors	-5.2	-5.9	-5.9	-6.0	-0.6	-1.4
total	-21.1	-5.8	-21.0	-3.4	-8.8	-2.3

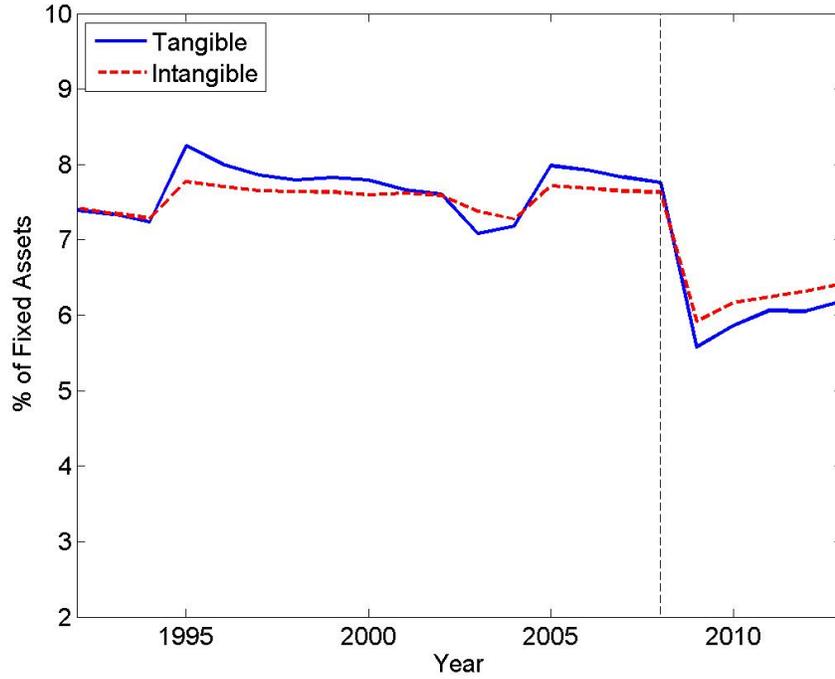
Percentual contributions to the deviation in GDP with respect to trend.

after shocks, allocative efficiency worsens in the Great Recession. However, this component does not generate persistence, as it has fully recovered by 2018. In this model, measured TFP in revenues is equal to aggregate GDP divided by the contribution of physical capital and labor: $(k^\alpha l^{1-\alpha})^{\frac{\sigma-1}{\sigma}}$. The measured TFP fall between 2008-13 is 6.1 percent in the model and 5.0 percent in the ESEE data. More generally, the endogenous response of TFP suggests that financial shocks may explain a larger fraction of the business cycle than obtained by previous decompositions with exogenous TFP shocks (Jermann and Quadrini (2012)).

The contribution of the spillover channel itself can be gauged by comparing the first two columns with columns three and four, which present the decomposition results for a model where public intangible capital is kept constant relative to the trend. The magnitude of the fall in the Great Recession is not substantially different from the one predicted by the full model, but the recovery after the aggregate state goes back to normal is visibly faster. The GDP fall for the period 2008-2018 is 41 percent less than in the full model. In other words, spillovers are responsible for persistence but not for amplification.

In the exogenous intangible investment model (columns five and six), the response in the private and public intangible stocks is muted. Due to complementarities in the production function, this also leads to a lower contribution from labor and physical capital compared to the full model. We can quantify the relevance of the new channels for persistence considered in the paper by looking at the difference between the full and the exogenous-intangible-investment model for the whole decade (2008-2018). The differential contribution of private intangible capital is three times larger than for public intangible capital, and amplification effects through labor account for most of the difference between models. Somewhat surpris-

Figure 14: Investment Rates - Model

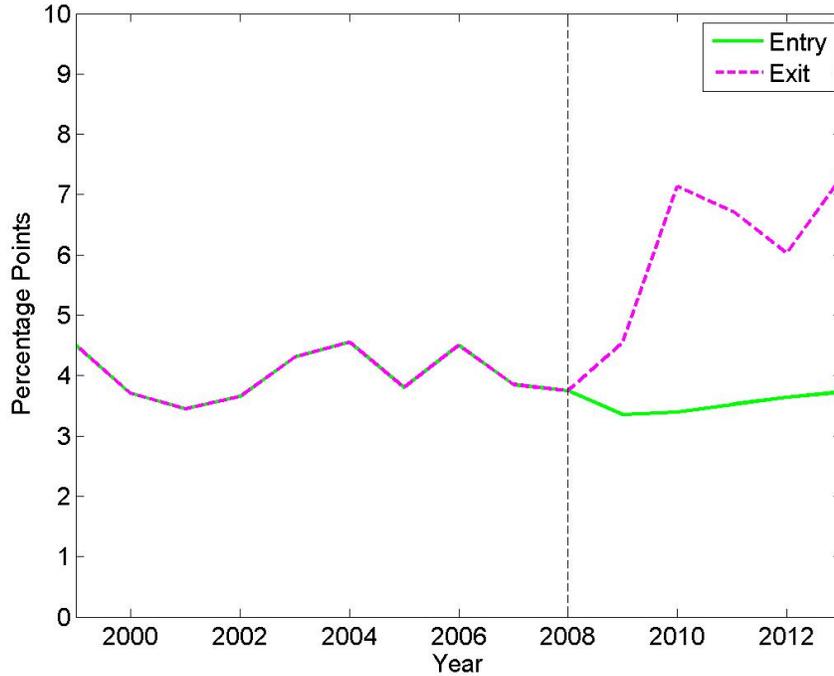


ingly, the fall in physical capital is almost the same in the two models. Lower amplification seems to be compensated by the fact that in the benchmark model physical capital is the only variable that provides an intertemporal adjustment margin for financially constrained firms. Adding up all channels, the model with endogenous intangible investment predicts an additional 12.3 percentual points of GDP fall between 2008-2013, and still a persistent difference of 3.5 percentual points by 2018.

To decompose into entrants, incumbents and exiters, I compute the difference between the contribution of each group and the average contribution on the BGP. It is necessary to establish this relative measure because, by definition, in any period entrants create value added and exiters destroy it. The first observation is that all groups contribute less than normal in the Great Recession, with exiters accounting for a larger chunk of the fall than entrants. The bulk of the changes when the financial shock hits is due to incumbents, but exiters seem to generate more persistence. This is because it takes some time for the balance sheet position of a firm to deteriorate and induce liquidation. Comparing to the exogenous-intangible-investment model, exiters are the group that accounts for larger differences in the whole decade.

To compare with the components in the aggregate data, Figures 14 and 15 display investment and entry and exit rates, respectively, in the full model. This is, they reproduce Figures 8 and 10 with model-simulated data. Overall, the model replicates the qualitative

Figure 15: Entry and Exit Rates - Model



patterns seen in the data. Investments in tangibles and intangibles fall in the Great Recession, with the former being more volatile, and firm exit rates rise persistently, while entry rates do not respond much. Nevertheless, the model response in investment rates is slightly more moderate than the one in the data.

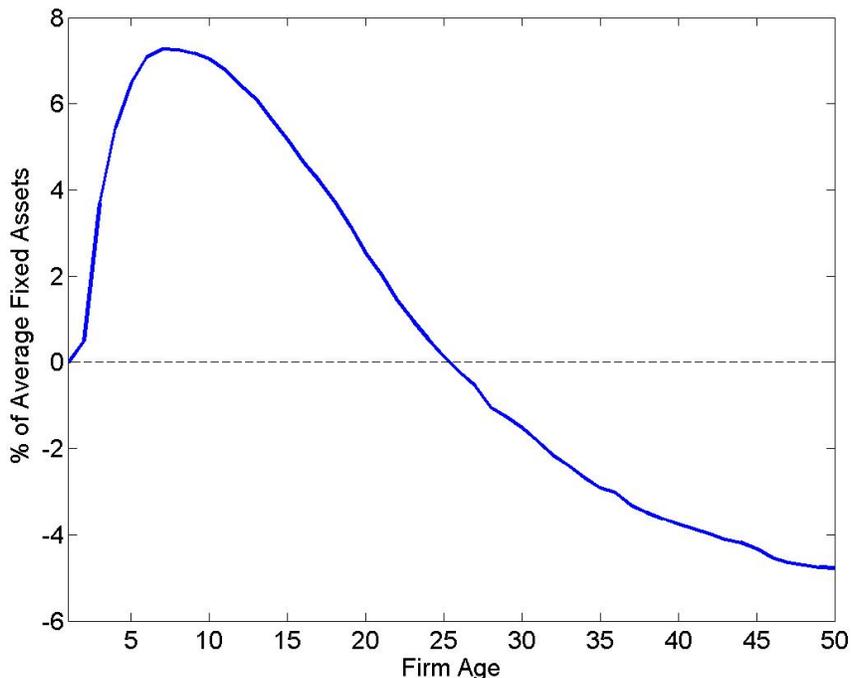
6.3 Policy

The policy debate in Europe is dominated by the need to speed up the recovery after the Great Recession. The European Commission is starting to implement the European Investment Plan, also known as the Juncker Plan, which is a program of subsidized credit to risky investments, with a stated goal to relieve credit constraints. This section proposes an implementable policy that could better help achieve this goal and move the economy closer to the first best at no public cost: a budget-neutral scheme of transfers based on firm age.³¹

The first best in the model implies equalizing the marginal product of physical capital and the marginal product of intangible capital across firms. However, the decentralized equilibrium is inefficient due to the presence of financial frictions, in the form of the no-equity issuance constraint and limited commitment, and intangible capital spillovers. Transferring equity to younger firms relaxes the borrowing constraint of the firms with a higher marginal

³¹This analysis abstracts from administrative costs of transfer collection and distribution.

Figure 16: Optimal Transfer by Age in 2009



product of tangible capital, and especially intangible capital.³²

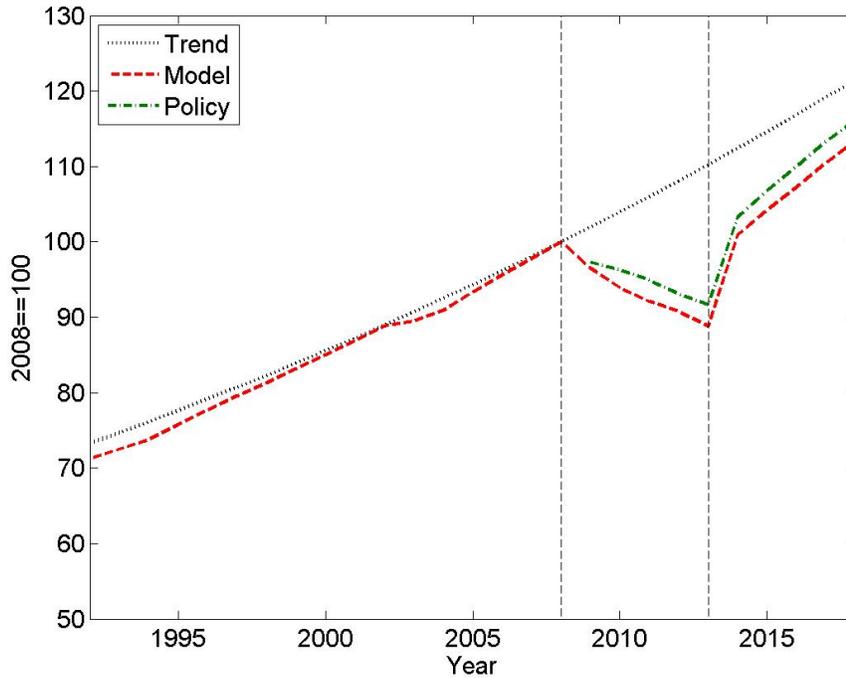
To avoid concerns about manipulation of firm (or establishment) age, I restrict the analysis to a one-time unanticipated transfer. I compute the optimal set of unanticipated transfers by age in 2009, conditional on the transfers being budget neutral, i.e. summing up to zero across firms. In this model, expected welfare is proportional to the sum of existing firm value, since all agents own a perfectly diversified portfolio. Hence, the optimal policy is the one maximizing the sum of incumbent firm value in the Spanish manufacturing sector in 2009. For tractability, I search for the optimum within the class of transfer schemes proportional to the average firm net debt interest rate $(q_b)^{-1} - 1$ by age. By firm optimality, the interest rate is approximately equal to the expected marginal private return to tangible and intangible investment.³³ Hence, the sum of firm value tends to be maximized if resources are reallocated towards firms with higher interest rates in equilibrium. Such a reallocation boosts aggregate investment and reduces inefficient firm exit.

Figure 16 plots the optimal transfer by age as a percentage of average firm fixed assets. The transfer is positive for young firms, which are more financially constrained, and negative

³²Dyrda (2014) shows how firm age may matter for financial constraints in the presence of long-term financial contracts. Here, the relevance of firm age is due to the combination of low initial equity levels and investment adjustment costs.

³³It is not exactly equal because the bond price q_b is a function of current tangible and intangible investment, so the marginal cost of debt includes the decrease in the bond price as a firm invests more.

Figure 17: Effect of the Optimal Transfer on GDP



for older firms. Notably, for very young firms, the transfer is increasing in age. This is because with positive investment adjustment costs entrants take some time to accumulate leverage, and so the most financially constrained firms are those between 5 and 15 years of age. Figure 17 shows the effects of the policy on aggregate GDP. Even if this is a one-time policy, it generates a persistent increase in GDP with respect to the no-policy benchmark. It avoids 3.2 percentage points of the fall between 2008 and 2013 (15 percent of the total fall) and brings the economy back to the trend faster.

My analysis tries to stay within the realm of implementable macro policies. Basing the policy on firm age avoids the need for the government to collect information about harder to observe and contract upon variables such as corporate loan interest rates, leverage, assets or tangible and intangible investments. An indicator that these costs are relevant in practice is the fact that many young and/or small firms do not report any R&D expenditures in spite of the presence of tax credits to R&D in many OECD countries, including Spain. The one-time unanticipated nature of the policy should avoid manipulation of firm age such as firms changing their name or their establishment location to appear younger.³⁴ Obviously, this

³⁴Even if the policy is anticipated some months in advance, the result in Figure 16 that the optimal transfer is close to zero for one-year-old firms means that firm entry in response to the policy does not yield substantial fiscal gains. Regarding effects on exit, I find that very few additional firms are prompted to liquidate production by the policy.

type of analysis has the caveat that the policy scheme is not time consistent. Anticipation of this policy could lead to an even larger increase in investment rates, which would be desirable, but also to inefficient firm entry or even to the appearance of screen companies created with the purpose of cashing in the transfer.

An alternative implementable policy would be targeting firms based on their size (employment), instead of their age. I follow the same procedure as for age-based transfers and compute the optimal one-time unanticipated budget-neutral scheme of transfers proportional to labor l in 2009.³⁵ Compared to conditioning on age, size is less correlated with a firm's marginal return. Firms which are small not because they are young, but because they have suffered negative idiosyncratic shocks, do not have higher marginal returns. On the other hand, targeting transfers to small firms helps reduce inefficient exit even further, as small firms are proportionally more affected by the fixed production cost. Numerically, I find that conditioning on firm size is slightly less effective than conditioning on age, as the optimal scheme only avoids 2.7 percentage points of the 2008-2013 GDP drop.

The outcome of the Juncker Plan will depend on its implementation details, i.e., on which firms end up being granted credits, which is still uncertain. However, in a framework with heterogeneous firms and endogenous borrowing constraints, a policy of credit subsidies is dominated by (well-targeted) outright transfers. Lowering the interest rates paid by firms by a moderate amount increases their capacity to leverage only marginally, through the positive income effect on net worth, but the incentives to default are barely changed. Therefore, government-subsidized credit crowds out most of private unsubsidized credit. On the contrary, if the discount on interest rates is too large, the policy can also distort the investment decisions of unconstrained firms by inducing them to leverage in excess.

In any case, it is important to keep in mind that targeted policies can only be second-best, as the correlation of the marginal returns to investment with firm characteristics which are observable by the regulator is not perfect. Microeconomic legal reforms aimed at increasing pledgeability of assets or at facilitating the development of external equity financing channels would be first-best. In the model, raising the creditor recovery rate for intangibles to the level of tangibles ($\psi_a = \psi_k = 0.6$) generates a 37 percent smaller GDP fall from 2008 to 2013, and a 45 percent smaller fall for 2008-2018, compared to the estimated baseline. In fact, in countries with a more developed private equity sector, such as the U.S., the fall in both GDP and TFP after the Great Recession has been shallower and much less persistent than in most European countries (see [Fernald \(2012\)](#) and [Hall \(2015\)](#)), which rely more heavily on bank loans.

³⁵Firms are allowed to readjust their labor choice in the current period (2009) after the policy transfers take place.

7 Conclusions

Standard macroeconomic models of financial frictions have difficulties generating large real effects after financial shocks and cannot explain qualitatively why financial recessions last longer. In this paper I show that modeling the properties of intangible assets generates additional channels for amplification and persistence in response to an increase in the price of aggregate risk. Intangible assets are less collateralizable, take longer to recover after firm exit, and have lower social depreciation rates due to their spillovers to other firms. These properties imply that intangible investment is disproportionately sensitive to financial conditions and that shocks to intangibles can have more persistent effects.

I estimate the model structurally with data on Spanish manufacturing firms and compare the simulated data with the aggregate macro time series in Spain. Endogenous intangible investment can explain the extent and the components of the fall in output after the Great Recession. As in the data, lower intangible investment by incumbents and increased exit rates are two important channels for amplification.

My model also provides a framework to predict the short and medium-run effects of firm fiscal policy. In particular, transferring funds to younger firms could be a more efficient policy than targeting small firms or subsidizing credit.

Avenues for future research include studying the frictions related to public and private equity issuances for firms investing in intangibles, as well as allowing for imperfect portfolio diversification by firm owners, longer lags in the formation of intangible capital, and differentiated parameters for each type of intangible capital. Regarding the empirical part, the analysis in this paper would benefit from linking data on firm-level debt interest rates to measures of intangible investment and asset tangibility. That would enable a more direct identification of the parameters determining financial constraints. More broadly, an explicit consideration of the cyclical changes in the price of aggregate risk observed in the data should be in the agenda of future work on the real effects of financial crises. For example, the framework in this paper could be adapted to study the impact of financial crises on employment of permanent and temporary workers, for which I also have firm-level data, modeling the former as non-collateralizable long-run investments subject to aggregate risk.

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Appendix

A Steady-State Solution without Frictions

I solve the static problem of a firm maximizing profits taking factor prices W for labor and R for the two types of capital as given, absent investment adjustment costs and financial constraints, for $z = 1$. This is, I maximize

$$(27) \quad \max_{a,k,l} D^{\frac{1}{\sigma}} \left(A^{1-\alpha-\beta} a^{\beta} k^{\alpha} l^{1-\alpha} \right)^{\frac{\sigma-1}{\sigma}} - Wl - R(k + a).$$

The first order conditions are

$$(28) \quad \alpha \frac{\sigma-1}{\sigma} D^{\frac{1}{\sigma}} \left(A^{1-\alpha-\beta} a^{\beta} k^{\alpha} l^{1-\alpha} \right)^{\frac{\sigma-1}{\sigma}} = Rk,$$

$$(29) \quad \beta \frac{\sigma-1}{\sigma} D^{\frac{1}{\sigma}} \left(A^{1-\alpha-\beta} a^{\beta} k^{\alpha} l^{1-\alpha} \right)^{\frac{\sigma-1}{\sigma}} = Ra$$

and

$$(30) \quad (1-\alpha) \frac{\sigma-1}{\sigma} D^{\frac{1}{\sigma}} \left(A^{1-\alpha-\beta} a^{\beta} k^{\alpha} l^{1-\alpha} \right)^{\frac{\sigma-1}{\sigma}} = Wl.$$

Thus, optimal physical capital is

$$(31) \quad k = \left[\frac{\alpha}{R} \frac{\sigma-1}{\sigma} D^{\frac{1}{\sigma}} \left(A^{1-\alpha-\beta} \left(\frac{1-\alpha}{\alpha} \frac{R}{W} \right)^{1-\alpha} \left(\frac{\beta}{\alpha} \right)^{\beta} \right)^{\frac{\sigma-1}{\sigma}} \right]^{\frac{\sigma}{\sigma-(1+\beta)(\sigma-1)}}$$

and optimal intangible capital is given by

$$(32) \quad a = \frac{\beta}{\alpha} k.$$

Optimal labor is given in equation (19).

B Computation of the Equilibrium

Given a set of structural parameters, I need to solve numerically for the optimal investment in tangible and in intangible capital of a firm as a function of its state variables. The method employed is value function iteration. The computational algorithm consists of the following steps:

1. Construct a grid of state values for k , $\frac{a}{k}$, $\frac{b}{k+a}$, z , A , and the three possible values for M . For k and $\frac{a}{k}$, the grid must be sufficiently dense between the initial (age-zero firm) values and the potential frictionless steady-state values. The grid is denser in regions of the state space where the continuation and the liquidation value are closer.
2. Assume a parametric form for the continuation function \mathcal{C} in each aggregate state M . To save on parameters, I replicate the form of the analytical value function without frictions and idiosyncratic shocks. The parametric form is linear in $\{r, zr, k, a, b\}$, where $r \equiv py - Wl$ are revenues net of labor costs, and has a different parameter set for each M . Let us see why these are the relevant terms. If the firm continues production forever, the analytical solution is linear on debt b and on r , which is a function of the current state vector (k, a, A, b, z, M) given the optimal choice for labor. If the firm liquidates production, the analytical solution is linear on the stocks of physical k and intangible a capital and debt b (if $b < \bar{b}$). Hence, the approximated continuation function must include all these terms. To capture the value of the idiosyncratic shock to depreciation z , which correlates with next period's z and thus to accumulation of private intangible capital, I add the term zr to the linear specification. The term is interacted with r because z is more valuable if the firm continues operating. Iterating on the continuation function rather than on the ex-ante value function allows me to solve explicitly for the non-differentiable continuation-liquidation decision in the current period without smoothing.
3. Use non-uniform discretization to compute expectations over realizations of the idiosyncratic shock z given an aggregate state M' . Again, the discretization is denser for regions where the liquidation option is closer. In this case, for high values of z . To compute expectations for A' , I approximate $A' = f(M) + A$, and iterate on the values of f with the simulated data.³⁶

³⁶This is only an approximation because growth in A' , which depends on the distribution of private intangible investment i_a across firms, may also be affected by the distribution of state variables other than M . However, $f(M)$ is typically two orders of magnitude smaller than A , so the error in this variable does not substantially affect the resulting investment policy functions.

4. Maximize numerically over investment in the two types of capital i_k and i_a for each grid point, taking into account:
 - (a) labor optimality in equation (19),
 - (b) dividends optimality, i.e., $d = 0$, and
 - (c) bond pricing by investors, i.e., the debt price, given by equation (21), is endogenous to the investment decision.
5. Iterate until the coefficients in the parametric guess for the value function converge. The correlation between the grid values produced by the old and the new guess of the continuation value function must be higher than 99.99 percent.
6. Compute investment policy functions for $\frac{i_k}{k+a}$ and $\frac{i_a}{k+a}$ with a rich parametric form, linear on

$$\left\{ 1, py, r, \frac{r}{k}, \frac{r}{a}, rz, \frac{rb}{k+a}, \frac{1}{r}, k, k^2, \frac{a}{k+a}, \left(\frac{a}{k+a}\right)^2, A, \frac{b}{k+a}, \left(\frac{b}{k+a}\right)^2, \frac{1}{k+a-b}, z, \frac{zb}{k+a}, zk, \frac{za}{k+a} \right\}.$$

The parametrization of investment rates can be richer than the one for the continuation function because it is only used for simulation, not iteration.

7. Simulate an economy with as many heterogeneous firms as in the data for many periods, using the parametric investment policy functions. Compute the moments of interest both in the simulated and in the real data for the period 1992-2013, using the same aggregate shock process for M as in the aggregate E.U. data.
8. Iterate on the model's fundamental parameters until the GMM optimal distance measure between simulated and data moments is minimized. See Section 4 for a more detailed description of the two last steps.

C Firm-Level Data Variables

Table 5 provides summary statistics for the variables used in structural estimation and the rules used for winsorizing outliers, as well as the correspondence with the variable names in the original datasets (ESEE and DIRCE). With respect to the legal form of the firm, I exclude from the sample self-employed owners, cooperative firms and the category "Other". These groups together constitute less than 6 percent of the sample, and could be driven by goals other than firm-value maximization. In the language of the ESEE, I only include observations with variable FORJUR equal to 2 (limited liability companies - *Sociedad Limitada* in Spanish) or 3 (stock corporations - *Sociedad Anónima* in Spanish).

Table 5: Data Variables

(a) Summary Statistics

concept (unit)	label	mean	p10	p90	winsorizing
value added (EUR)	py	2,023,511	200,465	2,130,631	-
phys. capital (EUR)	k	1,720,838	26,948	2,100,430	> EUR100
tangibility (%)	$\frac{k}{k+a}$	73.0	28.9	100.0	INM > EUR100
leverage (%)	$\left(\frac{b}{k+a}\right)^+$	26.8	0	63.4	< 100%
tang. invest. rate (%)	$\frac{i_k}{k+a}$	11.1	0	34.7	< $\pm 200\%$
intang. invest. rate (%)	$\frac{i_a}{k+a}$	6.9	0	18.8	< $\pm 200\%$
age (years)	-	22.6	6	42	-
labor share (%)	$\frac{Wl}{py}$	62.3	-	-	-
entry rate (%)	-	5.2	-	-	-
exit rate (%)	-	2.7	-	-	-
entrants rel. empl. (%)	-	57.1	-	-	-
firm weights	-	0.84	0.04	2.95	-

(b) Variable Definitions

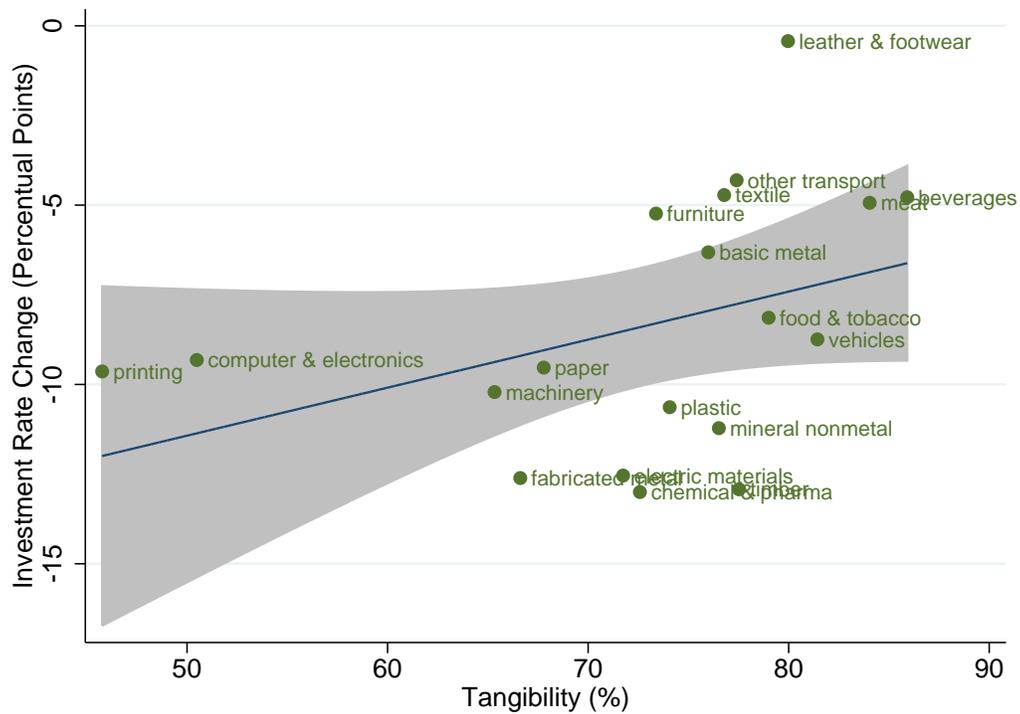
concept (unit)	label	name/formula in survey
value added (EUR)	py	VA
phys. capital (EUR)	k	IN-INM
tangibility (%)	$\frac{k}{k+a}$	(IN-INM)/IN
leverage (%)	$\left(\frac{b}{k+a}\right)^+$	FACC/PASIVO
tang. invest. rate (%)	$\frac{i_k}{k+a}$	(CIM-VIM)/IN
intang. invest. rate (%)	$\frac{i_a}{k+a}$	(GEFT+GTID+GPV*VENTAS/100+IMPTEC)/IN
age (years)	-	year-AEMP
labor share (%)	$\frac{Wl}{py}$	CP/VA
entry rate (%)	-	DIRCE Tables 287-292, <i>Altas/Total</i>
exit rate (%)	-	DIRCE Tables 287-292, <i>Bajas/Total</i>
entrants rel. empl. (%)	-	PERTOT
firm weights	-	DIRCE Tables 296, 297

Notes: Monetary units are 2008 Euros. Entrants (age= ≤ 5) employment is relative to older firms (age > 5).

D Cross-Industry Evidence

Asset tangibility also influenced the behavior of different industries in the Great Recession. In Figure 18, I plot for each industry the change in the average total investment rate $\frac{i_k + i_a}{k+a}$ from the period 1991-2008 to 2008-2013, as a function of the average tangibility for 1991-2008.³⁷ Industries are classified into 20 sectors of activity in the manufacturing sector. Firms in industries with lower average asset tangibility were the ones that reduced their investment rates more after the Great Recession.

Figure 18: Change in Investment Rate Before and After 2008 by Industry Tangibility



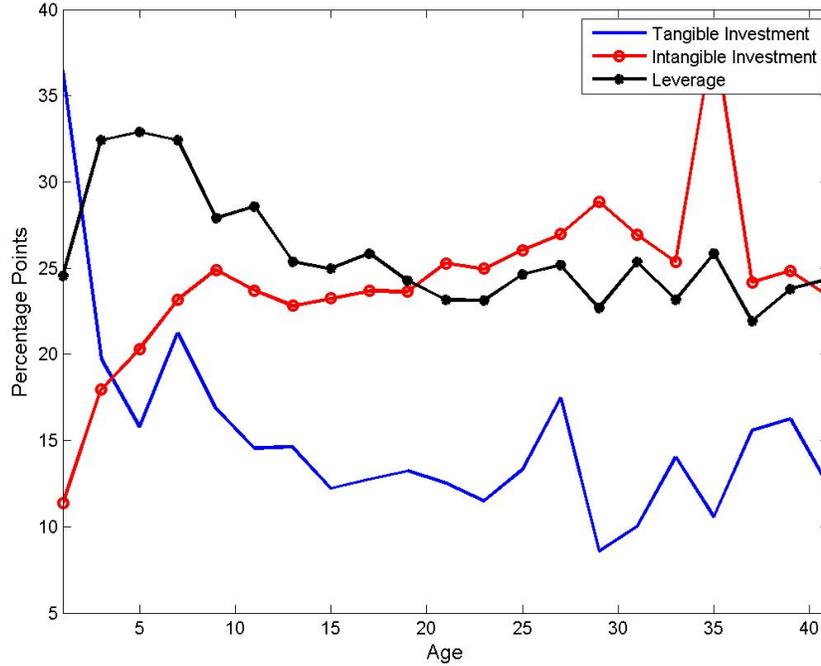
E Non-Targeted Moments

This Section discusses firm-level data moments which are not targeted in the estimation, including the life cycle of tangible and intangible investment and leverage, and the full regression of investment rates on the states of the firm.

Figure 19 replicates Figure 3 in the data. It plots tangible and intangible investment rates and leverage rates as a function of the age of the firm. I average every two years in the

³⁷These are averages across firms in an industry, as opposed to industry aggregates, to avoid that a large firm in an industry drives the results. The positive correlation is also present for industry aggregates.

Figure 19: Firm Life Cycle, Data



Notes: In this Figure, tangible and intangible investment are rates to tangible and intangible capital respectively. Leverage is debt over total assets.

data to minimize the error due to the low number of observations for some firm ages. The data shows the same qualitative patterns as the model, but the intangible investment rate is much lower for very young firms, probably due to lack of reporting of this variable.

Table 6 shows the regression results of tangible and intangible investment rates on the states of the firm, including firm and year fixed effects. Regressors are demeaned, so the constant in the regression reflects the average investment rates. For each regressor, the table shows the slope coefficient and the standard error. Standard errors are clustered at the firm level. It is important to bear in mind that even if one assumes that the model is the true data generating processes, these regressions are not informative about causal relationships because the idiosyncratic shock z is not observable in the data.

Both in the data and in the model, size, leverage and age affect tangible and intangible investment rates negatively. Current tangibility affects tangible investment negatively. Lagged tangible investment has little effect on current tangible and intangible investment in the data, while it does have a positive effect in the model. Lagged intangible investment has a positive effect for both investment rates in the data, while the model only captures the effect on intangible investment.

Table 6: Policy Function Regressions

dep. var.	data		model	
	$\frac{i_k}{k+a}$	$\frac{i_a}{k+a}$	$\frac{i_k}{k+a}$	$\frac{i_a}{k+a}$
const.	11.594	7.093	9.190	8.142
	0.452	0.169	0.054	0.030
$\log(k+a)$	-2.839	-1.282	-3.564	-1.643
	0.534	0.287	0.076	0.041
$\frac{k}{k+a}$	-10.418	-1.159	-15.389	4.184
	5.121	0.596	2.222	1.506
$\frac{b}{k+a}$	-0.063	-0.009	-0.011	-0.016
	0.018	0.005	0.001	0.001
age	-0.637	-0.008	-0.071	-0.039
	0.315	0.088	0.009	0.005
$\left(\frac{i_k}{k+a}\right)_{-1}$	-0.051	-0.011	0.444	0.154
	0.028	0.005	0.034	0.024
$\left(\frac{i_a}{k+a}\right)_{-1}$	0.167	0.250	-0.200	0.213
	0.074	0.039	0.051	0.035

Notes: Including firm and year FE. Standard errors, shown in the second row for each regressor, are block-bootstrapped at the firm level.

F Impact of Parameters on Moment Values

Table 7 includes the Jacobian matrix of the estimation method. Each entry contains the local elasticity of a moment with respect to changes in a parameter. These elasticities are computed numerically with a step size of 0.05 percent on the parameter. Matrix rows contain all the moments used for estimation and matrix columns the parameters. As discussed in Section 5.1, the Jacobian is useful to see how the moments help identify the parameters.

G Computation of Standard Errors

This Section describes the computation of standard errors for the moments and for the parameters.

I compute the variance-covariance matrix for firm-level moments in the data and in the model by block bootstrap with 500 samples. Bootstrap samples are generated with random draws at the firm-level. To compute standard errors for aggregate entry and exit rates, I assume that these two variables follow a joint VAR(1) process. Since the firm-level and aggregate moments come from two separate datasets, for tractability I assume that their cross-covariances are zero, although the presence of aggregate shocks could potentially

Table 7: Jacobian Matrix (Elasticities)

parameter	α	β	δ_k	δ_a	T	γ	ψ_k	ψ_a	η_k	η_a	ρ	θ	b_0	σ
labor costs / value added	-0.2	0.0	0.0	0.0	0.0	0.0	-0.0	-0.0	0.0	0.0	0.0	0.0	0.0	0.3
tangible / fixed assets	8.3	-0.4	8.4	10.5	9.5	2.7	-5.5	-6.3	8.5	10.3	4.1	7.6	4.8	78.7
average $\frac{i_k}{k}$ mature firms	33.3	26.5	26.0	48.1	40.3	45.6	-81.7	-50.0	24.8	9.6	80.3	27.7	46.7	221.3
average $\frac{i_a}{a}$ mature firms	0.4	19.6	-4.2	13.9	5.5	6.8	-14.9	-7.3	3.7	-15.9	19.8	-0.8	3.2	13.3
average entry and exit rates	20.3	-19.4	21.3	12.4	0.2	8.1	-20.6	-12.2	-19.1	38.9	-16.5	22.2	20.1	-136.9
average entry-exit gap	-61.1	703.8	229.2	450.3	316.2	323.9	-63.8	-416.7	485.1	415.0	-75.6	218.2	268.2	851.8
within std. dev. $\frac{i_k}{a+k}$	-20.3	12.0	-51.8	-58.3	-59.4	-56.1	31.0	80.0	-57.4	-39.4	-44.0	-405.9	-59.2	-83.0
within std. dev. $\frac{i_a}{a+k}$	-26.3	15.5	-47.4	-76.2	-62.0	-62.9	36.3	92.7	-68.3	-35.4	-69.5	617.1	-65.7	-108.1
corr. $\frac{i_a}{a}$ and growth in a	449.4	58.1	610.9	-58.0	402.5	444.3	-172.8	-72.6	5.5	-218.0	725.5	186.0	565.1	644.6
relative employment entrants	40.1	-11.7	8.4	18.1	13.7	5.1	-56.3	-2.5	2.9	11.1	56.5	25.5	14.2	231.5
debt issuance high tangibility	62.6	-57.0	-61.4	30.3	-30.5	-51.9	-109.5	70.3	-75.3	-46.1	86.8	64.2	-53.7	644.8
debt issuance low tangibility	-171.2	86.5	-154.9	-4.3	-143.2	-61.5	6.2	83.2	-39.1	-46.1	-39.7	33.3	-78.2	-595.1
slope coeff. $\frac{i_k}{a+k}$ on $\frac{b}{a+k}$ *	-129.2	405.0	-479.7	-660.0	-305.3	-287.8	121.9	456.9	-230.5	-414.6	-274.0	-734.3	-156.8	-237.5
slope coeff. $\frac{i_a}{a+k}$ on $\frac{b}{a+k}$ *	-0.9	263.8	-143.0	-194.8	-111.6	-83.4	18.0	185.1	-93.1	-141.6	-116.5	-1724.0	-58.2	172.3
autocorr. $\frac{i_a}{a+k}$ *	149.4	135.4	21.5	522.9	267.2	250.7	-242.7	-196.1	5.2	226.8	1667.3	-3075.3	234.0	964.7
average leverage	81.6	30.8	43.9	128.8	86.6	44.5	-175.1	-51.2	7.9	44.8	139.5	113.5	50.0	848.3

Notes: Elasticity of each moment with respect to a change in each parameter, computed numerically with a step size of 0.05 percent.

generate a correlation.

The variance-covariance matrix for the parameters is given by

$$(33) \quad \left(H'\Sigma^{-1}H\right)^{-1} + \left(H'\tilde{\Sigma}^{-1}H\right)^{-1},$$

where H is the numerical Jacobian matrix in levels, Σ is the estimated variance-covariance matrix of the moments in the data, and $\tilde{\Sigma}$ is the equivalent of Σ for the model-simulated data. The second term in the summation accounts for the error due to the simulation of one finite sample of observations from the model (see [Gourieroux and Monfort \(1997\)](#)). For parameters whose estimated standard error is smaller than the minimum grid step in the maximization algorithm, I report the grid step as an upper bound for the standard error. This is the case for ψ_k , η_k and θ .

The weighting matrix used to measure the distance between data and model-simulated moments is Σ^{-1} .

H Benchmark Model Parameters

Table 8 shows the estimated parameters for the benchmark model with exogenous investment in intangible capital. The fixed production cost T is larger than in the full model in order to generate enough exit in equilibrium. Then, the entry cost γ and the initial equity of entrants b_0 adjust to keep fitting the entry-exit gap and the size of entrants respectively.

Table 8: Firm-Level Parameters - Benchmark Model

concept	label	value	target(s)
physical capital share	α	0.17	labor costs / value added
intangible share	β	0.21	tangible / fixed assets
depreciation tangibles	δ_k	0.08	$\frac{i_k}{k}$ mature firms
depreciation intangibles	δ_a	0.14	$\frac{i_a}{a}$ mature firms
fixed cost	T	0.17	average entry and exit rates
entry cost	γ	0.10	average entry-exit gap
recovery creditor tang.	ψ_k	0.60	leverage, debt issuance tang., slope $(\frac{i_k}{a+k}, \frac{b}{a+k})$
recovery creditor intan.	ψ_a	0.15	leverage, debt issuance intan., slope $(\frac{i_a}{a+k}, \frac{b}{a+k})$
adj. cost tangibles	η_k	0.09	within std. dev. $\frac{i_k}{a+k}$
adj. cost intangibles	η_a	0.20	within std. dev. $\frac{i_a}{a+k}$
autocorr. shock	ρ	0.08	autocorr. $\frac{i_a}{a+k}$
std. dev. shock	θ	1.00	corr. $\frac{i_a}{a}$ and growth in a
entrants net debt	b_0	-0.80	relative employment entrants
elasticity of subs. varieties	σ	4	calibrated

The simulation of the model without intangible capital spillovers does not lead to visible changes in the moments compared to the full model, so for this intermediate model I keep the full-model parameters (listed in Table 2). The largest differences between these two models appear in the recovery period (after 2013), which is not captured in the data.

I Results under Flexible Wages

The acyclicity of wages observed in the Spanish manufacturing sector is one of the main reasons why aggregate shocks lead to large fluctuations in output. Table 9 contains the GDP change decomposition for a model where wages are allowed to adjust in recessions. In particular, I assume that wages respond by an amount such that labor is unaffected by exogenous shocks. This is, movements in labor are driven exclusively by changes in the other production factors. We can see from the labor optimality condition (19) that this is equivalent to setting $W(M) = (D(M))^{\frac{1}{\sigma}}$. Comparing Table 9 to the results from the full model in Table 4, in general the contributions of all channels are diminished when wages adjust more. It is still the case that labor is the variable contributing to the largest share, so this result in the full model is not entirely explained by wage rigidities. To keep fitting average exit rates when wages are more flexible, the estimation algorithm leads to a higher fixed production cost T . This leads to the result that entrants, which start small and face a higher relative fixed cost, are more affected by the Great Recession than in the model with rigid wages.

Table 9: GDP Change Decomposition - Flexible Wages

decomposition	2008-13	2008-18
global income	-2.0	0.0
physical cap.	-0.5	-0.3
priv. intan. cap.	-1.1	-0.3
publ. intan. cap.	-0.1	-0.2
labor	-4.8	-1.6
alloc. efficiency	-1.1	-0.2
entrants	-4.8	0.2
incumbents	-3.4	-2.5
exiters	-1.7	-0.8
total	-9.5	-2.4