Macroeconomic Dynamics (2023), **27**, pp. 1455–1480
doi:10.1017/S136510052200030X

CAMBRIDGE UNIVERSITY PRESS

ARTICLE

Financial shocks and the relative dynamics of tangible and intangible investment: Evidence from the euro area†

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Abstract
We develop an extended real business cycle model with financially constrained firms and non-pledgeable intangible capital. Based on a model-consistent series for firms' borrowing conditions, we find, within a structural vector autoregression framework, that, in response to an adverse financial shock, tangible investment falls more than intangible investment. This positive co-movement between tangible and intangible investment as well as the relative resilience of intangible investment pose a challenge for the theoretical model. We show that investment-specific adjustment costs help in reconciling the model with the observed empirical evidence. The estimation of the theoretical model using a Bayesian limited information approach yields support for the presence of much larger adjustment costs for intangible investment than for tangible investment.

Keywords: Tangible investment; intangible investment; financial shocks

1. Introduction

Since the Great Recession of 2008–2009, research using dynamic stochastic general equilibrium (DSGE) models has been devoted to studying the macroeconomic effects of financial shocks. Such work shows that this type of disturbance generates fluctuations in real macroeconomic variables.[1] In this paper, we focus on the effects of financial shocks on the relative dynamics of tangible and intangible investment. An inspection of the data suggests that adverse financial shocks lead firms to cut back more on tangible investment than on intangible investment. Figure 1 displays the business cycle components of tangible and intangible investment as a whole in the four largest euro area countries, as derived from Eurostat's national accounts data. We measure tangible investment as machinery and equipment investment plus nonresidential construction investment. Intangible investment is measured as investments in intellectual property products, which, according to the current accounting standard, cover expenditures on research and development (R&D), mineral exploration and evaluation, computer software and databases, entertainment, literary, and artistic originals.[2] Focusing on the period of the Great Recession, when borrowing conditions for firms in the euro area's big four economies deteriorated considerably (see, e.g. Gilchrist and Mojon (2018)), we can make two observations: First, both tangible investment and intangible investment fell below their trends. Second, intangible investment registered only a small decline, while tangible investment showed a marked drop. Note that these observations also hold for alternative

† The views expressed in this paper are those of the author(s) and do not necessarily reflect the views of the Deutsche Bundesbank or the Eurosystem.

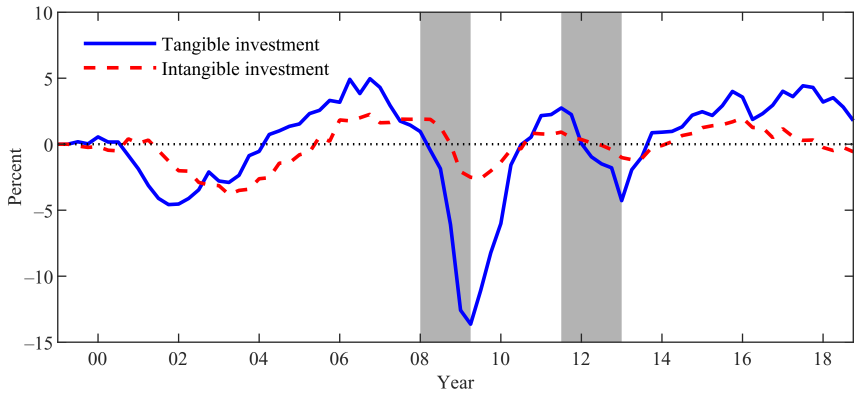

Figure 1. Tangible and intangible investment.

Note: The figure displays tangible and intangible investment in the four largest euro area countries as a whole, as derived from Eurostat's national accounts data. Tangible investment is measured as machinery and equipment investment plus non-residential construction investment. Intangible investment is investment in intellectual property products. All data are seasonally adjusted, expressed in real terms and detrended in logs with a one-sided HP filter using a smoothing parameter of $\lambda = 1600$. The shaded areas indicate Center for Economic Policy Research (CEPR) recession dates for the euro area as a whole.

detrending methods.[3] Furthermore, they are consistent with the findings of Corrado et al. (2018) for European countries and the US based on annual data from the INTAN-Invest database.[4]

To explore the effects of financial shocks on tangible and intangible investment, we use a modified version of the Jermann and Quadrini (2012) model. This model is a real business cycle (RBC) model augmented by financially constrained firms and financial shocks. In this economy, firms use equity and intertemporal debt. Furthermore, they raise funds with interest-free intraperiod loans to finance working capital. Since firms cannot commit to repaying these loans, they face a borrowing constraint. This constraint is subject to stochastic disturbances, that is, financial shocks. In Jermann and Quadrini's model, firms hire labor from households and hold productive capital, which can be pledged as collateral in debt contracts. A negative financial shock lowers the amount that the firm can borrow and so the firm reduces labor and investment in response to the shock. Here, we distinguish between two different types of productive capital, namely tangible and intangible capital. These two types of capital are assumed to differ in several dimensions. Most importantly, given the limited collateralizability of intangible capital, we assume in our baseline specification that only tangible capital is pledgeable as collateral in debt contracts (see also Lopez and Olivella (2018) and Bianchi et al. (2019)). Working within this modeling framework, we show that, in response to an adverse financial shock, it is optimal for firms to shift resources toward pledgeable tangible capital and away from nonpledgeable intangible capital in order to mitigate the tightening of financial conditions.[5] Firms achieve this by sharply reducing intangible investment and increasing tangible investment after the shock is realized. Hence, tangible investment and intangible investment co-move negatively in the aftermath of a financial shock. One possible explanation for the negative co-movement between the two investment types is that it incurs no costs for firms to adjust tangible and intangible capital. We therefore add adjustment costs in the accumulation process for tangible and intangible capital and study the model dynamics.[6] We show that the presence of investment adjustment costs can alter the firm's incentives such that the firm reduces tangible investment along with intangible investment. Intuitively, if intangible investment is much more costly to adjust than tangible investment, the firm chooses to reduce tangible investment to a larger extent than intangible investment. As a result, in response to a negative financial shock, the model generates a positive co-movement between tangible and intangible investment as well as a rise in the intangible/tangible investment ratio, that is, intangible investment declines by less than tangible investment does. We are not the only ones to stress

https://doi.org/10.1017/S136510052200030X Published online by Cambridge University Press

that intangible investment has higher adjustment costs than tangible investment. For example, Chiavari and Sampreet (2021) also find higher adjustment costs for intangible investment relative to tangible investment by estimating production functions based on data on publicly traded US firms from Compustat. A number of papers have highlighted other, not mutually exclusive, mechanisms operating alongside adjustment costs that also make intangible investment more resilient to shocks. Crouzet and Eberly (2019) point out that high depreciation rates on intangible capital goods attenuate the response to a monetary policy shock because high depreciation rates dominate the user cost of capital. Döttling and Ratnovski (2020) present panel estimates to identified monetary policy shocks that are consistent with this view. It is reasonable to asssume that this mechanism, which is effective for a monetary policy shock, is also effective for financial shocks. Our model also implies that higher depreciation rates on intangible capital mitigate the decline of intangible investment and potentially solves the co-movement problem between intangible and tangible investment in response to a financial shock. In a related strand of literature, e.g., Falato, et al. (2013), Rampini and Viswanathan (2013) and Caggese and Ander (2020), it is argued that firms that rely heavily on intangible investments anticipate future financial constraints and hoard cash as a buffer stock. This is an additional mechanism that explains why firms with high shares of intangible investment are less responsive to shocks. The view that intangible intensive firms hold more cash is also well documented in the finance literature, see Bates et al. (2009).[7] In our model, we also provide evidence that an increasing share of intangible capital reduces the debt capacity of firms and makes them more vulnerable to shocks in borrowing constraints due to a lack of alternative sources of financing. Moreover, it is argued in the literature that payment schemes for highly skilled workers that are deferred to a later stage and therefore do not need to be financed by intra-period loans are an additional mechanism that makes intangible investment less sensitive to financial shocks.[8]

As for the broader empirical analysis of this paper, we use quarterly national and financial accounts data from Eurostat and the ECB. We focus on aggregated data for the big four euro area countries due to limited data availability and quality for the euro area as a whole.[9] Following Jermann and Quadrini (2012), we initially use the Solow residual approach to recover a model-consistent series for aggregate financial market conditions from the theoretical model. After we show that this series tracks reasonably well alternative indicators for proxying the degree of borrowing constraints for firms in the euro area big four, we include the constructed series in a structural vector autoregression (SVAR) and examine the effects of identified financial shocks on real economic quantities, notably tangible and intangible investment. We identify financial shocks by applying a recursive identification scheme (see, e.g. Gilchrist and Zakrajsek (2012)). That is, we assume that shocks to the financial conditions variable affect real economy variables only with a time lag, while shocks to real economy variables impact the financial conditions variable contemporaneously. Our results suggest that financial shocks lead to economically meaningful and statistically significant declines in aggregate economic activity, household consumption, tangible investment, and intangible investment. Importantly, we find that tangible and intangible investment co-move positively and that intangible investment proves to be much more resilient to financial shocks than tangible investment is. To our knowledge, this is the first paper to empirically investigate the relative dynamics of tangible and intangible investment in response to financial shocks within a SVAR framework.

Equipped with empirical impulse response functions, we finally estimate the theoretical model using the Bayesian impulse response estimation procedure developed in Christiano et al. (2010). The estimation results suggest that adjustment costs for intangible investment are much larger than those for tangible investment. This finding is consistent with results reported in Peters and Taylor (2017) and Chiavari and Sampreet (2021). In this literature, it is argued that intangible capital has relatively large adjustment costs because adjusting intangible capital requires firms to adjust the number of high-skilled workers (see, e.g. Brown et al. (2009)). Our work shows that the relatively high adjustment costs for intangible investment have major implications for the relative dynamics of tangible and intangible investment in response to financial shocks. When confronted with an unexpected tightening in borrowing conditions, firms attempt to maintain intangible investment by reducing tangible investment in order to minimize adjustment costs. Hence, intangible investment reacts less strongly to financial shocks than tangible investment does. Turning to the comparison between the empirical and the model-implied impulse response functions, we show that the model replicates well the observed transmission of an adverse financial shock based on the SVAR. The theoretical model accounts for the reduction in aggregate economic activity, household consumption, tangible investment, and intangible investment. Importantly, the model predicts a fall in tangible and intangible investment, although intangible investment declines much less than tangible investment.

The effects of financial shocks on tangible and intangible investment have been receiving attention in the literature using DSGE models. Lopez and Olivella (2018) study the role of intangible capital in the transmission of financial shocks using an RBC model with financial and labor market frictions but without costly capital accumulation. Bianchi et al. (2019) analyze the transmission of various types of financial shocks in the US economy through the lens of an estimated DSGE model which features endogenous growth and investment-specific adjustment costs. One key contribution made by our paper to this literature is to isolate the implications of the presence of investment-specific adjustment costs for the relative dynamics of tangible and intangible investment in response to financial shocks. Our model shares with Lopez and Olivella (2018) and Bianchi et al. (2019) the assumption that firms' borrowing is constrained and that intangible capital cannot be pledged as collateral in debt contracts.

The paper is organized as follows. Section 2 describes the theoretical model and discusses its dynamic behavior. Section 3 presents empirical evidence on the macroeconomic consequences of identified financial shocks. Section 4 estimates the theoretical model. Section 5 presents counterfactuals for the Great Recession. Section 6 concludes.

2. The model economy

In this section, we formally describe the theoretical framework and discuss the main mechanisms at work. Our model is a RBC model augmented by financially constrained firms and intangible capital. Intangible capital enters the production function as a third input factor, along with tangible capital and labor (see, e.g. McGrattan and Prescott (2010), Malik et al. (2014) and Lopez and Olivella (2018)). The financial structure is modeled following Jermann and Quadrini (2012). The assumption that intangible capital — unlike tangible capital — cannot be used as collateral in debt contracts is borrowed from Lopez and Olivella (2018) and Bianchi et al. (2019). The notion that intangible capital is less easy to pledge as collateral in debt contracts is supported by theoretical arguments (see, e.g. Shleifer and Vishny (1992)) and empirical work (see, e.g. Sibilkov (2009)). There is also literature that argues that firms primarily rely on internal funds to finance intangible assets (see, e.g. Falato et al. (2013)). The difficulty of using intangible capital as collateral in debt contracts stems from the fact that intangible investments are typically riskier, more firm-specific and less transferable than tangible investments. However, Loumioti (2012) shows that some intangible assets, such as patents, might have a limited collateral value. Our model also allows for a limited collateral value of intangibles to check robustness. In our baseline specification, however, we assume that intangible capital cannot be used as collateral at all in order to simplify the analysis in the sense that the role of tangible and intangible capital in firms' borrowing conditions is clearly defined, which helps to isolate the key mechanisms at work. We model investment adjustment costs following the standard modeling approach of Christiano et al. (2005). On the household side, we follow Smets and Wouters (2003) and assume external consumption habits, which are useful empirically to account for the persistence in the household's consumption process and thus also in output. The model consists of a representative firm and a representative household. The time period is in quarters.

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2.1 The representative firm

The representative firm produces final goods, Y_t, by combining tangible capital, $K_{T,t}$, with intangible capital, $K_{I,t}$, and labor, N_t. The production technology is given by the following three-factor Cobb—Douglas production function:

$$Y_t = K_{T,t}^{\alpha_{K_T}} K_{I,t}^{\alpha_{K_I}} N_t^{1-\alpha_{K_T}-\alpha_{K_I}}. \tag{1}$$

The firm hires labor from households and owns tangible and intangible capital. The law of motion of capital of type j is

$$K_{j,t+1} = (1-\delta_j)K_{j,t} + \left[1 - \Phi_j\left(\frac{I_{j,t}}{I_{j,t-1}}\right)\right] I_{j,t}, \quad \text{for} \quad j = T, I, \tag{2}$$

where $I_{j,t}$ is the time t investment, δ_j is the depreciation rate, and $\Phi_j(\cdot)$ is the adjustment cost function, which is a positive convex function of the change in investment. The functional form for $\Phi_j(\cdot)$ reads:

$$\Phi_j\left(\frac{I_{j,t}}{I_{j,t-1}}\right) = \frac{\phi_j}{2}\left(\frac{I_{j,t}}{I_{j,t-1}} - 1\right)^2, \quad \text{for} \quad j = T, I, \tag{3}$$

where ϕ_j is the parameter that characterizes the size of the adjustment costs for investment of type j. Note that $\Phi_j(\cdot)$ satisfies the following properties: $\Phi_j(1) = \Phi_j'(1) = 0$ and $\Phi_j^{''}(1) = \phi_j \geq 0$. When $\phi_T = \phi_I = 0$, the model economy is equivalent to one without costly capital accumulation.

As in Jermann and Quadrini (2012), we assume that firms use two broad categories of financing: equity and debt. Debt is preferred to equity because interest expenses are deductible (see also Hennessy and Whited (2005)). The effective gross interest rate for the firm is given by $R_t = 1 + r_t(1-\tau)$, where r_t is the interest rate on one-period intertemporal debt, B_t, and τ is the tax benefit. The firm raises funds with interest-free intraperiod loans, L_t, to finance working capital. This loan, which is repaied at the end of the period t, is defined as

$$L_t = W_t N_t + I_{T,t} + I_{I,t} + B_t - \frac{B_{t+1}}{R_t} + \varphi(D_t), \tag{4}$$

where W_t is the wage rate and $\varphi(D_t)$ are total equity payout costs. The latter comprise the actual equity payout and equity payout adjustment costs, which account for the empirical regularity with which firm managers tend to smooth dividend payments (see, for example, Lintner (1956) and Brav, et al. (2005)). The functional form for $\varphi(D_t)$ is given by

$$\varphi(D_t) = D_t + \kappa(D_t - D)^2, \tag{5}$$

where the parameter $\kappa > 0$ determines the sensitivity of the equity payout adjustment costs to the actual equity payout, D_t, and D denotes the steady state level of D_t. The firm's flow of funds constraint is

$$W_t N_t + I_{T,t} + I_{I,t} + B_t + \varphi(D_t) = \frac{B_{t+1}}{R_t} + Y_t. \tag{6}$$

Substituting equation (4) into equation (6), it is possible to verify that the intraperiod loan is equal to the firm's production (i.e. $L_t = Y_t$).

Following closely Jermann and Quadrini (2012), we assume that firms' debt capacity is limited due to a limited enforceability of debt contracts, as firms can default on their obligations. Crucial to understand the financial contract is the assumption that the firm has all the bargaining power in the renegotiation and that the lender receives only the threat value. More specifically, it is assumed that liquidity can be easily diverted and the lender can only expropriate capital. At any time t, a default may materialize after the realization of revenues but before the redemption of the intraperiod loan. At the time of default, the firm's total liabilities are $L_t + \frac{B_{t+1}}{1+r_t}$ and the only assets available for liquidation are tangible capital and a fraction λ_I of intangible capital. As in Jermann and Quadrini (2012), we assume that, at the moment of contracting the loan, the liquidation value of capital is uncertain and with probability χ_t the lender is able to recover the full value of tangible capital, whereas with probability $1 - \chi_t$ the lender recovers zero. When the condition occurs in which capital has a positive liquidation value, the firm offers a payment of $K_{T,t+1} + \lambda_I K_{I,t+1} - B_{t+1}/(1 + r_t)$ in period t and promises to pay B_{t+1} tomorrow to make the lender indifferent. If capital has a liquidation value of zero, the firm does not need to make a payment in period t, as the lender has no claims to settle. Based on the anticipated outcome of the renegotiation process between the firm and the lender, we derive the following borrowing constraint for the firm:[10]

$$L_t \leq \chi_t \left(K_{T,t+1} + \lambda_I K_{I,t+1} - \frac{B_{t+1}}{1 + r_t} \right). \tag{7}$$

The parameter λ_I, with $0 \leq \lambda_I \leq 1$ reflects the limited collateral value of intangible capital.[11] Equation (7) implies that the maximum amount of the intratemporal loan available to the firm is tied to the value of tangible capital and a limited value of intangible capital net of intertemporal debt. Hence, it is implicitly assumed that firms can also not commit to repay interperiod debt. As in Jermann and Quadrini (2012), we conjecture that the borrowing constraint is always satisfied with equality.[12] Using $L_t = Y_t$, we can thus rewrite equation (7) as

$$Y_t = \chi_t \left(K_{T,t+1} + \lambda_I K_{I,t+1} - \frac{B_{t+1}}{1 + r_t} \right). \tag{8}$$

Note that, throughout the paper, we refer to χ_t as the financial conditions variable. Similar to Jermann and Quadrini (2012), this variable is assumed to depend on (unspecified) financial market conditions and is subject to stochastic disturbances, that is, financial shocks.

The optimization problem of the firm is to maximize the expected present value of the future equity payouts, which is given by

$$E_{t-1} \sum_{s=0}^{\infty} \beta^s \frac{U_{C,t+s}}{U_{C,t}} (D_{t+s}), \tag{9}$$

where β is the household's discount factor, $U_{C,t}$ is the household's marginal utility of consumption, and E_{t-1} is the expectation operator conditional on information available in period $t - 1$.[13] The firm chooses $\{D_t, Y_t, K_{T,t+1}, K_{I,t+1}, I_{T,t}, I_{I,t}, N_t, B_{t+1}\}$ to maximize (9) subject to equations (1), (2), (6), and (8). Denoting by μ_t the multiplier for the borrowing constraint, we can summarize the first-order conditions for the firm's optimization problem as follows:

Debt:

$$1 = \beta R_t E_{t-1} \left(\frac{U_{C,t+1}}{U_{C,t}} \frac{\varphi'(D_t)}{\varphi'(D_{t+1})} \right) + \chi_t \mu_t \varphi'(D_t) \frac{R_t}{1 + r_t}, \tag{10}$$

Labor:

$$\frac{\partial Y_t}{\partial N_t} = \frac{W_t}{1 - \mu_t \varphi'(D_t)}, \tag{11}$$

Tangible capital:

$$\begin{aligned} Q_{T,t} = \beta E_{t-1} \left(\frac{U_{C,t+1}}{U_{C,t}} \frac{\varphi'(D_t)}{\varphi'(D_{t+1})} \left[\frac{\partial Y_{t+1}}{\partial K_{T,t+1}} \left(1 - \mu_{t+1} \varphi'(D_{t+1})\right) + Q_{T,t+1}(1 - \delta_T) \right] \right) \\ + \chi_t \mu_t \varphi'(D_t), \end{aligned} \tag{12}$$

Intangible capital:

$$Q_{I,t} = \beta E_{t-1}\left(\frac{U_{C,t+1}}{U_{C,t}}\frac{\varphi'(D_t)}{\varphi'(D_{t+1})}\left[\frac{\partial Y_{t+1}}{\partial K_{I,t+1}}\left(1-\mu_{t+1}\varphi'(D_{t+1})\right)+Q_{I,t+1}(1-\delta_I)\right]\right)$$
$$+\chi_t\lambda_I\mu_t\varphi'(D_t), \tag{13}$$

Tangible and intangible investment:

$$Q_{j,t} = \frac{1-\beta E_{t-1}\left(\frac{U_{C,t+1}}{U_{C,t}}\frac{\varphi'(D_t)}{\varphi'(D_{t+1})}Q_{j,t+1}\Phi_j'\left(\frac{I_{j,t+1}}{I_{j,t}}\right)\left(\frac{I_{j,t+1}}{I_{j,t}}\right)^2\right)}{1-\Phi_j\left(\frac{I_{j,t}}{I_{j,t-1}}\right)-\Phi_j'\left(\frac{I_{j,t}}{I_{j,t-1}}\right)\left(\frac{I_{j,t}}{I_{j,t-1}}\right)}, \quad \text{for} \quad j=T,I, \tag{14}$$

where $\frac{\partial Y_t}{\partial N_t}$ is the marginal productivity of labor, $\frac{\partial Y_{t+1}}{\partial K_{T,t+1}}$ and $\frac{\partial Y_{t+1}}{\partial K_{I,t+1}}$ are the future returns on tangible capital and intangible capital, respectively. $Q_{j,t}$ denotes the current value of type-j capital, and $\varphi'(D_t)$ is the first derivative of $\varphi(D_t)$ with respect to D_t.[14] Equation (10) is the optimally condition for intertemporal debt. It implies that a negative financial shock induces a rise in the multiplier for the borrowing constraint. Equation (11) is the optimally condition for labor demand that requires the firm to equate the marginal productivity of labor to its marginal cost. The marginal cost of labor depends negatively on μ_t. A higher μ_t (i.e. a tighter borrowing constraint in period t) increases the effective costs of labor and thus reduces its demand. Equations (12) and (13) are the optimally conditions for tangible capital and intangible capital, respectively. Note that the financial shock χ_t operates through opposing transmission channels in equilibrium on the value of tangible capital $Q_{T,t}$. On the one hand, an adverse shock reduces the value of tangible capital and thus the available amount of intra-period loans. This is the direct effect of the shock to the borrowing constraint in equation (7). On the other hand, there exists an opposing indirect transmission channel operating through μ_t. Concretely, the current value of tangible capital, $Q_{T,t}$, depends positively on μ_t and negatively on μ_{t+1}. The higher μ_t, the higher the benefit of acquiring today an additional unit of tangible capital, which allows, by relaxing the borrowing constraint, to increase the current production. Hence, when μ_t rises, the firm demands more tangible capital. Since intangible capital cannot be pledged as collateral in debt contracts when $\lambda_I = 0$, μ_t has no direct impact on the current value of intangible capital, $Q_{I,t}$. Similar to tangible capital, intangible capital also depends negatively on μ_{t+1}. A higher μ_{t+1} (i.e. a tighter borrowing constraint in period $t+1$), decreases the current value of an additional unit of tangible capital, respectively, intangible capital, as the additional capital requires a higher working capital loan in the future. Thus, a higher μ_{t+1} reduces the demand for both tangible capital and intangible capital. Equation (14) is the Euler equation for investment in capital of type j. Note that when $\phi_T = \phi_I = 0$, it follows that $Q_{T,t} = Q_{I,t} = 1$.

2.2 The representative household

The representative household maximizes its expected lifetime utility, which reads:

$$E_{t-1}\sum_{s=0}^{\infty}\beta^s U_{t+s}(C_{t+s}, N_{t+s}), \tag{15}$$

where β denotes the household's discount factor, C_t is the consumption, and N_t stands for labor supply. The period utility function is defined as

$$U_t = \log(C_t - \epsilon C_{t-1}) + \nu\log(1-N_t). \tag{16}$$

Following Smets and Wouters (2003), we assume external habit formation in consumption, with ϵ measuring the influence of past economy-wide average consumption on current utility.

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The household's budget constraint is

$$C_t + \frac{B_{t+1}}{1+r_t} + T_t = B_t + W_t N_t + D_t, \tag{17}$$

where W_t denotes the wage rate, D_t is the equity payout, B_{t+1} stands for the new one-period intertemporal bond issued by the firm, r_t is the interest rate, and $T_t = \frac{B_{t+1}}{R_t} - \frac{B_{t+1}}{1+r_t}$ is a lump-sum tax, which is equal to the firm's tax benefit of debt.

The household chooses $\{C_t, N_t, B_{t+1}\}$ to maximize (15) subject to equation (17). The first-order conditions for the household's optimization problem are given by

$$\beta(1+r_t)E_{t-1}\left(\frac{U_{C,t+1}}{U_{C,t}}\right) = 1, \tag{18}$$

$$U_{N,t} + U_{C,t} W_t = 0 \tag{19}$$

where $U_{C,t} \equiv \frac{\partial U_t}{\partial C_t}$ is the marginal utility of consumption and $U_{N,t} \equiv \frac{\partial U_t}{\partial N_t}$ is the marginal utility of labor supply.

2.3 Discussion

In this section, we discuss the main mechanisms at work. To this end, we show in Figure 2 impulse response functions of selected model variables to a negative one standard deviation financial shock.[15] The solid lines correspond to the responses when we hold the key model parameters at their calibrated or estimated values (see Section 4), implying, most importantly, that intangible investment is much more costly to adjust than tangible investment. The dashed lines in Figure 2 correspond to the responses for an alternative setting of the investment adjustment cost parameters, where we set $\phi_T = \phi_I = 0$ so that the model economy is equivalent to one without costly capital accumulation.

We first discuss the model-implied responses for the latter case. As is evident from the figure, a negative financial shock reduces the available amount of liabilities to finance the firm's operations, which illustrates the direct effect of tighter financial conditions. In response, the firm reacts by reducing the equity payout. Since it is costly for the firm to change the equity payout, the firm is also forced to reduce labor. Overall, the direct effect from the borrowing constraint dominates, as output, labor, liabilities, intangible investment, and the equity payout decline. However, the indirect effect of the shock operating through an increase in the multiplier μ_t dominates on impact for the response of tangible investment. Interestingly, the firm increases tangible investment and sharply reduces intangible investment in response to the shock. The reason for this is that the tighter borrowing constraint leads the firm to reallocate resources toward pledgeable tangible capital and away from nonpledgeable intangible capital in order to mitigate the tightening of financial conditions. The firm achieves this by sharply reducing intangible investment and increasing tangible investment after the shock is realized. Hence, tangible investment and intangible investment co-move negatively in the aftermath of the financial shock.[16] This finding illustrates that the financial shock operates through two opposing transmission channels on the relative attractiveness of tangible capital. On the one hand, the direct borrowing constraint channel reduces the attractiveness of tangible investment as a marginal unit of tangible investment has a smaller relieving effect on the collateral constraint. On the other hand, the current value of tangible capital, $Q_{T,t}$, depends positively on μ_t. The higher μ_t, the higher the benefit of acquiring today an additional unit of tangible capital, which allows, by relaxing the borrowing constraint, to increase the current production. To illustrate the quantitative importance of the direct effect from the tighter borrowing constraint for tangible investment, we shut down the multiplier channel μ_t on the value of tangible capital, $Q_{T,t}$. To do so, we simulate the model by fixing the multiplier μ_t in equation (12) at its steady-state value to prevent that an increase in the multiplier makes tangible

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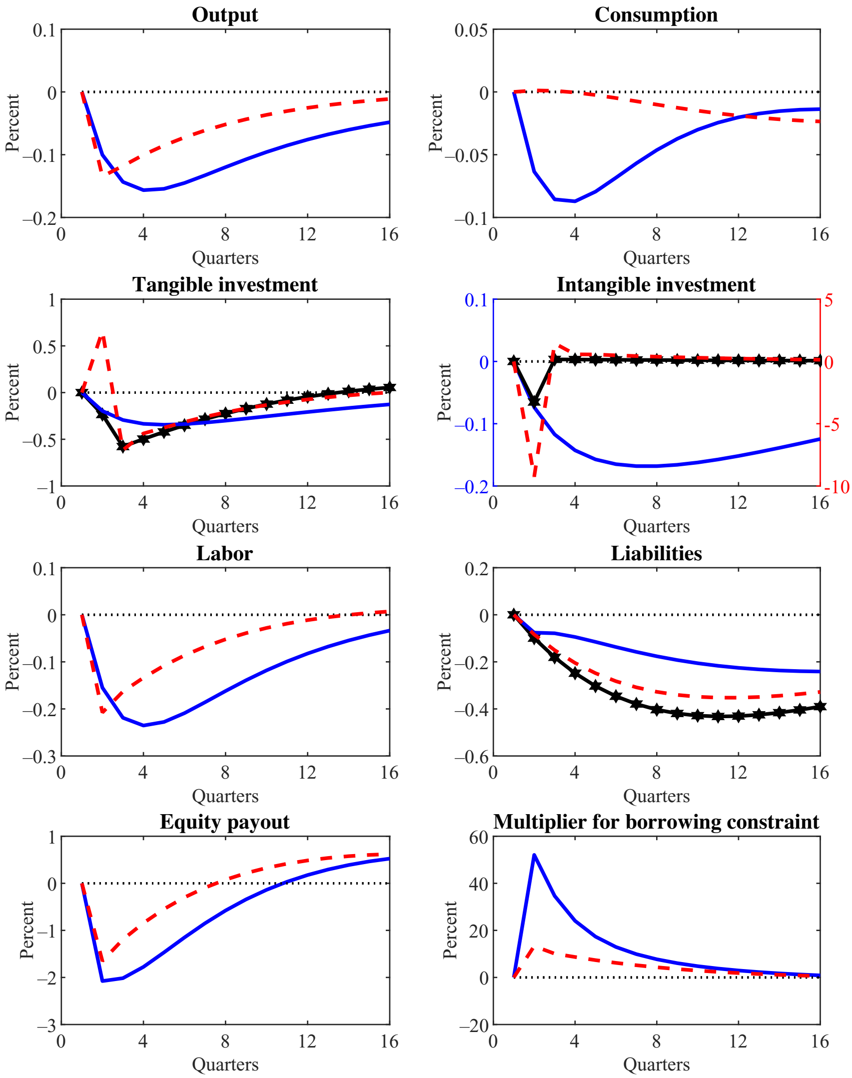

Figure 2. Impulse response functions of selected model variables.
Note: The figure displays impulse responses to a negative one standard deviation financial shock. The solid lines correspond to the responses when we hold the model parameters at their calibrated or estimated values, implying, most importantly, that intangible investment is much more costly to adjust than tangible investment. The dashed lines correspond to the responses of a model economy without investment adjustment costs. The marked solid lines correspond to a model economy without investment adjustment costs when we shut down the endogenous feedback of a tightening in μ_t on the value of tangible capital, $Q_{T,t}$. Note that the dashed line and the marked solid line in the subplot for *Intangible investment* correspond to the scale of the y-axis on the right-hand side.

investment more attractive. The solid marked lines illustrate that, once the multiplier effect on the value of tangibles $Q_{T,t}$ is shut down, both types of investment decline on impact as the incentive to increase tangible investment disappears. Overall, in equilibrium, the distance between the dashed and the solid marked lines illustrates the importance of the increase of the multiplier μ_t for the case with no adjustment cost in dominating the direct effect of the borrowing constraint on impact for tangible investment.

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One possible explanation for the negative co-movement between the two investment types in response to the financial shock is that it involves no cost for the firm to adjust tangible and intangible capital. The crucial role played by the presence of investment adjustment costs in the relative dynamics of tangible and intangible investment in the aftermath of a financial shock becomes evident from the solid lines in Figure 2. As can be seen, the tighter borrowing constraint forces the firm to reduce all productions inputs, which is reflected in the fall in labor as well as in tangible and intangible investment. In the presence of investment adjustment costs, it is costly for the firm to change tangible and intangible investment and, therefore, the firm is forced to cut tangible investment along with intangible investment. Intuitively, when intangible investment is much more costly to adjust than tangible investment is, the firm reduces tangible investment to a larger extent than intangible investment in order to minimize adjustment costs. Hence, the model generates a positive co-movement between tangible and intangible investment in the aftermath of the shock, with intangible investment declining much less than tangible investment.

In Figure 3, we take a closer look at the role of the relative size of the adjustment costs for tangible and intangible investment and also discuss the role of depreciation rates and the collateral value of intangible capital. To do so, we display in the figure the response of the intangible/tangible investment ratio in the left-hand side panels along with the responses of tangible and intangible investment in the right-hand side panels. The responses of tangible and intangible investment on the right correspond to the dashed-dotted lines on the left (representing the most favorable calibration of model parameters in terms of solving the co-movement problem), except in the first row where they correspond to the solid line. As the figure illustrates in the first row on the left-hand side, when tangible investment is equally costly to adjust as intangible investment is (i.e. $\phi_T = \phi_I = 9$), the firm still reduces intangible investment by more than tangible investment so that the intangible/tangible investment ratio declines (dashed line). In this case, the firm is indifferent, in terms of minimizing adjustment costs, between reducing tangible or intangible investment. Thus, the larger decline in intangible investment than in tangible investment is due to the positive impact of the tighter borrowing constraint on the firm's demand for tangible investment. However, at some point, when the adjustment costs for intangible investment are much higher than those for tangible investment (i.e. $\phi_T = 2, \phi_I = 9$), the costs of reducing intangible investment to maintain tangible investment outweigh the benefits. On the one hand, the tightening of the borrowing constraint leads the firm to tilt resources toward pledgeable tangible capital at the expense of nonpledgeable intangible capital. On the other hand, the relatively high adjustment costs for intangible investment forces the firm to maintain intangible investment by reducing tangible investment. On balance, when adjustment costs for intangible investment are sufficiently larger than those for tangible investment, the firm reduces tangible investment by more than it reduces intangible investment so that the intangible/tangible investment ratio increases. The panel on the right-hand side in the first row illustrates that the impulse responses for $\phi_T = 2$ and $\phi_I = 9$ supports two prominent features of the data in response to a shock to the borrowing constraint. First, intangible investment is more resilient to shocks to the collateral constraint than intangible investment. Second, there is a positive co-movement between the impulses of tangibles and intangibles investment. Moreover, investment adjustment costs lead to the typical hump-shaped responses that characterizes the empirical impulse responses.

In the model, tangible and intangible capital differ not only in terms of adjustment costs but also in terms of collateralizability, depreciation rates, and investment-to-output ratios, which we address in the following sensitivity analysis. In the panels in the second row, we set the investment adjustment costs to zero but alter the collateralizability of intangibles with λ_I moving from no collateralbility, $\lambda_I = 0$, to full collateralizability, $\lambda_I = 1$. The right-hand panel in row two illustrates that full collateralizability solves the negative co-movement in the impulse responses of tangible and intangible investment. Nevertheless, the ratio of intangible to tangible investment falls, as shown in the panel on the left. Since the capital share of tangibles is larger than the share of intangibles, firms have an incentive to cut back more on intangible investment to cushion the tightening

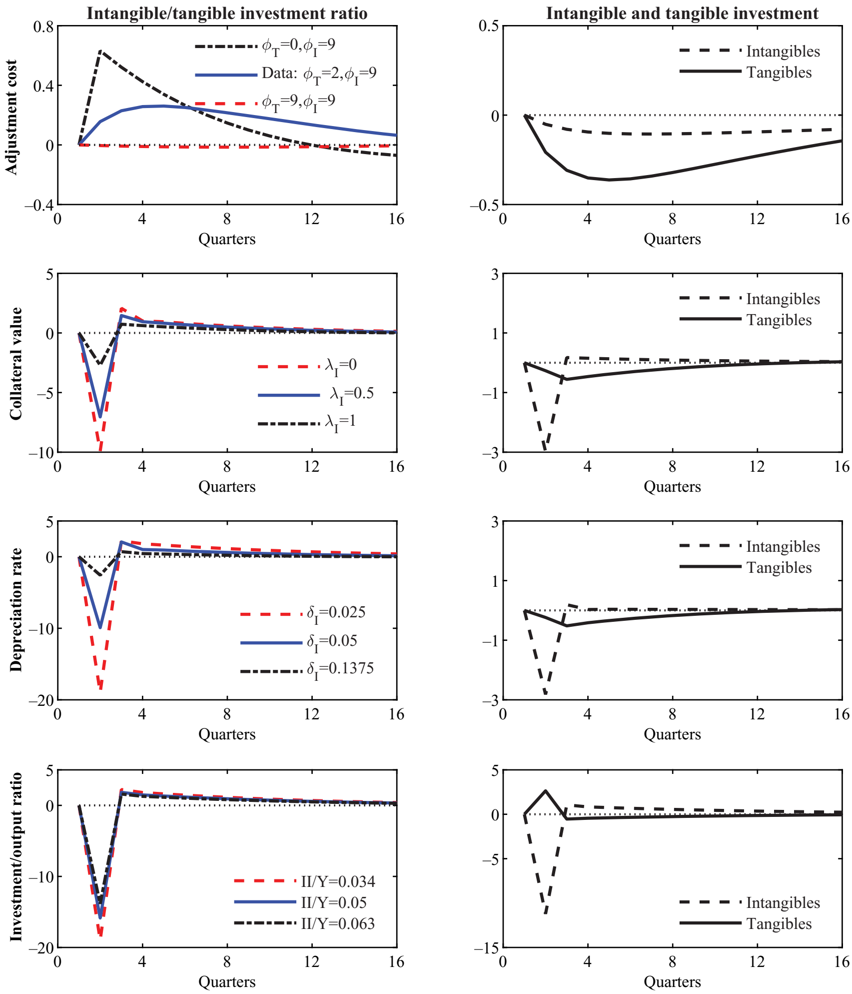

Figure 3. Impulse response functions of the intangible/tangible investment ratio as well as tangible and intangible investment.

Note: The figure displays on the left-hand side the response of the intangible/tangible investment ratio to a negative one standard deviation financial shock based on alternative settings for the investment adjustment cost parameters, the degree of collateralizability, depreciation rates and investment-to-output ratios. In the subplots in the column on the right-hand side, we show the responses for intangible and tangible investment that correspond to the dashed-dotted lines on the left, except in the first row where they correspond to the solid line.

of financial conditions in the face of a shrinking debt capacity. However, this incentive weakens as the collateral value of intangible capital increases. Furthermore, the introduction of collateralizability into the model does not accommodate hump-shaped responses of the impulse responses of tangible and intangible investment. In the panels in the third row, we set the investment adjustment costs to zero and assume that intangible capital is not collateralizable, but let the depreciation rates move from $\delta_I = 0.025$ to $\delta_I = 0.1375$. The impulse responses are shown on the right, and it can be seen that higher depreciation rates solve the co-movement problem in terms of responses of tangible and intangible investment and mitigate the decline in intangible investment. This is in line with the literature that argues that higher depreciation rates for intangibles tend to dominate the user cost of capital and make other factors, such as variations in financial conditions, relatively unimportant (see, e.g. Crouzet and Eberly (2019)). Again, variations in the depreciation rate do

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not lead to hump-shaped responses and do not prevent the investment ratio (left-hand side) from falling, contrary to the data. In the panels in the last row, we illustrate the effects of increasing the intangible investment-to-output ratio from 3.4%, which is the value from the national accounts data, to 6.3%, which is the value for the big four euro area countries when defining intangibles in a broader sense along the lines of Corrado et al. (2018). The impulse response analysis reveals that higher shares of intangible investment do not solve the co-movement problem for the range of values under consideration. The incentive to mitigate financial frictions remains the driving factor in the light of a binding collateral constraint. In sum, the results confirm our main finding within our model that when tangible and intangible investment are not costly to adjust, the intangible/tangible investment ratio falls in response to a negative financial shock.

3. The empirical evidence

In this section, we quantify the macroeconomic consequences of identified financial shocks. To do so, we follow Jermann and Quadrini (2012) and use the Solow residual approach in order to construct the series for the financial conditions variable from the theoretical model. Then, we compare this measure to alternative indicators for proxying the degree of borrowing constraints for firms in the euro area big four. Finally, we introduce the constructed series for the financial conditions variable into a SVAR in order to examine the effects of identified financial shocks on real economic quantities, notably tangible, and intangible investment.

3.1 Financial conditions

As in Jermann and Quadrini (2012), we use the Solow residual approach to recover the series for the financial conditions variable from the model's borrowing constraint. As shown in Section 2, the ability of the firm to borrow is affected by the variable χ_t via equation (8). Rearranging this equation and defining $B^e_t \equiv \frac{B_{t+1}}{1+r_t}$ as the end-of-period t debt as well as $K^e_{T,t} \equiv K_{T,t+1}$ as the end-of-period t stock of tangible capital, we can rewrite χ_t as

$$\chi_t = \frac{Y_t}{K^e_{T,t} - B^e_t}. \tag{20}$$

Log-linearizing equation (20) around the steady state, we obtain

$$\hat{\chi}_t = \chi \frac{B^e}{Y} \hat{B}^e_t - \chi \frac{K^e_T}{Y} \hat{K}^e_{T,t} + \hat{Y}_t, \tag{21}$$

where the variables without a time subscript denote steady-state values and those with a hat sign represent log-deviations from steady-state values. We can use equation (21) to compute the $\hat{\chi}_t$ series once we have empirical measurements for $\hat{B}^e_t$, $\hat{K}^e_{T,t}$, and $\hat{Y}_t$ as well as appropriate values for χ, $\frac{B^e}{Y}$ and $\frac{K^e_T}{Y}$.

To compute the series for $\hat{B}^e_t$, $\hat{K}^e_{T,t}$ and $\hat{Y}_t$, we extract the business cycle components of the empirical series for B^e_t, $K^e_{T,t}$ and Y_t, respectively.[17] For the B^e_t, $K^e_{T,t}$ and Y_t series, we use aggregated quarterly national and financial accounts data from the four largest euro area countries for the period from 1999.Q1 to 2018.Q4. The data are taken from Eurostat and ECB databases. The beginning of our sample is determined by the financial accounts data, which are available as of 1999.Q1. We construct the series for B^e_t using the cumulative sum of new borrowing of non-financial corporations measured by the net flows of debt securities issued and loans received. The initial debt is set to the outstanding stock of debt securities and loans in 1999.Q1.[18] To construct the series for $K^e_{T,t}$, we use the perpetual inventory method based on a geometric depreciation at the constant rate δ_T. Following Jermann and Quadrini (2012), we compute the initial stock of tangible capital so that the tangible capital-to-output ratio fluctuates around a zero growth trend over the period from 1999.Q1 to 2018.Q4.[19] We assume that $\delta_T = 0.025$, which implies an annual depreciation rate of tangible capital of 10%, and iterate forward using the empirical series for tangible investment, which is measured as machinery and equipment investment plus non-residential construction investment. Furthermore, we use total GDP as an empirical proxy for Y_t. All data are seasonally adjusted and expressed in real terms.[20] To pin down χ, $\frac{B^e}{Y}$ and $\frac{K_T^e}{Y}$, we evaluate the model equations described in Section 2 in the steady state. After calibrating the parameters that govern the steady state of the model, we obtain $\chi = 0.13$, $\frac{B^e}{Y} = 3.3$, and $\frac{K_T^e}{Y} = 11$. Note that we provide a detailed description of the model calibration in Section 4.

Next, given the series for $\hat{B}_t^e$, $\hat{K}_{T,t}^e$, and $\hat{Y}_t$ as well as the values for χ, $\frac{B^e}{Y}$, and $\frac{K_T^e}{Y}$, we compute the $\hat{\chi}_t$ series. The results are shown in Figure 4. The solid line in the upper panel depicts the level series of $\hat{\chi}_t$ and the solid line in the lower panel depicts the series of the one-period changes in $\hat{\chi}_t$. As is evident from the figure, the constructed financial conditions variable is pro-cyclical and displays pronounced fluctuations. According to our measure, borrowing conditions for firms in the euro area big four deteriorated prior to the Great Recession and tightened sharply during it. Following a temporary improvement, the measured borrowing conditions also tightened somewhat during the 2011—2013 recession, which is associated with the euro area sovereign debt crisis. Figure 4 further compares our measure to alternative indicators for proxying the degree of firms' borrowing constraints. In the upper panel of the figure, we compare the level series of $\hat{\chi}_t$ and the credit spread index as provided by Gilchrist and Mojon (2018), which carefully measures the cost of market funding for non-financial firms in the four largest euro area countries a whole. For comparison purposes, the credit spread index, which is shown with dashed lines, is multiplied by -1, standardized and rescaled to have the same mean and standard deviation as $\hat{\chi}_t$. In the lower panel of the figure, we compare the series of the changes in $\hat{\chi}_t$ and the weighted average of the national diffusion indices of the change in bank credit standards for loans to non-financial corporations for the four largest euro area countries.[21] The bank credit standards indicator is shown by dashed lines. Note that it is multiplied by -1, standardized and rescaled to have the same mean and standard deviation as the changes in $\hat{\chi}_t$. Our financial conditions variable constructed from the theoretical model is quite good at tracking alternative measures of borrowing constraints for firms in the euro area big four. In particular, all three measures indicate a sharp deterioration in borrowing conditions during the Great Recession.

3.2 Estimation results from the SVAR

In this section, we examine the macroeconomic effects of exogenous financial shocks. We do so by introducing the constructed financial conditions variable into a SVAR that comprises the following variables: output, household consumption, tangible investment, and intangible investment. The SVAR takes the following form:

$$A \begin{bmatrix} \hat{Y}_t \\ \hat{C}_t \\ \hat{I}_{T,t} \\ \hat{I}_{I,t} \\ \hat{\chi}_t \end{bmatrix} = B(L) \begin{bmatrix} \hat{Y}_{t-1} \\ \hat{C}_{t-1} \\ \hat{I}_{T,t-1} \\ \hat{I}_{I,t-1} \\ \hat{\chi}_{t-1} \end{bmatrix} + u_t, \tag{22}$$

where the factor $B(L)$ denotes a lag polynomial, with L denoting the lag operator, A and B_i are 5×5 matrices of coefficients, and u_t is a mean-zero, serially uncorrelated 5×1 vector of stochastic disturbances with a diagonal variance-covariance matrix. To estimate the SVAR, we use

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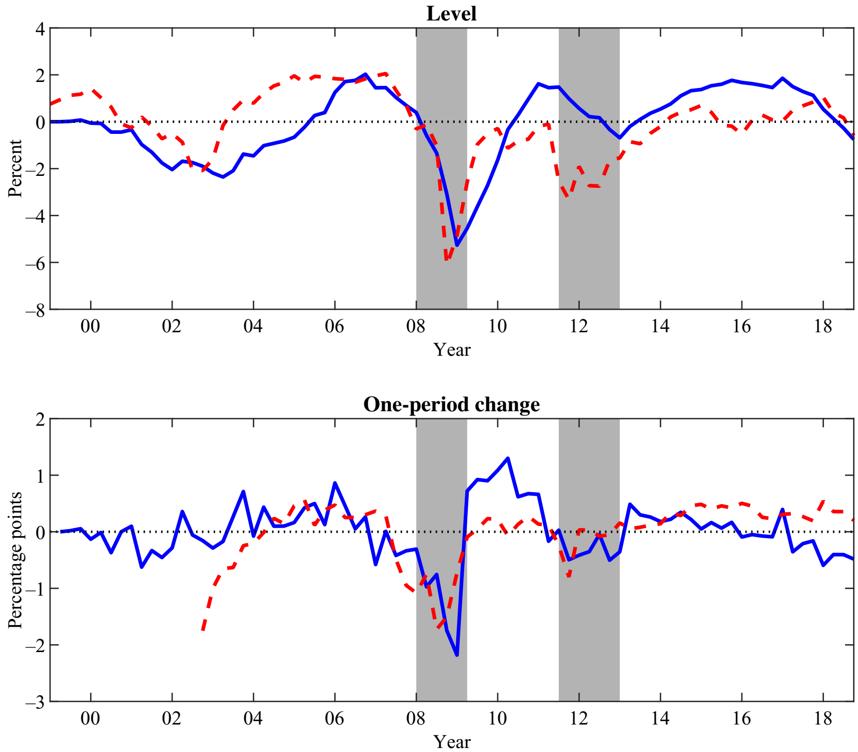

Figure 4. Constructed financial conditions variable and alternative indicators.
Note: Upper panel: The solid line depicts the level series of $\hat{\chi}_t$. The dashed line depicts the quarterly averages of the monthly series for the credit spread index as provided by Gilchrist and Mojon (2018). The credit spread index is multiplied by -1, standardized and rescaled to have the same mean and standard deviation as $\hat{\chi}_t$. Lower panel: The solid line depicts the series of the one-period changes in $\hat{\chi}_t$. The dashed line depicts the weighted average of the national diffusion indices of the net tightening of bank credit standards for loans to non-financial corporations for the four largest euro area countries. The series for the change in bank credit standards is multiplied by -1, standardized and rescaled to have the same mean and standard deviation as the changes in $\hat{\chi}_t$. The shaded areas in the upper and lower panel indicate Center for Economic Policy Research (CEPR) recession dates for the euro area as a whole.

aggregated national accounts data from France, Germany, Italy, and Spain, which we obtain from Eurostat's national accounts database. We measure output as total GDP, household consumption as final consumption of households and nonprofit institutions serving households, tangible investment as machinery and equipment investment plus nonresidential construction investment and intangible investment as investment in intellectual property products. All data are seasonally adjusted, expressed in real terms and detrended in logs using the same detrending procedure used for the construction of the $\hat{\chi}_t$ series. Following the related literature (see, e.g. Lown and Morgan (2006), Gilchrist and Zakrajsek (2012), and Walentin (2014)), we identify financial shocks by applying a recursive identification scheme. That is, we assume that financial shocks affect real economy variables only with a time lag, while shocks to real economy variables impact the financial conditions variable contemporaneously. We implement these restrictions by requiring the matrix A to be an unit lower triangular matrix. The SVAR is estimated over the sample from 1999.Q1 to 2018.Q4. Note that the SVAR features a constant and two lags of each variable.

Figure 5 presents the impulse response functions of all variables included in the SVAR to a negative one standard deviation financial shock. The solid lines correspond to the point estimates, and the shaded areas indicate one and two standard deviations confidence intervals, which we obtain from 2000 bootstrap replications. As can be seen, a negative financial shock causes a

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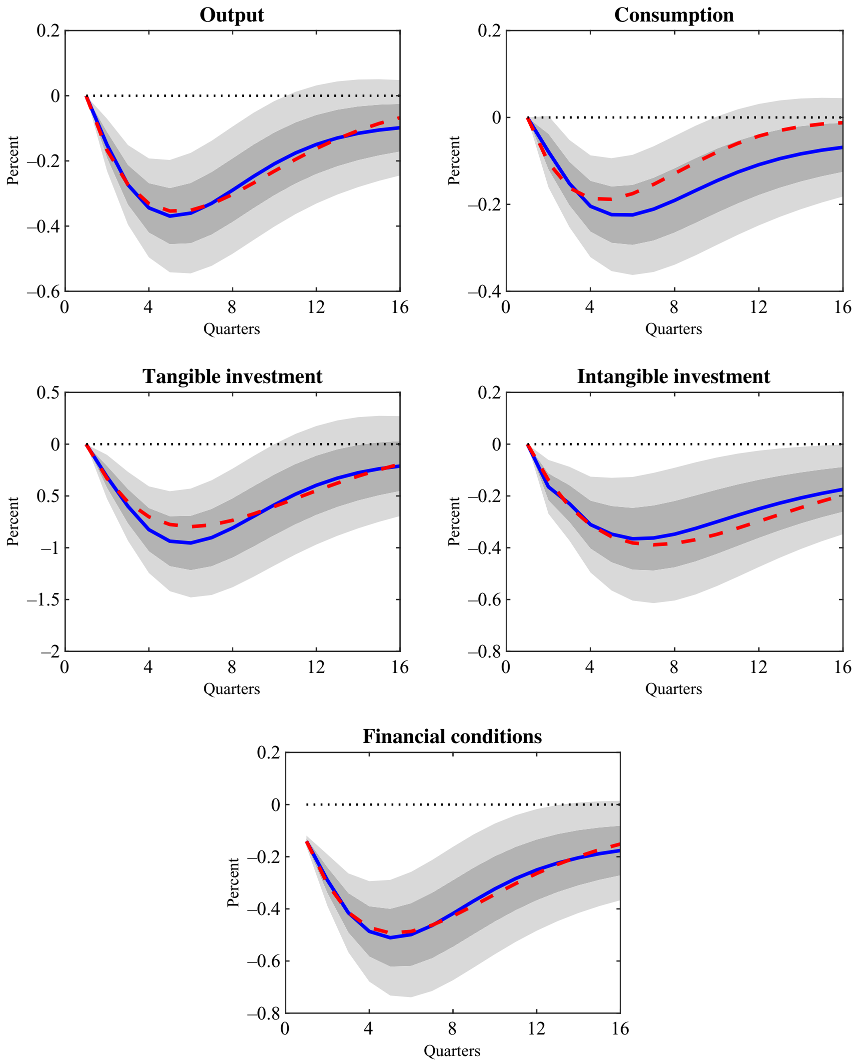

Figure 5. SVAR- and model-based impulse response functions.
Note: The figure displays SVAR- and model-based impulse responses to a negative one standard deviation financial shock. The solid lines are SVAR-based impulse responses and the dashed lines are model-based impulse responses (see Section (4)). The shaded areas denote the one and two standard-deviations confidence intervals around the SVAR-based estimates based on 2,000 bootstrap replications.

significant hump-shaped reduction in the aggregate quantities as well as the constructed financial conditions variable. GDP bottoms out around 0.4% below trend around one year after the shock. The fall in household consumption is somewhat less pronounced in terms of amplitude than the decline in output, while the contraction in tangible investment is relatively large. The fall in intangible investment is much smaller at the peak than the decline in tangible investment. The shock also causes a gradual decline in the financial conditions variable, which bottoms out after about one year and reverts to the trend after about four years. Overall, the results suggest that financial shocks lead to economically meaningful and statistically significant declines in output, household consumption, and the two investment aggregates. Importantly, tangible and intangible investment co-move positively in response to the financial shock, with intangible investment declining much less than tangible investment. Note that these results are robust to the

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Table 1. Percentage variance due to financial shocks

Variable	4 quarters ahead	8 quarters ahead	12 quarters ahead	16 quarters ahead
Output	27	48	47	47
	[7,50]	[11,63]	[10,62]	[10,61]
Household consumption	14	31	33	34
	[2,35]	[3,52]	[4,53]	[4,53]
Tangible investment	18	37	35	35
	[3,36]	[6,54]	[6,53]	[6,53]
Intangible investment	13	30	39	42
	[2,32]	[3,53]	[4,57]	[4,58]
Financial conditions	41	62	63	64
	[15,62]	[18,72]	[16,72]	[16,70]

Note: The table displays SVAR-based variance decompositions from a one standard deviation financial shock. The numbers in square brackets denote the boundaries of the associated 95% confidence interval.

specification of additional lags, the use of alternative detrending methods and the introduction of additional variables.[22] In addition, these results are in line with what Bianchi et al. (2019) find for the US. In particular, they report that intangible investment roughly drops by only half as much as tangible investment does in response to a debt financing shock.

Table 1 depicts the amount of variation in the variables included in the SVAR explained by the identified financial shock. The financial shock accounts for a significant fraction of the variation in output, household consumption, tangible investment, and intangible investment. The finding that the financial shock is an important source of variation in intangible investment is consistent with the view that the collateral constraint implies quantitatively important spill over effects from tangible to intangible investment. For the US, Bianchi et al. (2019) argue that debt financing shocks are more important for variations in tangible investment compared to intangible investment. The structural differences between euro area and US debt and equity markets may be responsible for the divergent outcomes. Interestingly, we find that up to around 60% of the variation in the constructed financial conditions variable is due to the financial shock itself. Hence, a large part of the variation in the constructed financial conditions series is not due to exogenous shifts but, rather, reflects other shocks.

4. Bayesian impulse response matching

In this section, we estimate the theoretical model by using a Bayesian variant of the standard impulse response matching procedure discussed in Rotemberg and Woodford (1997) and Christiano et al. (2005), which minimizes the weighted distance between the theoretical and empirical impulse response functions. The particular Bayesian variant that we use is developed in Christiano et al. (2010) and applied in other papers (see, e.g. Christiano et al. (2015, 2016)). Hence, here, we start by presenting the calibrated parameters and the driving process for $\hat{\chi}_t$.[23] Next, we describe the prior and posterior distributions of the estimated parameters and investigate the ability of the model to account for the empirical evidence on the macroeconomic effects of financial shocks.

4.1 Calibrated model parameters and driving process for the financial conditions variable

Table 2 provides an overview of the calibrated model parameters. These parameters pertain to the steady-state values of observable variables in the model and can therefore be set with steady-state targets.[24] We set $\beta = 0.995$, which implies a steady-state annual real interest rate of 2%. The

Table 2. Calibrated model parameters

Parameter	Description	Value				
Households						
β	Discount factor	0.995				
ν	Labor disutility parameter	16				
Firms						
α_{K_T}	Tangible capital income share	0.31				
α_{K_I}	Intangible capital income share	0.04				
τ	Tax wedge	0.3				
δ_T	Depreciation rate of tangible capital	0.025				
δ_I	Depreciation rate of intangible capital	0.05				
χ	Steady-state value of χ_t	0.13				
Driving process for $\hat{\chi}_t$						
A^5	5th row of matrix A	−0.819	−0.192	−0.003	−0.151	1
B_0^5	5th row of matrix B_0	−0.806	−0.222	0.011	−0.061	0.892
B_1^5	5th row of matrix B_1	−0.015	0.038	−0.019	−0.077	0.089
σ_{u_χ}	Standard deviation of financial shock	0.0014				

labor disutility parameter, ν, is set in such a way that the steady-state labor supply is equal to 0.3.[25] We choose the intangible capital income share parameter, α_{K_I}, to have a steady state share of intangible investment in output of $\frac{I_I}{Y} = 0.035$, which is equal to the observed average share of investment in intellectual property products in total GDP for the euro area big four for the period from 1999.Q1 to 2018.Q4. The tangible capital income share parameter, α_{K_T}, is set so as to have a steady state share of labor income in output of $\frac{WN}{Y} = 0.64$. The tax wedge, τ, is set to 0.3. The depreciation rate of tangible capital, δ_T, is 0.025. As for the depreciation rate of intangible capital, δ_I, we set $\delta_I = 0.05$, which implies an annual depreciation rate of 20%. This magnitude of δ_I reflects the assumption that intangible assets depreciate faster overall than tangible assets and roughly matches the unweighted average of the annual depreciation rates of R&D (15%), mineral exploration (7.5%), and computer software and databases (32%) as provided in Corrado et al. (2018). We set the steady-state value of χ_t to have the steady-state end-of-period debt-to-output ratio equal to $\frac{B^e}{Y} = 3.3$, which matches the observed average ratio of the end-of-period debt of nonfinancial corporations over total GDP for the four largest economies of the euro area as a whole for the period from 1999.Q1 to 2018.Q4. Given the values for χ, β, $\frac{WN}{Y}$, $\frac{I_I}{Y}$, τ, δ_T, δ_I, and $\frac{B^e}{Y}$, the steady-state end-of-period tangible capital-to-output ratio is $\frac{K_T^e}{Y} = 11$. Turning to the assumed driving process for the financial conditions variable, we consider a process with feedback effects from other variables, as in the empirical model. More specifically, we assume that the driving process for $\hat{\chi}_t$ in the theoretical model is identical to the last equation of the SVAR system, which reads:[26]

$$A^5 \begin{bmatrix} \hat{Y}_t \\ \hat{C}_t \\ \hat{I}_{T,t} \\ \hat{I}_{I,t} \\ \hat{\chi}_t \end{bmatrix} = B_0^5 \begin{bmatrix} \hat{Y}_{t-1} \\ \hat{C}_{t-1} \\ \hat{I}_{T,t-1} \\ \hat{I}_{I,t-1} \\ \hat{\chi}_{t-1} \end{bmatrix} + B_1^5 \begin{bmatrix} \hat{Y}_{t-2} \\ \hat{C}_{t-2} \\ \hat{I}_{T,t-2} \\ \hat{I}_{I,t-2} \\ \hat{\chi}_{t-2} \end{bmatrix} + u_{\chi,t}, \tag{23}$$

where A^5, B_0^5, and B_1^5 are 5×1 row vectors of coefficients that correspond to the 5th row of the matrices A, B_0, and B_1, respectively, and $u_{\chi,t}$ is the financial shock. Note that this implies that

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Table 3. Prior and posterior distributions of model parameters

Parameter	Description	Prior distribution		
		Distr.	Mean	Std. dev.
Households				
ϵ	Habit formation	Beta	0.7	0.1
Firms				
κ	Equity payout costs	Inv. gamma	0.2	0.1
ϕ_T	Tangible investment adj. costs	Gamma	4	2
ϕ_I	Intangible investment adj. costs	Gamma	4	2
Parameter	**Description**	**Posterior distribution**		
		Mode	Mean	95% CI
Households				
ϵ	Habit formation	0.87	0.87	[0.83,0.90]
Firms				
κ	Equity payout costs	0.57	0.63	[0.39,0.91]
ϕ_T	Tangible investment adj. costs	1.75	1.84	[1.41,2.32]
ϕ_I	Intangible investment adj. costs	8.04	8.68	[6.34,11.21]

Note: Posterior distributions of model parameters are obtained using the Metropolis-Hastings algorithm with 500,000 draws and a burn-in of 25%. The acceptance rate is 30%.

the theoretical model includes the same feedback effects between the financial conditions variable and the real economy variables as given in the SVAR. However, the dynamic behavior of the real economy variables is dictated by the mechanisms embedded in the theoretical model. As a result, the theoretical and the empirical responses of the financial conditions variable to a financial shock are not necessarily identical (see also Ravn et al. (2012)). The standard deviation of the financial shock, which is also obtained from the SVAR, is set to $\sigma_{u_\chi} = 0.0014$.

4.2 Prior and posterior distributions

In the upper half of Table 3, we present the prior distributions of the estimated parameters. We assume that the habit formation parameter, ϵ, follows a beta distribution. We choose a prior mean of 0.7 and a standard deviation equal to 0.1. The equity payout cost parameter, κ, is assumed to follow an inverse gamma distribution and is centered at 0.2, as in Jermann and Quadrini (2012). The prior probabilities of the investment adjustment cost parameters, ϕ_T and ϕ_I, are gamma distributions. We set the prior means to 4 and the standard deviations to 2. Hence, we do not force intangible investment to be more persistent than tangible investment and allow for a large parameter domain.

The lower half of Table 3 reports the posterior mode, mean, and 95% probability intervals for the estimated parameters. We obtain a posterior mean of 0.87 for the habit formation parameter, implying that household consumption adjusts very slowly to financial shocks. The posterior mean of κ is 0.6. This value is larger than the value for the US as estimated in Jermann and Quadrini (2012). Turning to the investment adjustment cost parameters, we find that the posterior estimates of ϕ_T and ϕ_I are significantly different from zero, confirming that investment adjustment costs are an important feature of the model for capturing the empirical persistence of both tangible and intangible investment. Interestingly, the posterior mean of the adjustment cost parameter for intangible investment is much higher than that for tangible investment, even though we set the same prior means. Specifically, the posterior mean of ϕ_I implies an estimate of the elasticity of intangible investment with respect to a 1% temporary increase in the current price of installed intangible capital of 0.1. The corresponding elasticity for tangible investment is found to be 0.5.

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These elasticities are close to those implied by the estimates for the US reported in Bianchi et al. (2019), who use R&D investment from the national accounts to proxy intangible investment. The finding that intangible investment adjusts much more slowly to its costs than is the case for tangible investment is also fully in accord with what is obtained in the finance literature, as found in Peters and Taylor (2017). In addition, the finding is in line with the estimates presented in Chiavari and Sampreet (2021), who report higher adjustment costs for intangibles compared to tangible investment. In the literature, many argue that intangible capital (in particular R&D capital) has high adjustment costs and possibly much higher adjustment costs than tangible capital (see, e.g. Himmelberg and Petersen (1994), Hall (2002) and Brown et al. (2009)), because adjusting intangible capital typically involves adjusting the number of highly educated employees, who have high searching, training or replacement costs. Our estimation results are consistent with this view. Overall, we find that the priors and posteriors are quite different, suggesting that the data are informative about the model's parameters. Given the relatively large posterior estimates for the habit formation parameter, ϵ, and the equity payout costs parameter, κ, we have performed a sensitivity analysis with respect to these parameters. We found that the posterior estimates for the investment adjustment cost parameters, ϕ_T and ϕ_I, are not particularly sensitive to lower values of ϵ and κ.

4.3 Model-implied impulse response functions

Figure 5 depicts with dashed lines the model-implied impulse response functions of output, household consumption, tangible investment, intangible investment, and the constructed financial conditions variable to a negative one standard deviation financial shock. As can be seen from the figure, the theoretical model does well at reproducing the observed transmission of financial shocks based on the SVAR results. The model accounts for the hump-shaped reduction in the real economic quantities as well as the constructed financial conditions variable. Most of the model responses are close to the point estimates from the SVAR; and almost all model responses lie within the one standard deviation confidence intervals around the SVAR-based estimates. Importantly, the model predicts a strong fall in tangible investment and a relatively small decline in intangible investment. As explained above, this positive co-movement between tangible and intangible investment as well as the relative resilience of intangible investment poses a challenge for a model without costly capital accumulation.

5. Modeling the responses of tangible and intangible investment during the Great Recession

In this section, we study the dynamics for tangible and intangible investment implied by our model for the period of the Great Recession. To do so, we feed the series of the identified financial shocks from the SVAR into the theoretical model and compute the responses of tangible and intangible investment.

In Figure 6, we recover the series of the identified financial shocks from the SVAR estimated in Section 3. As can be seen, a sequence of large negative disturbances occur prior to and during the Great Recession. Note that the largest negative shock (i.e. -2.4 standard deviations) arises in 2008.Q1, which according to the CEPR marks the peak of the economic expansion in the euro area as a whole before the Great Recession.

The model-implied dynamics for tangible and intangible investment induced by the series of the identified financial shocks from the SVAR are shown for the Great Recession period in Figure 7. We illustrate the corresponding empirical measurements in the same figure to facilitate a visual test of how well the model fits the empirical data. For a description of how the empirical measurements for tangible and intangible investment are constructed see the footnote of Figure 1. The vertical lines represent 2008.Q1. As can be seen from the figure, the model replicates quite well the relative resilience of intangible investment to the Great Recession observed in the data.

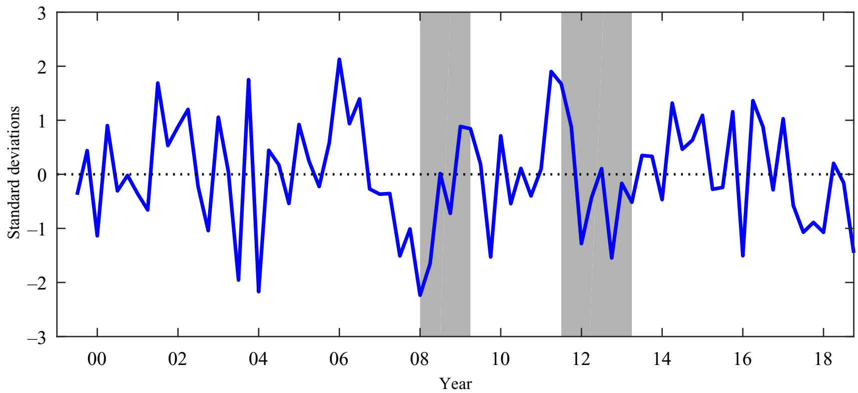

Figure 6. Identified financial shocks.
Note: The figure displays the series for the identified financial shocks from the SVAR expressed in terms of standard deviations. The standard deviation is 0.13 basis points. The shaded areas indicate Center for Economic Policy Research (CEPR) recession dates for the euro area as a whole.

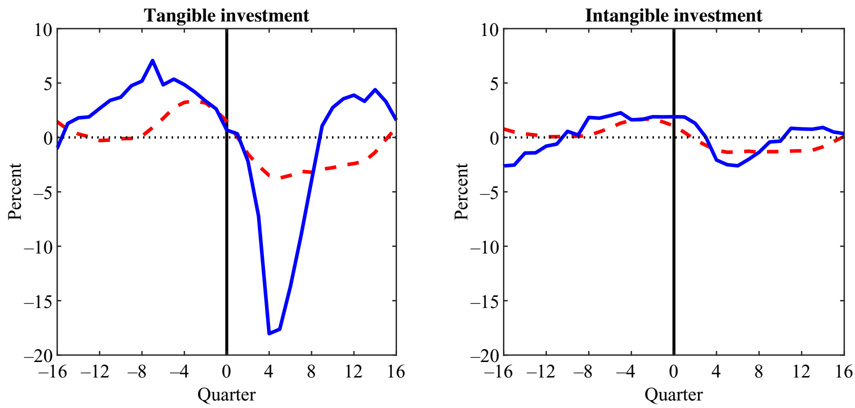

Figure 7. Impact of the Great Recession on tangible and intangible investment.
Note: The figure displays the responses of tangible and intangible investment around and during the Great Recession. The dashed lines correspond to the model responses induced by the series of the identified financial shocks from the SVAR. The solid lines represent the corresponding empirical series. For a description of how the empirical measurements for tangible and intangible investment are constructed see the footnote of Figure 1. The vertical lines represent 2008.Q1.

The model responses for both tangible investment and intangible investment fell below the trend during the period of the Great Recession, whereby intangible investment declined by much less than tangible investment. We observe similar dynamics in the data. Viewed through the lens of our model, the relative resilience of intangible investment to the Great Recession seems to be due to the relative large costs associated with changing intangible investment. According to our model, when confronted with an adverse financial shock, firms attempt to maintain their investment in intangible capital by reducing their investment in tangible capital in order to minimize adjustment costs. Hence, the Great Recession, which according to the results from the SVAR can be associated with a sequence of large negative financial shocks, had a much smaller impact on intangible investment than on tangible investment. Bianchi et al. (2019) report for the Great Recession that debt financing shocks largely fail to explain the evolution of intangible investment, which constitutes a notable difference between the US and the euro area against the backdrop of our findings. Consistent with the results reported in Table 1, we find in this computation that debt financing shocks matter. While our model accounts very well for the relatively modest decline in intangible

https://doi.org/10.1017/S136510052200030X Published online by Cambridge University Press

investment during the Great Recession, it is also clearly evident from the figure that the drop in tangible investment generated by the model is much smaller than in the data. This result comes as no surprise, since we would not expect our model to match all the variation in the data perfectly. However, the result is interesting insofar as it points to a further asymmetry in the behavior of tangible and intangible investment during the Great Recession beyond that identified in this paper.

6. Conclusion

We investigate the effects of financial shocks on the relative dynamics of tangible and intangible investment using an extended RBC model with financially constrained firms, pledgeable tangible capital, and nonpledgeable intangible capital. We show that, within this framework, the presence of adjustment costs in the accumulation process for tangible and intangible capital plays a crucial role in the relative dynamics of tangible and intangible investment in response to financial shocks.

Based on a model-consistent series for firms' borrowing conditions, we identify within an SVAR framework the effects of financial shocks on tangible and intangible investment in the four largest euro area economies as a whole. We find that an adverse financial shock leads to a sharper fall in tangible investment than in intangible investment.

The estimation of the theoretical model adopting a Bayesian limited information approach provides evidence in favor of relatively high adjustment costs for intangible investment compared to those for tangible investment. This is consistent with what is obtained in the finance literature, as reported in Peters and Taylor (2017) and Chiavari and Sampreet (2021). The estimated model replicates well the empirical impulse responses of the aggregate quantities. Importantly, the model predicts a relatively sharp decline in tangible investment in response to an adverse financial shock, whereas intangible investment falls much less than tangible investment.

We show that the relative large adjustment costs for intangible investment are crucial to the model's success in replicating the empirical dynamics of tangible and intangible investment in the aftermath of an adverse financial shock. When it is assumed that adjusting tangible and intangible capital is without costs, it is optimal for the firm to shift resources toward pledgeable tangible capital and away from nonpledgeable intangible capital. Hence, tangible investment and intangible investment co-move negatively in response to the shock. The presence of investment adjustment costs alters the firm's incentives such that the firm reduces tangible investment along with intangible investment. Intuitively, when it is much more costly to adjust intangible investment than to adjust tangible investment, the firm reduces tangible investment to a larger extent than it does intangible investment. Our modeling approach is deliberately parsimonious in order to put forward this particular feature of the model in generating a positive co-movement between tangible and intangible investment as well as a relatively resilient reaction of intangible investment in response to a financial shock.

Notes

1 Important examples are Nolan and Thoenissen (2009) and Jermann and Quadrini (2012).

2 Investments in intellectual property products accounted for about 20% of total gross fixed capital formation in the big four euro area countries in 2018. Around 50% of these investments consisted of R&D.

3 See Appendix A.1 for a sensitivity analysis.

4 The INTAN-Invest database covers the business sector and allows for a broader measurement of intangible investment by including expenditures for design, branding, new financial products, organizational capital, and firm-specific training. Such expenditures are currently treated as intermediate costs in national accounts. As reported in Corrado et al. (2018), the share of intangible investment in GDP increases by a large amount when including the above mentioned items. For France, the intangible to GDP ratio increases from 4.2% to 8.7%, for Germany from 2.8% to 5.9%, for Italy from 1.9% to 5.3%, and for Spain from 2.1% to 4.8%. As part of our analysis in Section (2.3), we explain the effects of switching from low to high intangible investment ratios as a robustness check.

5 This result also remains in a sensitivity analysis if we take into account limited collateralizability of intangible capital.
6 More specifically, we follow the standard modeling approach of Christiano et al. (2005) and assume that it is costly for firms to change the levels of tangible and intangible investment between periods.
7 Given the strand of literature on which we built our paper, in particular, Lopez and Olivella (2018) and Bianchi et al. (2019), we abstract from modeling a cash hoarding channel.
8 For a full discussion see Eisfeldt et al. (2018), Sun and Xiaolan (2019) and Döttling, Ladika, and Perotti (2020).
9 This pertains in particular to investment in intellectual property products, for which data for Belgium and Cyprus are not available. Moreover, existing data for the Netherlands and Ireland are heavily influenced by the relocation of intellectual property products of large multinational companies and complicate the economic analysis for the euro area as a whole.
10 More specifically, as the firm has all the bargaining power, it must apply that the going concern value is higher than the anticipated value of cash flows to creditors in the two states. Thus, from the perspective of the firm, it needs to hold that $Em_{t+1}V_{t+1} \geq L_t + Em_{t+1}V_{t+1} - \chi_t\left(K_{T,t+1} + \lambda_I K_{I,t+1} - \frac{B_{t+1}}{1+r_t}\right)$, where V_{t+1} denotes the cum-dividend market value of the firm and m_{t+1} is the stochastic discount factor.
11 When we estimate the model, we set $\lambda_I = 0$.
12 The borrowing constraint is always satisfied with equality in the steady state. The assumption that this condition continues to hold in the neighborhood of the steady state allows us to solve the model with a log-linear approximation.
13 This specification of the information set is in line with the restrictions for the identification of financial shocks in the SVAR (see Section 3). It implies that decisions in period t are made before the realization of the shock.
14 Note that, in the tradition of Smets and Wouters (2003), we define Tobin's $Q_{j,t}$ as the ratio of the Lagrangian of the capital accumulation equation and the Lagrangian of the flow of funds constraint $\frac{\lambda_t^{K_j}}{\lambda_t^B}$, for $j = T, I$ with $\lambda_t^B = \frac{1}{\varphi'(D_t)}$. $Q_{j,t}$ thus reflects the supply price of capital $\lambda_t^{K,j}$ relative to the reproduction costs of capital λ_t^B. In steady state, we set $Q_j = 1$, for $j = T, I$.
15 For the sake of argument, we assume here that the financial conditions variable follows an exogenous first-order autoregressive process. More formally, the assumed process is given (in logs) by $\log(\chi_t) = (1-\rho_\chi)\log(\chi) + \rho_\chi \log(\chi_{t-1}) + u_{\chi,t}$, where χ is the steady-state value of χ_t and $u_{\chi,t}$ is a zero-mean, serially uncorrelated stochastic disturbance with standard deviation σ_{u_χ}. We set $\rho_\chi = 0.95$ and $\sigma_{u_\chi} = 0.002$ in order to model a persistent and economically meaningful impact of the financial shock. Note that, when we estimate the theoretical model, we consider a driving process with feedback effects from other variables, as in the empirical model (see Section 4).
16 Note that the joint determination of tangible and intangible investment within the same firm is key to trigger and understand the co-movement problem between tangible and intangible investment. If firms are divided into two sectors, one producing tangibles and the other produces intangibles, the co-movement problem is solved by assumption. However, given the strand of literature on which we built our paper, in particular, Lopez and Olivella (2018) and Bianchi et al. (2019), we choose to model the joint determination of tangible and intangible investment within the same firm. In addition, the two-sector approach also requires adjustment costs in investment to replicate the hump-shaped responses from the SVAR. This means that although the two-sector approach solves the co-movement problem, it fails to replicate the data sufficiently in the absence of investment adjustment costs.
17 Throughout the paper, we detrend the data by taking logs and applying a one-sided HP filter with a smoothing parameter of $\lambda = 1600$. We implement the one-sided HP filter as discussed in Stock and Watson (1999).
18 We use the cumulative sum of flows rather than the series for the published stocks to remove the impact of any changes in the published stocks that do not arise from transactions.
19 The empirical series for output as well as tangible investment are available as of 1995.Q1. Hence, we started the iteration process for the construction of the $K^e_{T,t}$ series from 1995.Q1.
20 Appendix A.2 provides further details on the data used in the paper.
21 The national diffusion indices are obtained from the ECB's Bank Lending Survey (BLS), which was not introduced until 2003. They each measure the weighted difference between the percentage of banks reporting that credit standards have tightened over the past three months and the percentage of banks reporting that they have been eased. We aggregate the national results using a weighting scheme based on the national percentage shares in the outstanding amount of loans (all maturities) from monetary financial institutions (MFIs, excluding the Eurosystem) to euro area nonfinancial corporations (see Scopel et al. (2016)).
22 Note that our results are robust to the inclusion of monetary variables. When we include monetary variables in the SVAR, such as the shadow rate for the euro area as provided by Wu and Xia (2017) and the euro area HICP inflation rate, the point estimates of the impulse responses for tangible and intangible investment as well as the point estimates for the financial conditions index are located within the reported one standard deviation tunnel of our baseline specification. Thus, the reported impulse responses do not significantly change when monetary variables are included.
23 The estimation strategy borrowed from Jermann and Quadrini (2012) is explicitly designed to avoid circularity. For example, the steady-state value of the capital-to-output ratio $\frac{K^e_T}{Y}$ and the depreciation rate δ_T, which serves as inputs to the perpetual inventory method to construct the financial condition series χ_t, are independent of the estimated parameters of the model. In other words, any adjustment to the estimated parameters, for example, the investment adjustment cost parameters, does not affect the constructed financial conditions index.

24 For details on the calculation of the steady state, see Appendix A.3.
25 The labor disutility parameter, ν, depends on the habit persistence parameter, ϵ, which is determined during the impulse response matching procedure. That is, during the estimation, we update ν for every parameter draw such that the steady-state labor supply is equal to 0.3. In Table 2, we report the value for ν based on the posterior mean of ϵ.
26 This approach is adopted from Ravn et al. (2012), who study the transmission of government spending shocks in a two-country model with deep habits.

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A. Appendix

A.1 Sensitivity analysis

In this section, we focus on the procedure used to extract the business cycle components of the data. In Figure 1, we use a one-sided HP filter with a smoothing parameter of $\lambda = 1600$. Here, we replace this detrending procedure by applying a quadratic trend. Figure 8 shows the log-deviations from trend for both tangible and intangible investment in the euro area's big four economies as a whole obtained after removing a quadratic trend. Comparing this figure with Figure 1, it can be seen that the relative dynamics of tangible and intangible investment are quite similar to those obtained using the one-sided HP filter. In particular, tangible and intangible investment co-move positively during the Great Recession, while the drop in intangible investment is much smaller than the one in tangible investment. This suggests that intangible investment reacts much less strongly to financial shocks than tangible investment does.

A.2 Data description

Here, we provide further details on the data used in the paper. Note that all data are derived by means of aggregation based on quarterly national and financial accounts data for the four largest euro area economies in terms of output (i.e. France, Germany, Italy, and Spain). The national accounts data are obtained from Eurostat in nominal seasonally adjusted terms. We convert all nominal variables into real variables using an aggregate GDP deflator, which is a weighted average of the national GDP deflators. We measure output as total GDP, household consumption as final consumption of households and non-profit institutions serving households, tangible investment as machinery and equipment investment plus non-residential construction investment, and intangible investment as investments in intellectual property products. According to the current accounting standard, the latter cover expenditures on research and development (R&D), mineral exploration and evaluation, computer software and databases, entertainment, literary and artistic originals. Note that Eurostat publishes quarterly data for total investments in intellectual property products but not for the individual components. The source of the financial accounts data is the ECB. This data are not adjusted for seasonal variation. We apply the Census X-12 filter to seasonally adjust the data. The national diffusion indices of the change in bank credit standards for loans to non-financial corporations come from the ECB's Bank Lending Survey. The data on MFI loans are taken from the ECB database. The series of the credit spreads for non-financial corporations in

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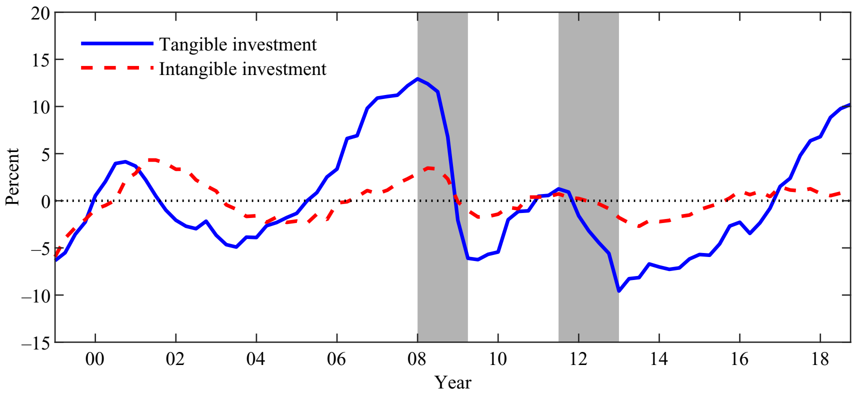

Figure 8. Tangible and intangible investment.
Note: The figure displays tangible and intangible investment in the four largest euro area countries as a whole, as derived from Eurostat's national accounts data. Tangible investment is measured as machinery and equipment investment plus non-residential construction investment. Intangible investment is investment in intellectual property products. All data are seasonally adjusted, expressed in real terms and detrended in logs by applying a quadratic trend. The shaded areas indicate Center for Economic Policy Research (CEPR) recession dates for the euro area as a whole.

the four largest euro area countries a whole is provided in monthly terms by Gilchrist and Mojon (2018). We convert the monthly data to quarterly data by taking 3-month averages.

A.3 Steady state

Here, we list the steady state relations of the theoretical model. The time subscripts are dropped from all variables, because the variables are constant in the steady state. We set the steady state labor supply to $N = 0.3$ and the steady state share of labor income in output to $\frac{WN}{Y} = 0.64$. The steady state end-of-period debt-to-output ratio, $\frac{B^e}{Y}$, and the steady state intangible investment-to-output ratio, $\frac{I_I}{Y}$, are set to 3.3 and 0.035, respectively.

Effective gross interest rate:

$$R = \frac{1-\tau}{\beta} + \tau. \tag{24}$$

Multiplier for the borrowing constraint:

$$\mu = \frac{1-R\beta}{\chi} \frac{R-\tau}{R(1-\tau)}. \tag{25}$$

Output:

$$Y = \left(\left(\frac{\alpha_{K_T}(1-\mu)}{\frac{1-\chi\mu}{\beta} - (1-\delta_T)} \right)^{\alpha_{K_T}} \left(\frac{\alpha_{K_I}(1-\mu)}{\frac{1-\chi\mu\lambda_I}{\beta} - (1-\delta_I)} \right)^{\alpha_{K_I}} N^{1-\alpha_{K_T}-\alpha_{K_I}} \right)^{\frac{1}{1-\alpha_{K_T}-\alpha_{K_I}}}. \tag{26}$$

Tangible capital:

$$K_T = \frac{\alpha_{K_T}(1-\mu)Y}{\frac{1-\chi\mu}{\beta} - (1-\delta_T)}. \tag{27}$$

Intangible capital:

$$K_I = \frac{\alpha_{K_I}(1-\mu)Y}{\frac{1-\chi\lambda_I\mu}{\beta} - (1-\delta_I)}. \tag{28}$$

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Investment in capital of type j:

$$I_j = \delta_j K_j, \quad \text{for} \quad j = T, I. \tag{29}$$

Current price of installed capital of type j:

$$Q_j = 1, \quad \text{for} \quad j = T, I. \tag{30}$$

Wage rate:

$$W = \frac{(1 - \alpha_{K_T} - \alpha_{K_I})(1 - \mu)Y}{N}. \tag{31}$$

Intertemporal debt:

$$B = \frac{R - \tau}{1 - \tau}\left(K_T + \lambda_I K_I - \frac{Y}{\chi}\right). \tag{32}$$

Equity payout:

$$D = Y + B\left(\frac{1}{R} - 1\right) - WN - \delta_T K_T - \delta_I K_I. \tag{33}$$

Household consumption:

$$C = B\left(1 - \frac{1}{R}\right) + WN + D. \tag{34}$$

Tangible capital income share:

$$\alpha_{K_T} = 1 - \alpha_{K_I} - \frac{WN}{Y}\frac{1}{1 - \mu}. \tag{35}$$

Intangible capital income share:

$$\alpha_{K_I} = \frac{I_I}{Y}\frac{\frac{1 - \mu\lambda_I\chi}{\beta} - (1 - \delta_I)}{(1 - \mu)\delta_I}. \tag{36}$$

Labor disutility parameter:

$$\nu = \frac{(1 - N)W}{(1 - \epsilon)C}. \tag{37}$$

By rearranging equation (27), we obtain the steady state ratio of tangible capital to output:

$$\frac{K_T}{Y} = \frac{\alpha_{K_T}(1 - \mu)}{\frac{1 - \chi\mu}{\beta} - (1 - \delta_T)}. \tag{38}$$

Combining this with equation (32), we have

$$\frac{B^e}{Y} - \frac{\alpha_{K_T}(1 - \mu)}{\frac{1 - \chi\mu}{\beta} - (1 - \delta_T)} - \lambda_I\frac{\alpha_{K_I}(1 - \mu)}{\frac{1 - \chi\lambda_I\mu}{\beta} - (1 - \delta_I)} + \frac{1}{\chi} = 0, \tag{39}$$

where $\frac{B^e}{Y} \equiv \frac{B}{Y}\frac{1 - \tau}{R - \tau}$ is the end-of-period debt-to-output ratio. Given the values for β, $\frac{WN}{Y}$, $\frac{I_I}{Y}$, τ, δ_T, δ_I, λ_I as well as $\frac{B^e}{Y}$ and using equations (24), (25), (35) and (36), we can numerically solve this expression for the value of χ.

Cite this article: Gareis J and Mayer E (2023). "Financial shocks and the relative dynamics of tangible and intangible investment: Evidence from the euro area." *Macroeconomic Dynamics* **27**, 1455–1480. https://doi.org/10.1017/S136510052200030X