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Interactions between financial constraints and economic growth

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A B S T R A C T

The financial economy and the real economy are interconnected through various, complex, and evolving transmission mechanisms, whose literary coverage is far from comprehensive. In this context, we wish to contribute to the literature on the interactions between financial constraints and economic growth. We introduce financial dynamics in the R&D-based growth literature, by bringing Bernanke, Gertler and Gilchrist's (1999) informational asymmetries into Romer's (1990) growth model. With the developed framework, our main goal is to examine if and how such asymmetries impact economic growth. We find that the overall impact of this form of financial constraints on long-term growth is negative.

1. Introduction

In the first decade of the 21st century, the world realized that what happens in the financial economy does not stay in the financial economy; rather it also has a concrete impact on the real economy. Financial markets, alternative sources of finance to the banking system, have conquered fundamental importance in most developed countries, connecting virtually all countries through increasingly complex and sophisticated instruments, thereby increasing the forms of liquidity available in the world, moving trillions of dollars on a daily basis.

Such ever-growing, ever-changing global finance interconnectedness implies, on the other hand, increased systemic risk and financial over-sensitivity. It can also cause significant resource misallocations during the expansion phase of one financial cycle.

Existing literature acknowledges fluctuations in asset prices, credit and capital flows as key influencers of real macroeconomic variables (Claessens and Kose, 2018). Still, the role of financial frictions in the shock transmission mechanisms into the real economy, e.g., through asset prices, net worth, interest rates and/or monetary channels has not yet been thoroughly analyzed (Christiano et al., 2005).

Reflecting the literary divergence on the importance of "financial channels" to the real economy (Gerke et al., 2013), most economic growth models do not consider financial frictions. However, if financial-economic crises occur as extreme manifestations of an existing relationship between the financial sector and the real economy (Claessens and Kose, 2013) then a deeper understanding of the macro-financial interactions is required. Jokivuolle and Tunaru (2017) do point out that knowledge-systemization efforts are challenged by the fact that each financial-economic crisis seems to be different from its predecessor, with few observed common factors except for the fact that real estate assets appear to be relatively more sensitive to financial fluctuations.

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Nevertheless, as for instance hinted by the adoption of similar key policy-model parameters by the Bundesbank, the European Central Bank, Banca d'Italia, Sveriges Riksbank and the National Bank of Poland (Gerke et al., 2013), recently emerged academic and political literature have been able to identify a few common denominators to financial dynamics. In this context, Blanchard (2018), Borio (2018), Brunnermeier and Sannikov (2016), among others, argue that macroeconomic theory needs to capture the role of finance and financial restrictions in the real economy in a more comprehensive way.

Financial restrictions are present, for instance, in Greenwald and Stiglitz (1993), where firms' bankruptcy risks affect aggregate output's price level. Also in Kiyotaki and Moore (1997), where financial intermediaries impose collateral constraints on credit extension to farmers.

Still, the most widely accepted form of introducing financial frictions in dynamic economic modelling is Bernanke, Gertler and Gilchrist's (1999) specification of a cost state verification problem that leads entrepreneurs to pay a financial premium for external financing. In particular, the existence of uncertainty around the entrepreneurs' net worth realization creates information asymmetries between lender and borrower that endogenously generate an external finance premium to compensate the lender for adverse selection and moral hazard. This informational asymmetry constitutes one financial friction that can lead to more pronounced macroeconomic fluctuations, through Bernanke, Gertler and Gilchrist's (1999) financial accelerator (Claessens and Kose, 2018, pp-75-79).

We wish to contribute to the literature on the interactions between financial constraints and the real economy with an aggregate dynamics model that captures both the macroeconomic nature of the financial-real economy interactions and the microeconomic foundations to the macro-financial linkages. Hence, we consider Bernanke, Gertler and Gilchrist's (1999) agent-based phenomena and propose to introduce their financial asymmetry specification in Romer's (1990) economic growth model.

Bernanke, Gertler and Gilchrist's (1999) is a microeconomics model with uncertainty, finitely-lived agents and the possibility of firms going out of business. In this model there is a one-period gap between the economic decision and the stochastic net worth's realization. The idiosyncratic nature of each entrepreneur's bankruptcy case renders symmetry impossible to assume in this setting, which is consequently restricted to individual agents' partial equilibrium analyses at arbitrary moments in time. In its turn, Romer's (1990) is a macroeconomics, general equilibrium, deterministic and symmetric model, with infinitely-lived individuals and infinitely-lived firms, as Romer's horizontal-differentiation feature implies no bankruptcies. Marrying these two frameworks poses therefore some analytical challenges, which we go through proposing a complete model of endogenous growth with financial frictions à la Bernanke, Gertler and Gilchrist's (1999).

We hope to contribute to literature by offering further insight into the interactions between financial constraints and macroeconomic variables; into the channels through which one financial friction affects not only business cycles, but also long-term economic growth. We find that there is one limit where financial frictions are irrelevant for economic growth. In this limit we are back to Romer's (1990) model. Outside the neighborhood of this limit, financial frictions always have a negative impact on economic growth.

The paper continues as follows: In Section 2, we give some intuition to our developed growth model's underlying roots and mechanisms, as well as to the Bernanke, Gertler and Gilchrist's (1999) financial-frictions specifications. In Section 3, we set up the model, solve for its balanced growth path solution and discuss its main predictions. We analyze in Section 4 the effects on economic growth of informational asymmetries between the model's agents. An empirical analysis of the developed framework follows in Section 5, and Concluding Remarks close the paper.

2. Underlying theory

We propose a R&D-based growth model that contemplates financial frictions and investigate the interactions between financial constraints caused by informational asymmetries and real growth variables over an infinite time horizon.

Adopting, like Morales (2003), Bernanke et al. (1999) and Jerónimo et al. (2021), the cost state verification problem specified by Bernanke, Gertler and Gilchrist's (1999) – henceforth BGG – we introduce financial dynamics in the R&D-based growth literature and develop one generalization of Romer's (1990) endogenous growth model, the original framework becoming its special case.

Romer's (1990) familiar model has three productive sectors, namely the R&D, the final good and the capital goods sectors. While the final good firms operate in perfect competition, the capital goods sector is set in monopolistic competition, as capital firms enjoy monopoly rights over the use of a patent, whose price is the initial investment required to enter the capital goods market. On the consumption/savings side of the economy, a representative immortal household maximizes her discounted CRRA-like utility of consumption flows, subject to an intertemporal budget constraint. The interactions between the interplaying agents, under optimal behavior and a perfect-foresight hypothesis, give rise to a unique general equilibrium balanced growth path solution for the economy's growth rate.

Financial phenomena do not exist in Romer's (1990) model, hence, with the present paper, we propose to introduce BGG's (1999) financial asymmetries into Romer's (1990) model.

Integration of one version of BGG's partial equilibrium setting in Romer's general equilibrium model requires addressing some modelling incompatibilities between the two theoretical frameworks. Firstly, we have the perfect-foresight hypothesis, assumed in Romer's deterministic model, but not present in BGG (1999). In BGG's model, there is a one-period gap between the economic decision and the stochastic net worth's realization, that is, the entrepreneur's net worth in $t + 1$ is uncertain, subject to a decomposed risk measure that captures both an aggregate risk and an idiosyncratic risk. The uncertainty around the net worth's realization creates an informational asymmetry between lender and borrower, which endogenously generates an external finance premium that compensates the lender for adverse selection and moral hazard.[1] Romer's deterministic setting constitutes then a challenging ground for our introduction of BGG's stochastic financial imperfections.

Secondly, while Romer's is a symmetric, general equilibrium model, in BGG's setting symmetry is impossible to assume due to the idiosyncratic nature of each entrepreneur's bankruptcy case.

The third analytical challenge that we face is that whereas Romer's model has infinitely lived households and firms, the BGG model assumes finite-horizon agents. BGG's entrepreneurs can go bankrupt and disappear if the cut-off value of the following period's capital returns goes below the outstanding debt value multiplied by the economy's risk-free interest rate. This is the external finance rule that borrowers must meet, at each moment in time, in order to obtain external financing at t and continue production until, at least, $t+1$.

Summing up, in the next section we expand Romer's model through the introduction of BGG's financial restrictions. In order to do so we must overcome some analytical incompatibilities between the two frameworks. We must bring BGG's stochastic and idiosyncratic, partial equilibrium setting with finitely-lived agents into Romer's deterministic and symmetric, general equilibrium model with infinitely lived agents.

3. The model

3.1. Aggregate production

Romer's economy has three producing activities for obtaining the final good (aggregate output), capital goods and new designs (the R&D sector), respectively. Labor $L(t)$ is constant throughout time. Labor devoted to R&D is $L_A(t)$ and labor dedicated to final good's production is $L_Y(t)$. Equilibrium in the labor market implies at each time that:

$$L_A(t) + L_Y(t) = L(t)$$

The production function for the final good is a Cobb-Douglas-like function:

$$Y(t) = F(L, x()\,) = L_Y(t)^{1-\alpha}\left(\int_0^{A(t)} x_i(t)di\right)^{\alpha}, \alpha \in]0,1[, \tag{1}$$

in which, at each time, $K(t) = \int_0^{A(t)} x_i(t)di$ is the capital stock of the economy, $A(t)$ represents the continuous range of differentiated capital goods that have already been designed (equal to ideas/designs/patents, and representative of the economy's technological level), and $x_i()$ represents the quantities produced of type i's capital good. The same technology is used for producing: (i) the aggregate final good $Y(t)$ and (ii) physical capital machines for the $i = 0,\ldots,A(t)$ types of capital goods that have already been invented. The aggregate production function has constant returns to scale and diminishing returns to scale in $x_i()$, which are compensated by technological progress.

3.2. Consumption

The model assumes infinitely lived inhabitants (equal to labor). As consumers they wish to maximize their lifetime consumption. Their representative agent maximizes her discounted CRRA-like utility of aggregate consumption $C(t)$ of aggregate output $Y(t)$.

$$\int_0^{\infty} e^{-\rho t} u(C(t)\,)dt, \tag{2}$$

with:

$$u(C(t)\,) = \frac{C(t)^{1-\sigma}}{1-\sigma}, \tag{3}$$

subject to the budget constraint that the individual's lifetime present valued consumption cannot exceed her initial wealth plus her lifetime present valued income. In equations (2) and (3), ρ is the discount rate and σ is the intertemporal elasticity of substitution.

Each agent wishing to become a capital good producer must buy one patent whose price is $P_A(t)$. Let us assume that amount $P_A(t)$ is financed through loans, which are partially repaid by each capital firm, at each time, from the moment it enters the market. The debt repayments scheme is specified within the representative consumer's budget constraint:

[1] The existence of uncertainty around the net worth's realization and the drawing of an optimal contract as a solution to an agency problem is also present in KM and other studies like Carlstrom and Fuerst (1997), who integrates collateral constraints on the firm's side by assuming that labor employment is financed partially through loans.

$$\dot{B}(t) = rB(t) + r\beta(t)P_A(t)A(t) + w(t)L(t) - C(t) - \int_t^{\infty} e^{-r(\tau-t)}(P_A(\tau) - \beta(\tau)P_A(\tau))d\tau,$$

where r is the real interest rate, $B(t)$ is consumers' assets, $P_A(t)A(t)$ is shares on capital firms, $\beta(t)\rangle 0$ represents the portion of outstanding debt paid by capital firms at each time, $w(t)$ represents the household's wage, $L(t)$ the aggregate working hours and $C(t)$ is aggregate consumption.

At each time, households build a diversified portfolio of firm loans, which is why their opportunity cost is the risk-free interest rate. This functional form is consistent with Durusu-Ciftci et al. (2017), given the allocation of households' funds in two kinds of investment.

In order to preserve the original aggregate capital accumulation equation, we introduce the following transversality condition:

$$\int_t^{\infty} e^{-r(\tau-t)}(P_A(\tau) - \beta(\tau)P_A(\tau))d\tau = 0,$$

which means full repayment of outstanding debt, in the long run.

The consumer's intertemporal optimization problem results in the representative agent, faced with a constant rate of return r, rationally choosing to have her consumption growing at the rate given by the usual Euler equation:

$$g_c = \frac{\dot{C}(t)}{C(t)} = \frac{1}{\sigma}(r-\rho). \tag{4}$$

3.3. Information asymmetries

The optimal contract established between lender and borrower characterizes itself by the following minimum-requirement rule for external financing:

$$\overline{w}_j\gamma R_j(t)x_j(t) = rx_j(t) + r\beta_j(t)P_{A,j}(t), \tag{5}$$

where $\overline{w}_j$ represents the limit value of one idiosyncratic shock w_j that ensures an agreed-upon loan repayment, γ reflects the aggregate risk, $R_j(t)$ represents the j-th firm's renting price for its capital good $x_j(t)$, and r represents the risk-free interest rate. We omit the expected-value operators for easiness of reading. The capital firm must meet, at each time, both the cost of producing its capital good and its debt obligations. This constitutes the minimum requirement to be met by the j-th capital firm and provides a reinterpretation of the capital firm's profit function in Evans et al (1998), extended in order to include a decomposed risk measure that affects sales. Here, we link uncertainty to the cost state verification à la BGG's (1999) assumption, which gives an endogenously motivated reason for the existence of an external finance premium, i.e., an opportunity cost to internal funding, meant to compensate the lender for adverse selection and moral hazard.

The premium depends on the borrower's ability to repay its loan in the following period – i.e., its net worth –, which in turn depends on a default probability. For such a probability to exist, we assume that any capital firm (the borrower) can go bankrupt. In so doing, we also capture the natural continuous stochastic occurrence of "births" and "deaths" of firms in one economy.

Once capital firms can go bankrupt, there are, under (5), two possible outcomes in any given period: If $w_j \geq \overline{w}_j$, the borrower pays amount $rx_j(t) + rP_{A,j}(t)$ and keeps the difference $w_j\gamma R_j(t)x_j(t) - rx_j(t) - rP_{A,j}(t)$. If $w_j < \overline{w}_j$, the borrower goes bankrupt, and receives nothing. The lender pays monitoring cost $hw\gamma R_j(t)x_j(t)$, required to observe the firm's sales inflows and keeps what he finds. Given that the cardinality of the possibilities space is equal to two, we modify the rule including default probability $F(\overline{w}_j) = \Pr[w_j < \overline{w}_j]$ and, by extension, the external finance premium, such that:

$$\left\{[1-F(\overline{w}_j)]\overline{w}_j + (1-h)\int_0^{\overline{w}_j} wdF(w)\right\}\gamma R_j(t)x_j(t) = r\left(x_j(t) + \beta_j(t)P_{A,j}(t)\right)$$

Similarly to BGG's (1999) framework, we assume that borrowers are risk neutral, hence willing to absorb lenders' monitoring costs, thus facing the external finance premium given by $h\int_0^{\overline{w}_j} wdF(w)$.

Assuming zero depreciation, capital accumulates according to the real economy's equilibrium condition that investment equals savings:

$$\dot{K}(t) = Y(t) - C(t) - \int_t^{\infty} e^{-r(\tau-t)}(P_A(\tau) - \beta(\tau)P_A(\tau))d\tau.$$

3.4. R&D sector

The production function for new ideas/new designs is Romer's (1990):

$$\dot{A}(t) = \delta L_A(t)A(t), \tag{6}$$

where $\delta > 0$ represents research activities' efficiency, $A(0)\rangle 0$, and linearity of $\dot{A}(t)$ in $A(t)$ ensures a balanced growth path solution with $L_A(t)$ constant. Knowledge affects production in two ways. Firstly, a new design implies the production of a new capital good, used in final good (aggregate output) production. Secondly, it increases the stock of knowledge, hence constituting a *positive*[2] economic externality, through knowledge's *non-rivalry* property and carries important implications for the model's results. In turn, knowledge's *partial excludability,* through patent rights, is responsible for the monopolistic competition environment in the capital goods' sector. Specification (6) also implies that researchers' marginal productivity increase with the stock of knowledge, $A(t)$, due to the functional form of (1).

3.5. Capital good's sector

Given that final good's sector lives in perfect competition, capital firms rent their goods at $R_i(t) = \frac{dY(t)}{dx_i(t)}$, thus facing demand curve:

$$R_i(t) = \alpha {L_Y}^{1-\alpha} x_i(t)^{\alpha-1}.R(t) = \alpha {L_Y}^{1-\alpha} x(t)^{\alpha-1}$$

The *j*-th capital firm maximizes its profits, at each time, subject to finance constraint (5). The result is, we find, one generalization of Romer's (1990) original problem:

$$\max_{x_j(t),\overline{w}_j} \left(1-\Gamma\left(\overline{w}_j\right)\right) sR_j(t)x_j(t) \tag{7}$$

$$s.t.\left[\Gamma\left(\overline{w}_j\right) - h\Phi\left(\overline{w}_j\right)\right] sR_j(t)x_j(t) = x_j(t) + \beta_j(t)P_{A,j}(t),$$

where $\Gamma(\overline{w}_j) \equiv \int_0^{\overline{w}_j} wf(w)dw + \overline{w}_j \int_{\overline{w}_j}^{+\infty} f(w)dw$ is the lender's expected gross share of profits; $h\Phi(\overline{w}_j) \equiv h\int_0^{\overline{w}_j} wf(w)dw$ are the expected monitoring costs; and $s = \frac{\gamma}{r}$. While $\Gamma(\overline{w}_j)$ and $h\Phi(\overline{w}_j)$ are constant, s remains variable in the steady state. In order to obtain a balanced growth path solution, we propose the following definition:

Def: *A steady state solution is the vector* $R \in \mathbb{R}^{\mathscr{T}_t}$ *that solves optimization problem (7) such that* $E\{s\} = \frac{1}{r}$, *where* $\mathscr{T}_t$ *represents the cardinality of the set of capital firms in existence at each t.*

This definition implies an expected absence of aggregate shocks in equilibrium, for any probability distribution of variable γ, hence ensuring the existence of a balanced growth path solution. The first order conditions for problem (7) are[3]:

$$\left[1-\Gamma\left(\overline{w}_j\right) + \lambda\left(\Gamma\left(\overline{w}_j\right) - h\Phi\left(\overline{w}_j\right)\right)\right] sR_j(t) - \lambda = \lambda\alpha\beta_j(t)\frac{1-\alpha}{\delta}L_{Y,i}^{-\alpha}x_j^{\alpha-1}; \tag{8.1}$$

$$\Gamma'\left(\overline{w}_j\right) sR_j(t) = \lambda\left(\Gamma'\left(\overline{w}_j\right) - h\Phi'\left(\overline{w}_j\right)\right) sR_j(t), \tag{8.2}$$

where λ is the Lagrange multiplier. This is true because solutions are interior. Condition (8.2) leads to:

$$\lambda = \frac{\Gamma'\left(\overline{w}_j\right)}{\Gamma'\left(\overline{w}_j\right) - h\Phi'\left(\overline{w}_j\right)}, \tag{9}$$

which is always positive assuming, like BGG, that $\left(\frac{\overline{w}_j f(\overline{w}_j)}{1-F(\overline{w}_j)}\right)' > 0$. Solving (9), we obtain $\frac{f(\overline{w}_j)(1-F(\overline{w}_j) - \overline{w}_j f(\overline{w}_j))}{\left(1-F(\overline{w}_j)\right)^2} > 0$, which is the same as having $\Gamma'(\overline{w}_j)\rangle\Phi'(\overline{w}_j)$.

Now, let:

$$\rho\left(\overline{w}_j\right) = \frac{\lambda}{1-\Gamma\left(\overline{w}_j\right) + \lambda\left(\Gamma\left(\overline{w}_j\right) - h\Phi\left(\overline{w}_j\right)\right)}$$

Then, the optimal renting price of *j*-th capital firm is given by:

[2] This is true because R&D firms are not required to compensate researchers for past ideas. It is, however, neglected here, hence creating a source of non-optimality of the final general-equilibrium solution.

[3] These conditions result from the existence of a perfectly competitive labor market, under Romer's framework, together with the accumulation of intellectual stock $A\dot{(}t) = \delta L_A(t)A(t)$.

$$R_j = \frac{\rho(\overline{w}_j)(1-\alpha)}{s\alpha(1-\rho(\overline{w}_j)(\Gamma(\overline{w}_j) - h\Phi(\overline{w}_j)))}, \tag{10}$$

where $\rho(\overline{w})$ is a measure of the elasticity between the lender's and the borrower's expected return, relative to the total contractual expected return. It follows that the equilibrium capital good consumption in a non-symmetric economy with informational asymmetries between lenders and borrowers is:

$$x_j(t) = L_Y(t)\left[\frac{s\alpha^2(1-\rho(\overline{w}_j)(\Gamma(\overline{w}_j) - h\Phi(\overline{w}_j)))}{\rho(\overline{w}_j)(1-\alpha)}\right]^{\frac{1}{1-\alpha}} \tag{11}$$

The non-symmetry of conditions (10) and (11) constitutes an obstacle to finding the model's aggregate dynamics. So, let $\mathscr{F}_t \subset \mathbb{N}$ be the non-empty number of capital firms in existence at any given time $t \in T$. Individual firms can disappear, but by guaranteeing that there is always at least one firm in existence at any time, we can study the optimal behavior of those in existence when $t \to \infty$. That is, in order to study the aggregate dynamics of the economy through the optimal behavior of capital firms, we must guarantee both intra-temporal and intertemporal symmetry, i.e., we must ensure the existence of one representative capital firm, at any given moment, whose optimal behavior is invariant across time. Following Acemoglu's theorem of the representative firm (Acemoglu, 2009), let $X_t = \left\{\sum_{j\in\mathscr{F}} x_j : x_j \in X_j foreachj \in \mathscr{F}_t\right\}$ be the economy's set of production possibilities and let $\widehat{X}(\widehat{R}) \subset X$ be the set of profit maximizing net supplies. Let $\widehat{x} = \sum_{j\in\mathscr{F}} \widehat{x}_j$ be the optimal production decision of the representative capital firm, for the optimal capital goods' price vector $\widehat{R} \in \mathbb{R}^F$, which corresponds to (14.6). Let us assume that $\widehat{x} \notin \widehat{X}(\widehat{R})$. This implies the existence of x' such that $\widehat{R}x' > \widehat{R}\widehat{x}$. It follows that, by definition of X, there exists $\{x_j\}_{j\in\mathscr{F}}$ with $x_j \in X_j$ such that:

$$\widehat{R}\left(\sum_{j\in\mathscr{F}} x_j\right)\Big\rangle\widehat{R}\left(\sum_{j\in\mathscr{F}} \widehat{x}_j\right),$$

there being at least one $j' \in \mathscr{F}$ such that $\widehat{R}x_{j'} > \widehat{R}\widehat{x}_{j'}$, and this contradicts the hypothesis that $\widehat{x}_j \in \widehat{X}_j(\widehat{R})$. Hence, we have sufficient conditions to guarantee the existence of a representative capital firm for whom we have that $\widehat{x} = \sum_{j\in\mathscr{F}} \widehat{x}_j$.

Maintaining Romer's symmetry in the final goods' sector, we can deduce symmetry over each capital firm's renting-price, in order to find the following optimal equations for the representative capital firm:

$$R = \frac{\rho(\overline{w})(1-\alpha)}{s\alpha(1-\rho(\overline{w})(\Gamma(\overline{w}) - h\Phi(\overline{w})))} \tag{12}$$

and

$$x(t) = L_Y(t)\left[\frac{s\alpha^2(1-\rho(\overline{w})(\Gamma(\overline{w}) - h\Phi(\overline{w})))}{\rho(\overline{w})(1-\alpha)}\right]^{\frac{1}{1-\alpha}}, \tag{13}$$

which aggregate the dynamics of all capital firms. From Acemoglu's theorem and proof of consistency, $\rho(\overline{w})$ in conditions (12) and (13) represents a sum of the individual $\rho(\overline{w}_j)$ over the set $\mathscr{F}_t \subset \mathbb{N}$. So, while individual capital firms can go bankrupt – meaning that, in the steady state, $\rho(\overline{w}_j) = 0$ –, the representative capital firm has an infinite horizon, because $\mathscr{F}_t$ is non-empty.

The assumption of monopoly rights over the use of an invented and patented capital good implies charging a price above marginal cost for such capital good. This generates profits that create incentives for R&D. The free-entry condition in the R&D sector implies that the present value of future discounted profits of selling the capital good embodying a new, patented idea must at least be equal to the cost of its patent, supported up front. That is, the intertemporal zero-profit condition is:

$$P_A(t) = \int_t^\infty \pi_u e^{-\int_t^u r_v dv} du$$

By applying the Leibniz rule to its time differentiation, we get:

$$\dot{P}_A(t) = -\left[\pi_u e^{-\int_t^u r_v dv}\right]_t^\infty + \int_t^\infty \pi_u \left[r(t)\left(e^{-\int_t^u r_v dv}\right)\right] du,$$

which is equivalent to the Hamilton-Jacobi-Bellman equation:

$$r(t)P_A(t) = \pi(t) + \dot{P}_A(t),$$

which Thompson (2008) interprets as the trade-off that each agent faces, at each time, between investing her endowment at the risk-free return r and investing in a patent and earning risky monopoly returns.

3.6. Dynamic general equilibrium

We analyze the model's long run dynamics in its balanced growth path solution, which we know to exist because of (6). The Euler equation (4) says that in a balanced growth path the interest rate r must be constant. Then the produced quantities of each capital good (13) are also constant, once $L_Y(t)$ is constant as well. This result yields that K and Y grow at the same rate as A:

$$g_Y = g_K = g_A. \tag{14}$$

Then, dividing (6) by $A(t)$, we find the technological progress mechanism:

$$g_A = \delta L_A(t),$$

which implies that at each time the rate of technological progress depends on the number of researchers (assuming full employment), that must be constant in a balanced growth path equilibrium.

The labor market is competitive, hence wages must equal across sectors. Intersection between the wages' equations:

$$w_Y(t) = \frac{dY(t)}{dL_Y(t)} = (1-\alpha)A(t)\left[\frac{x}{L_Y(t)}\right]^{\alpha}$$

and

$$w_A(t) = \frac{d\dot{A}}{dL_A(t)}P_A = \delta A(t)P_A,$$

yields the equilibrium price of investment in R&D:

$$P_A = \frac{1-\alpha}{\delta}\left[\frac{x}{L_Y(t)}\right]^{\alpha}. \tag{15}$$

Equation (15) reveals that, in a balanced growth path, $\dot{P_A} = 0$, following that:

$$r = \frac{\delta\alpha}{(1+\beta)(1-\alpha)}L_Y\left(1-\frac{\alpha l(\overline{w})}{1-\alpha}\right),$$

where:

$$l(\overline{w}) \equiv \frac{(1-\rho(\overline{w})(\Gamma(\overline{w})-h\Phi(\overline{w})\,)\,)}{\rho(\overline{w})}$$

Variable $l(\overline{w})$ constitutes our model's informational asymmetry parameter, which depends negatively on elasticity $\rho(\overline{w})$.

The economy's aggregate production function being Cobb-Douglas, we are able to build the general equilibrium system:

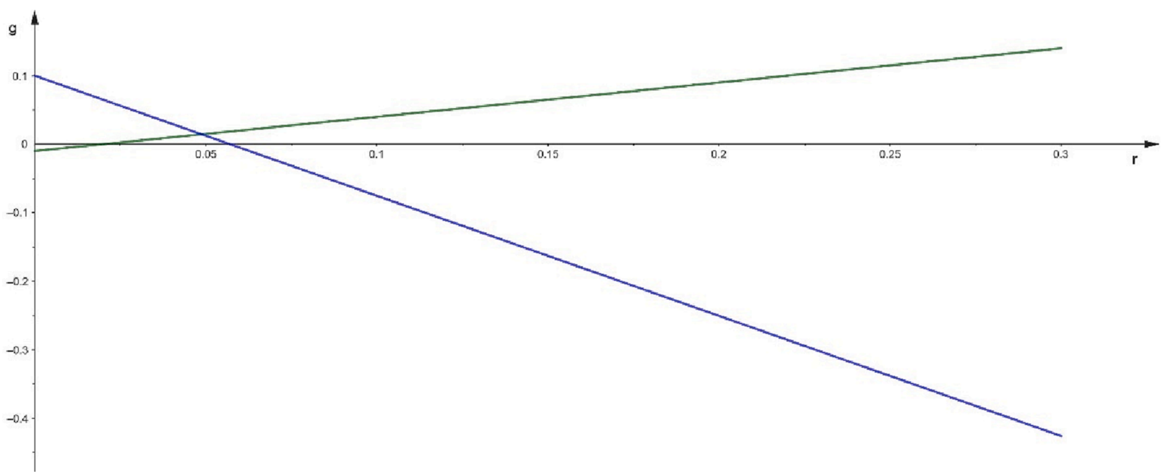

Fig. 1. General Equilibrium solution.

$$\begin{cases} g = \frac{1}{\sigma}(r-\rho) \\ g = \delta\overline{L} - \frac{r(1+\beta)(1-\alpha)}{\alpha\left(1-\frac{\alpha l(\overline{w})}{1-\alpha}\right)} \\ \dot{K}(t) = Y(t) - C(t) - \int_t^{\infty} e^{-r(\tau-t)}(P_A(\tau)-\beta(\tau)P_A(\tau))d\tau. \end{cases} \tag{16}$$

What we have done to prove equality between the growth rates of C and Y was to take the limit of $\frac{\dot{K}(t)}{K(t)}$ when $t\to\infty$. Because of the transversality condition, the third term of the capital accumulation equation disappears. The system's solution gives us the balanced growth path general equilibrium economic growth rate $g_C = g_Y = g_K = g_A = g$:

$$g = \frac{\delta\overline{L}\alpha\left(1-\frac{\alpha l(\overline{w})}{1-\alpha}\right) - \rho(1+\beta)(1-\alpha)}{\alpha\left(1-\frac{\alpha l(\overline{w})}{1-\alpha}\right) + \sigma(1+\beta)(1-\alpha)}. \tag{17}$$

Growth solution (17) is a generalization of Romer's (1990) equilibrium growth rate that encompasses the effects of financial frictions in the economy through parameter $l(\overline{w})$. Further details are available in Appendix A. Fig. 1 shows a simulation ran for our general equilibrium solution. We have assumed Thompson's (2008) parameter values:

$$\sigma = 2; \rho = 0.02; \alpha = 0.4$$

$$\overline{L} = 1; \beta = 1; \delta = 0.1$$

In addition, assuming a normal distribution for the contractual risks and therefore the existence of well-defined cumulative distribution functions, we have chosen value -1.0667 for $l(\overline{w})$.

The positively sloped plot represents the Euler equation, while the negatively sloped plot represents the Technology equation. The intersection occurs at the point where the interest rate equals 0.048818 and the economy's growth rate equals 0.014409.

Equation (17) represents the equilibrium long run growth rate of one economy with agent-based financial frictions. We see it as one generalization of Romer's (1990) growth solution. In the next section, we analyze the properties of the equilibrium regarding fluctuations in $l(\overline{w})$.

4. Interactions between informational asymmetries and economic growth

Function l evaluated at $\overline{w}$ formally represents the following relationship between the contractual returns:

$$l(\overline{w}) = -\varepsilon_{NL,GB}(1-\Gamma(\overline{w})) - 2(\Gamma(\overline{w}) - h\Phi(\overline{w}))$$

where $\varepsilon_{NL,GB} = \frac{1}{\lambda}$ represents a ratio of derivatives – one kind of elasticity measure between the lender's net expected returns and the borrower's gross expected returns. Then, from (17) we obtain:

$$g'(l(\overline{w})) = -\frac{\alpha^2(1+\beta)(\delta\overline{L}\sigma+\rho)}{\left[\alpha\left(1-\frac{\alpha l(\overline{w})}{1-\alpha}\right)+\sigma(1+\beta)(1-\alpha)\right]^2}$$

and

$$g''(l(\overline{w})) = -\frac{2\alpha^4(1+\beta)(\delta\overline{L}\sigma+\rho)}{(1-\alpha)\left[\alpha\left(1-\frac{\alpha l(\overline{w})}{1-\alpha}\right)+\sigma(1+\beta)(1-\alpha)\right]^3}$$

The effects of the specified asymmetries on economic growth are hence always negative. Fig. 2 plots the derivative of the growth rate in regards to $l(\overline{w})$, for the same parameter values as earlier.

In the general case, the applicable domain where the solution does not explode is $\left\{l(\overline{w}) \in [0,1] : l(\overline{w}) \langle \frac{\sigma(1+\beta)(1-\alpha)^2+\alpha(1-\alpha)}{\alpha^2}\right\}$ which maps to $\{y \in \mathbb{R} : y < 0\}$. The solution explodes when $l(\overline{w})$ tends to $\frac{\sigma(1+\beta)(1-\alpha)^2+\alpha(1-\alpha)}{\alpha^2}$. Here, increases in elasticity $\varepsilon_{NL,GB}$ further decrease economic growth at a marginally increasing rate, while increases in the external finance premium are benefic to economic growth. If one were to assume an inverse relationship between risk aversion and our elasticity measure, this could imply a positive effect of the risk aversion coefficient σ on growth, as suggested by Davidsson (2012). Furthermore, given that $g'\to 0$ when $l(\overline{w})\to 0$, the effects of these informational asymmetries on growth are asymptotically null.

The asymmetries' overall negative effect on growth is in line with studies such as Fu (1996), who argues that asymmetric information affects investment, hence economic growth negatively. Our hoped contribution to the literature on informational asymmetries, capital accumulation and growth is to explain the channel through which such effects may occur.

The overall increase in the elasticity measure results from a decrease in monitoring costs. Assuming that monitoring costs h are an increasing function of the representative firm's revenue (Jain, 2001), such decrease in h means lower revenues hence lower aggregate growth. In our numerical example, this happens in the neighborhood of value $\frac{21}{2}$. If the elasticity drops low enough, its effects on

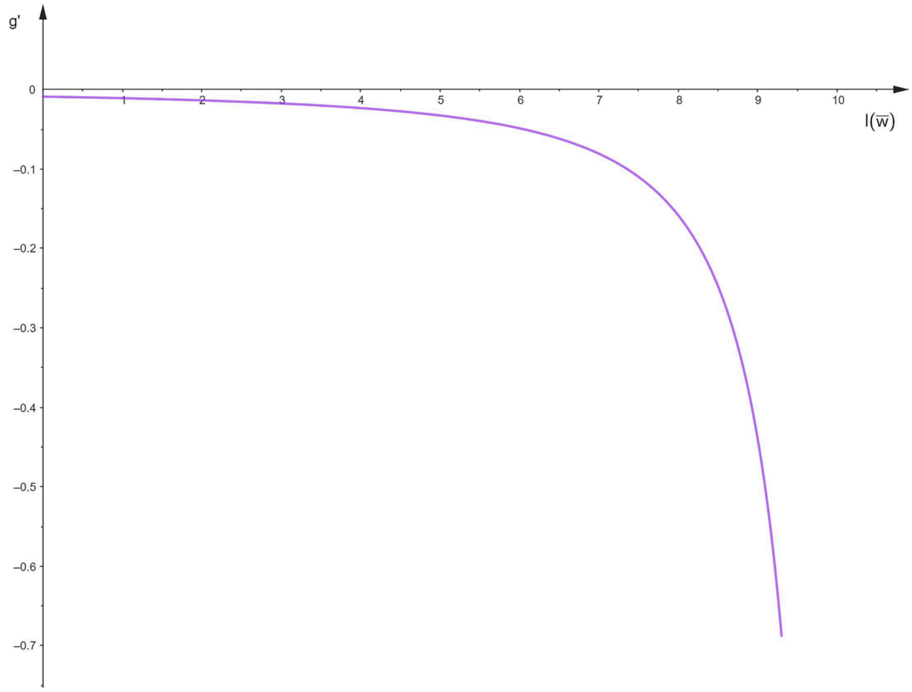

Fig. 2. Plot of the derivative of g, regarding financial parameter $l(\overline{w})$.

growth tend to zero.

As in the original partial equilibrium BGG's framework, the effects of isolated systemic shocks in some given period move across time. To help visualize the accelerator mechanism, let us take, between t and $t+1$, the aggregate shock $\gamma - \Delta$, where $\Delta > 0$ represents any unforeseen effect that affects the representative capital firm's output, relative to the previous period. We approximate $\dot{K(t)} \approx K(t+1) - K(t)$, which follows from the households' intertemporal constraint (5), because of the linearity of $\dot{K(t)}$ in its terms. We also assume that fluctuations in capital accumulation are very small, which is a plausible assumption given that the capital's growth rate $\frac{\dot{K(t)}}{K(t)}$ is constant. Facing a negative shock, the firm's profits are:

$$\pi_{\Delta}(t) = w(\gamma - \Delta)\frac{(1-\alpha)}{s\alpha l(\overline{w})}x(t) - rx(t) - x\beta(t)P_A(t),$$

which, in order to isolate the quantitative effects of the aggregate shock, can be represented as:

$$\pi_{\Delta}(t) = \pi(t) - \frac{\Delta w(1-\alpha)}{s\alpha l(\overline{w})}x(t),$$

which, in turn, given the proposed approximation, when replaced in the households' intertemporal constraint, will decrease the following period's aggregate capital by amount $\frac{\Delta w(1-\alpha)}{s\alpha l(\overline{w})}x(t)$. Appendix A offers technical details on the relationship between aggregate capital accumulation and capital firms' profits. Without loss of generality, we attach this representative household's balance sheet loss to the returns from loans to capital firms. Holding the remaining terms constant, this implies a decrease in the number of firms entering the capital market at $t+1$, given the decrease of the external financing needed to meet the capital firms' free entry condition. Under the representative capital firm premise, this implies a lower aggregate output in the following period, thus perpetuating and amplifying the isolated shock Δ at t.

5. Data and econometric model

Empirical research on the determinants of economic growth has knowingly identified several important growth influencers, among whom initial conditions stand out, rendering initial income one indisputable explanatory variable in any growth empirical model, as one can see, for instance, in studies such as Barro (1991), Mankiw et al. (1992), Borensztein et al. (1998), Alfaro et al. (2004) and Moral-Benito (2012).

For aggregate growth analysis, one of the advantages of dynamic panel data models relative to simpler data structures is that it allows for a better understanding of the adjustment dynamics (see e.g., Islam, 1995). The technical challenges that arise under this framework are well known, and while some of them can be fixed under relatively conventional procedures such as least squares' estimation – e.g., fixed effects (FE) and random effects (RE) commonly used on static panels –, others may require more specialized methods. Additional challenges may arise in panels with a small number of individuals N and large time period T – typical macro panels.

Our panel contains observations for 27 member states of the European Union[4] during the period 2008–2016 (i.e. $N = 27$ and $T = 9$). The baseline empirical growth model is the augmented Solow model,[5] which means that the selected variables comprise measures of initial income, human and physical capital, and population growth. In addition to these variables, we have constructed a variable that proxies our model's key parameter, $l(\overline{w})$, and we have also included some variables from Moral-Benito (2012), according to their Bayesian posterior probabilities, namely Population, Population under 15, Labor Force, Urban Population, and Consumption Share. Table 1 lists all the potential independent variables, as well as the dependent variable.

We have built variable lw_{it} according to definition (18). It has two components. Firstly, the elasticity of the lenders' liquid returns relative to the borrowers' gross returns was approximated by calculating the ratio between the countries' banks' return on assets (after tax) and the representative firms' gross profits, both as percentage variations. Banks' return on assets' data is from the World Bank's Global Financial Development. Amadeus provides national data for representative firms' gross profits. We have filtered the active firms with a maximum current ratio of 1, therefore limiting our analysis to companies with at least as many liabilities as assets. For each country in the panel, we then selected a number of firms ranging between 10% and 50% of the filtered firms, depending on how many firms met the initial requirements.[6] We then used Acemoglu's theorem to average each sample at each period, thus obtaining, for each country, a time-series of the representative firm's gross profits. We have obtained the second component of (18) in a similar fashion, by averaging the firm's annual operational revenues.

Due to data unavailability, we could not evaluate our variables before 2008, hence could not compare the pre and post crisis GDP's response to variations in the regressors. Tables 2 and 3 contain our variables' descriptive statistics for 2008 and 2016, respectively. The first period of the panel was marked by a low average lw_{it}, with high cross-sectional variability. As lw_{it} reflects the symmetric form of (18), this trend may suggest both a low average elasticity of the lenders' returns relative to the borrowers' returns and/or low representative firms' returns. By the end of the analyzed period, lw_{it}'s coefficient of variation was approximately 1/10 of its initial value.

Population growth decreased between 2008 and 2016, with slight variations in both the percentages of urban and young populations in these countries. This is not surprising, reflecting a global trend of decreasing birth rates in developed countries (see, e.g., Grant et al. 2004). The overall trend amongst the different levels of education in each country's labor force, reflecting human capital accumulation, was a substantial decrease between 2008 and 2016. The cross-sectional average of the labor force engaging in secondary education dropped from approximately 32% to 29% of the labor force. The cross-sectional (percentage) average of the labor force with a college degree registered a slight increase due to the overall drop of the cross-sectional averages.

The capital education level, Lfwe2, shows the highest effect, hence one would expect this variable to have a more significant impact on growth than its counterparts, during this period. Its downward trend may be related with the global phenomenon of slowing innovation and technological diffusion (Andrews et al., 2015). This effect, combined with a cross-sectional average decrease of approximately 10 percentage points in capital investment, despite an average increase in household spending, may explain the slow aggregate growth registered between 2008 and 2016. This appears to be consistent with the findings of a growing body of literature on the great productivity slowdown (see, e.g., Duval et al., 2020).

Table 4 displays the estimation results of our model, through ordinary least squares (OLS), fixed effects (FE) and random effects (RE) estimation procedures. All estimates are corrected for heteroskedasticity and random patterns of autocorrelation among countries. Furthermore, they have been calculated with year dummy variables to make the assumption of no correlation across individuals in the idiosyncratic disturbances, made by the robust estimates of the coefficient standard errors, more likely to hold. The choices made regarding the explanatory variables that were in fact included in the regression were influenced by the descriptive statistics - the major effect, regarding human capital accumulation, appears to lie with the capital level of education, which is supported by literature (Moral-Benito, 2012) – and by issues of collinearity involving the percentage of young population and the logarithm of household spending. Moreover, we have identified an adjustment process in the capital investment share of GDP, hence the use of its first lag.

The OLS estimation of the dynamic model presents highly statistically significant estimates, including those for variable lw_{it}. However, it faces one major problem, given that, by construction, $y_{i,t-1}$ is endogenous to the error term u_{it}: because $y_{i,t}$ is a function of the unobserved heterogeneity μ_i, it follows that $y_{i,t-1}$ is also a function of μ_i. This is called "dynamic panel bias". The existing positive correlation between the lagged dependent variable and the error term makes the OLS estimator upward biased and inconsistent. The RE GLS estimation is also biased, given that the demeaned transform renders the new lagged variable endogenous to the error term.

The FE estimation, despite eliminating μ_i, does not eliminate dynamic panel bias[7]. Under the Within Groups transformation, $y_{i,t-1}$ becomes $y^*_{i,t-1} = y_{i,t-1} - \sum_{t=2}^{T} y_{i,t-1}/(T-1)$ and the error becomes $u^*_{i,t-1} = u_{i,t-1} - \sum_{t=2}^{T} u_{i,t-1}/(T-1)$, which correlates negatively with

[4] Due to data unavailability, Denmark was not included in the analysis.

[5] Romer's (1990) aggregate production function (2) in our model is a Solow's aggregate production function: $Y = {L_Y}^{1-\alpha} \int_1^A {x_i}^{\alpha} = {L_Y}^{1-\alpha} A x^{\alpha} = K^{\alpha}(AL_Y)^{1-\alpha}$.

[6] For Austria, Cyprus, Greece, Lithuania and Luxembourg, we have selected the entirety of the output lists, due to the relative shortage of companies meeting the needed requirements.

[7] An Hausman test on the RE and FE estimates indicated that the cross-sectional differences are systematic, hence justifying the need to worry about dynamic panel bias and eliminating the fixed effect.

Table 1
Variable sources and definitions.

Variable	Source	Definition
Lgdp (Dependent Variable)	OECD	Logarithm of real gross domestic product (GDP) per capita
Invshare	PWT 6.2	Capital investment as a share of GDP
Lfp15	WDI	Labor force participation rate as a percentage of the population with ages 15+ (national estimates)
Lhsp	OECD	Logarithm of household spending in millions of USD
Lp	WDI	Logarithm of total population
Lfwe1	WDI	Percentage of total labor force with basic education
Lfwe2	WDI	Percentage of total labor force with capital education
Lfwe3	WDI	Percentage of total labor force with advanced education
Lw	Amadeus + GFD	Financial parameter from the extended version of Romer's model that proxies the behavior of $l(\overline{w})$
Popg	WDI	Population growth
Up	WDI	Logarithm of the total urban population
Yp	WDI	Logarithm of the population below 15 years old

Note: OECD refers to the Organization for Economic Cooperation and Development's digital database; PWT 6.2 refers to Penn World Table 6.2; WDI refers to World Development Indicators from The World Bank; GFD refers to Global Financial Development from The World Bank; and Amadeus refers to a European database with information about approximately 21 million firms, including financial reports, accounting and administrative data.

Table 2
Descriptive statistics – 2008.

	N	Mean	Standard deviation	p25	p50	min	max
VARIABLES							
Lgdp	27	10.30	0.389	9.944	10.34	9.553	11.37
Invshare	27	0.250	0.0519	0.214	0.248	0.165	0.343
Lfp15	27	57.97	4.909	53.81	59.24	49.10	66.55
Lhsp	27	3 362	4 805	429.8	1 351	61 44	16 822
Lp	27	15.89	1.448	14.98	16.04	12.92	18.22
Lfwe1	27	36.66	11.56	28.34	36.72	14.92	63.58
Lfwe2	27	68.07	5.135	63.88	66.89	60.32	79.37
Lfwe3	27	80.03	3.608	76.44	80.31	73.41	85.86
Lw	27	29.14	348.0	14.90	88.43	−1.017	684.7
Popg	27	0.328	0.869	−0.175	0.313	−1.666	2.039
Up	27	0.714	0.125	0.611	0.684	0.522	0.976
Yp	27	0.159	0.0174	0.145	0.155	0.133	0.204

Table 3
Descriptive statistics – 2016.

	N	Mean	Standard deviation	p25	p50	min	max
VARIABLES							
Lgdp	27	10.52	0.360	10.22	10.47	9.878	11.56
Invshare	27	0.146	0.0593	0.0958	0.131	0.0711	0.320
Lfp15	27	58.35	4.750	55.13	58.61	49.50	72.09
Lhsp	27	4 098	5 910	554.4	1 728	78.46	21 105
Lp	27	15.90	1.437	14.87	16.10	13.03	18.23
Lfwe1	27	33.99	10.87	26.05	33.86	15.30	58.56
Lfwe2	27	65.31	5.126	60.95	64.21	58.33	76.38
Lfwe3	27	78.62	3.946	74.80	78.82	71.52	84.25
Lw	27	146.4	174.4	26.09	142.8	−345.4	521.4
Popg	27	0.261	0.851	−0.315	0.129	−1.271	2.289
Up	27	0.728	0.129	0.627	0.708	0.538	0.979
Yp	27	0.156	0.018	0.144	0.152	0.131	0.217

Note: Own elaboration with Stata 14 software. The displayed data refers both to the first and last observed years of the panel.

$y_{i,t-1}$, by construction. This, therefore, renders the Within estimator of ρ downward biased and inconsistent. However, the estimator is consistent when $T \rightarrow \infty$. For this reason, some authors argue that, when analyzing macro panels, which typically cover a small number of countries N over a large period T, the bias of the Within estimator will not be that large for moderate T (Baltagi, 2005, pp. 135-136). But that is not the case here. Furthermore, given that the OLS estimates are upward biased and the FE estimates are downward biased, it follows that the "true" value of the parameter ρ must belong to interval $]0.6704, 1.0106[$. This gives us a useful check on the other estimators' results.

Table 4
Estimation Results of the Least Squares Methods.

	OLS	Random Effects	Fixed Effects
Log. GDPpc(t-1)	1.0106***	0.9995***	0.6704***
	(0.0118)	(0.0155)	(0.0532)
Investment share(t-1)	−0.3223***	−0.3301***	−0.0424
	(0.0753)	(0.1087)	(0.3212)
Lw	−0.0000**	−0.0000	−0.0000
	(0.0000)	(0.0000)	(0.0000)
Labor Education 2	−0.0001	0.0001	−0.0016
	(0.0005)	(0.0006)	(0.0019)
Population Growth	−0.0070		
	(0.0052)		
Urban Population		−0.0048	−0.5038
		(0.0555)	(0.3233)
R^2	0.99	.	0.93
RMSE	0.03	0.03	0.03
N	148	148	148

* $p < 0.1$; ** $p < 0.05$; *** $p < 0.01$.

While, in principle, the dynamic panel bias problem could be solved by instrumental variables estimation (2SLS), the estimators would be biased if in presence of weak instruments. Furthermore, following Baum et al (2003), we have performed a White test in order to exclude homoskedasticity, rendering the GMM-based methods preferable to IV, *ceteris paribus*. The difference GMM (dGMM) estimator introduces lagged levels of the endogenous variables, rendering them predetermined instead. The optimal estimators are obtained by solving a minimization problem in a system of moment conditions, where too many instruments can lead to over identification of the system, with too many algebraic solutions and, ultimately, inefficient estimates. It then uses the first-differences transformation to purge the fixed effects. Table 5 displays the GMM's estimation results. The results suggest high statistical significance, in particular for the capital investment share from the previous period, which presents a negative relationship with current period's logarithm of real GDP per capita. We have predicted the residuals of the first stage regression of the capital investment share on its first lag and used them on the full OLS equation. A *t*-test on the coefficient of the residuals resulted in rejection of the null hypothesis, thereby rendering the investment share endogenous, along with the lagged dependent variable. The lagged investment share's sign remains unchanged across the estimations. Assuming that aggregate capital investment is financed by credit growth – a necessary assumption for the validity of our proposed extension of Romer's model –, the negative sign of our estimate may be understood in light of Leitão (2012), whose results suggest that credit growth weakens the banking system, hence weakening the whole economy. The benefits to economic growth of the labor force's capital education may then depend on the amount of credit in the banking system. Relating with our proposed growth theory, this could yield some useful information on the nature of the different marginal relationships between financial asymmetries and growth discussed in Subsection 3.3. Nonetheless, the coefficient of the labor force with one capital level of education holds no statistical significance across the different estimations. However, given the underlying panel's dimension and Moral-Benito's (2012) rule of thumb for inference validity, one ought to be skeptical about generalizing these relationships to periods other than those following some great financial distress. Furthermore, both the results for population growth and initial income appear to be consistent in direction with other results such as the FE LSDV model for the unrestricted model of Islam (1995).

The difference GMM estimator's efficiency increases with T. However, it performed poorly on persistent series with small T (Baltagi, 2005, pp. 147-148). The system GMM (sGMM) estimator, on the other hand, has high efficiency gains relative to dGMM, as

Table 5
Estimation results of the generalized method of moments' methods.

	sGMM	dGMM
Log. GDPpc(t-1)	1.0737***	0.9553***
	(0.0207)	(0.0775)
Investment share(t-1)	−0.6098***	−0.8980***
	(0.0800)	(0.1412)
Lw	−0.0001***	−0.0001***
	(0.0000)	(0.0000)
Urban Population	0.0763**	−0.8255
	(0.0352)	(0.5218)
Labor Education 2	0.0013**	0.0025
	(0.0006)	(0.0029)
Population Growth	−0.0372***	−0.0251
	(0.0118)	(0.0287)
Sargan test	0.00	0.41
N	148	129

* $p < 0.1$; ** $p < 0.05$; *** $p < 0.01$.

$\rho \to 1$. However, the estimate obtained for ρ does not lie within the credible range – values above 1 suggest an unstable dynamics, with accelerating divergence away from equilibrium values. The dGMM estimate, nevertheless, not only lies within the credible range, but it is actually in pair with the estimates of Islam (1995) for OECD's sample. Both estimates underwent a small-sample correction to the covariance matrix estimate, resulting in t instead of z test statistics for the coefficients and an F instead of Wald χ^2 test for overall fit, which tends to over-reject the null as a result of small sample sizes (Roodman, 2009).

We have instrumented both $lgdp_{it}$ and the first lag of $invshare_{it}$ with second order levels, which are exogenous by construction. This means that Stata created seven instruments for $lgdp_{it}$ and six instruments for $invshare_{it}$. The remaining regressors were considered exogenous, along with seven time dummies – the first two rows of each country are eliminated in the equation in levels – making a total of 23 instruments in the dGMM estimation. Here, the Sargan test regarding over identifying restrictions did not reject the null hypothesis, with $Prob = 0.155$, which attests for the validity of these instruments. We have rejected the null hypothesis in the sGMM estimates, hence rendering the instruments invalid. Furthermore, the Arellano-Bond test for second-order autocorrelation – which is the one of interest, given the levels used as instruments for the endogenous regressors – did not reject the null hypothesis of inexistence of autocorrelation, with $Prob = 0.990$. As expected, in both models we have rejected the null of first order autocorrelation, which is built in the model by default. Finally, following Hayakawa (2009), we have applied the forward orthogonal deviations transform, instead of first differencing, to eliminate the country-specific effects. Theoretically, we find that the estimates obtained through dGMM are technically superior. As expected, $\widehat{\rho} \in]0.6704, 1.0106[$.

The results reported in Table 5 show that variable lw_{it} is statistically significant at 1% and has a negative coefficient, meaning that during the analyzed period the specified informational asymmetries between lenders and borrowers had a negative impact on economic growth in OECD countries. These results confirm our proposed model's prediction of a negative sign for the coefficient of lw_{it}, suggesting the empirical validity of introducing our financial parameter to explain economic growth.

Still, we must acknowledge that data limitations forced the analysis to be restricted to the post-crisis period, with a bounded panel dimension. The asymptotic properties of the GMM estimators revealed to suffer from finite-sample biases. Despite the careful choice of the estimation methods and the small-sample correction to the covariance matrix estimate, there may be efficiency gains in expanding the analysis to include a greater number of countries and a longer time span. Ideally, future data sets will be large enough to analyze pre and post crises relationships between informational asymmetries and economic growth. Furthermore, the employment of Bayesian analysis – specifically Bayesian Model Averaging – could potentially enrich the obtained results. Looking at Moral-Benito (2012), one could apply the BACE-SDM approach to the dynamic panel in order to obtain the parameters' posterior probabilities, after obtaining the model's posterior probabilities through Markov Chain Monte Carlo simulations. However, such approach should be based on least squares estimation of our dynamic panel data model – for efficiency purposes through the FE model – in order to obtain a value for each model's sum of squared errors. As we stand, such analysis would be inefficient, given the small T defining our panel and, very possibly, the lack of studies on which to base our $l(\overline{w})$'s prior assumption. We address this to future research.

6. Concluding Remarks

We have introduced Bernanke, Gertler and Gilchrist's (1999) cost state verification specification in Romer's (1990) growth model. Our developed extension of Romer's model thus contemplates financial frictions through the introduction of uncertainty in the capital sector's profit function. This has created endogenously motivated informational asymmetries between lenders and borrowers, which have an impact on the monopolistic capital market and on long-term real economic growth. We have found that the effects of the specified informational asymmetries on economic growth are significant and negative.

Additionally, in the introduced model's balanced growth path solution, the sensitivity of the representative parties' expected contractual returns to one another and the external finance premium directly influence economic growth. While this feature adds complexity to the original framework, we believe that it potentially makes it representative of the economic-financial interactive reality.

In the present paper, both the idiosyncratic and the aggregate shocks are exogenous. Further research, in line with Kiyotaki and Moore (1997) in the sense of introducing collateral constraints to the capital sector, may lead us to a growth model with endogenous financial shocks.

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Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

Appendix. A

In order to solve system (16) with the accumulation of capital over an infinite horizon, we need to study the wealth allocations within the economy. Let us start by analyzing the following equation:

(A1) $B(t) = K(t) + P_A(t)A(t)$,

where $B(t)$ represents the representative consumer (lender)'s assets, $K(t)$ the stock of physical capital and $P_A(t)A(t)$ the holding of shares on capital goods. The corresponding law of motion of the consumer's assets is given by:

$$\dot{B}(t) = rB(t) + r\beta(t)P_A(t)A(t) + w(t)L(t) - C(t) - \int_t^{\infty} e^{-r(\tau-t)}(P_A(\tau) - \beta(\tau)P_A(\tau))d\tau, \tag{A2}$$

where $w(t)$ represents the consumer's wage, $L(t)$ the working time and $C(t)$ the consumption. In each moment in time, consumers build a well-diversified portfolio with firm loans, which is why their opportunity cost is the risk-free rate. The functional form is in line with Durusu-Ciftci et al (2017), given the separation of the households' funds in two kinds of investment. Because of the finance rule built in the borrower's optimization problem, equation (A.2) is consistent with firms' behavior. Substituting (A.1) in (A.2) and solving for the evolution of the stock of physical capital, we get:

$$\dot{K}(t) = rK(t) + \left(rP_A(t) - \dot{P}_A(t)\right)(t) + r\beta(t)P_A(t)A(t) - P_A(t)\dot{A}(t) + w(t)L(t) - C(t) - \int_0^t (P_A(\tau) - \beta(\tau)P_A(\tau))d\tau$$

If we take equation (12), replace $s = \frac{R^k}{r}$ and solve it for r, we get the following:

(A3) $r(t) = \frac{\gamma\alpha^2 l(\overline{w})}{(1-\alpha)}\frac{Y(t)}{K(t)}$.

In equilibrium, final goods producers have zero profits, unlike the capital goods.

producers. In order to participate in the capital goods' market, one has to.

acquire a patent for the value of $P_A(t)$. After this initial investment, the producer has property rights over its time horizon. Notwithstanding, our representative producer in existence at each moment in time will enjoy property rights over an infinite horizon. The patent price is given by:

$$P_A(t) = \int_t^{\infty} \pi_u e^{-\int_t^u r_v dv} du,$$

because future cash flows are discounted at a rate that matches the cost of obtaining the necessary funds to finance those cash flows. Therefore:

$$\dot{P}_A(t) = -\left[\pi_u e^{-\int_t^u r_v dv}\right]_t^{\infty} + \int_t^{\infty} \pi_u \left[r(t)\left(e^{-\int_t^u r_v dv}\right)\right]du$$

which is equivalent to the Hamilton-Jacobi-Bellman:

$$\pi(t) = r(t)P_A(t) - \dot{P}_A(t)$$

Taking (A.3) and the fact that $K(t) = A(t)x(t)$, by solving for the amount of capital goods we get:

$$x(t) = \frac{\gamma\alpha^2 l(\overline{w})}{r(t)(1-\alpha)}\frac{Y(t)}{A(t)},$$

which we can now use in the capital firms' expanded profit function under optimal behavior, yielding

$$\pi(t) = \alpha\frac{Y(t)}{A(t)} - \frac{\gamma\alpha^2 l(\overline{w})}{(1-\alpha)}\frac{Y(t)}{A(t)} - r(t)\beta(t)P_A(t)$$

implying that:

$$\dot{K}(t) = rK(t) + \pi(t)A(t) + r\beta(t)P_A(t)A(t) - P_A(t)\dot{A}(t) + w(t)L(t) - C(t) - \int_0^t (P_A(\tau) - \beta(\tau)P_A(\tau))d\tau$$

Recalling (12), that the assumption of a competitive labor market implies $w_Y(t) = w(t) = w_A(t)$ and that the free entry condition in the capital goods market is equivalent to $P_A(t)\dot{A}(t) = w_A(t)L_A(t)$ and, therefore, $P_A(t)\dot{A}(t) = (1-\alpha)Y(t)\frac{L_A(t)}{L_Y(t)}$, we have that

$$\dot{K}(t) = rK(t) + \alpha Y(t) - \frac{\gamma\alpha^2 l(\overline{w})}{(1-\alpha)}Y(t) - P_A(t)\dot{A}(t) + w(t)L(t) - C(t) - \int_0^t (P_A(\tau) - \beta(\tau)P_A(\tau))d\tau,$$

which is equivalent to

$$\dot{K}(t) = Y(t) - C(t) - \int_0^t (P_A(\tau) - \beta(\tau)P_A(\tau))d\tau$$

which allows us to relate the BGP growth rates in (14).

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