The Dynamics of Firm Growth
A Re-Examination

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Abstract

This article provides evidence that shed further light on the dynamic relationships between finance, physical investment, R&D, productivity and profit. Estimating relationships for 5,289 observations on Swedish manufacturing firms with 50 or more employees over the 1992-2000 periods, the following substantial empirical findings emerge. First, physical investments are sensitive to both internal financing (profit) and external financing (expressed as leverage, or the ratio of debt over equity and debt) while R&D is only weakly affected by the firm's finance conditions. Second, no robust correlation between knowledge investments and ordinary investments can be established. Third, R&D has a strong effect on productivity and profit. The reverse relationship is fragile and typically insignificant. The causality between physical capital and productivity is bidirectional, while increased profit leads to more capital but not the vise versa.

Keywords: Financial constraints, R&D, Investments, Productivity, Panel data
JEL Codes: 031, O32

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1. INTRODUCTION

The empirical literature has shown inconsistent results regarding determinants to company growth. This article provides additional evidence on this issue. Using data for Swedish 5,289 firm level observations in the manufacturing sector with 50 or more employees over the 1992-2000 period, this paper re-examines the correlation between finance and investments, and the correlation between investments and firm performance.

The empirical study focuses on four possible causal relationships by asking the following questions: First, will higher interest expenditures due to increased leverage leave less room for investment expenditures? Is there evidence that capital and R&D investment are affected differently by increased leverage? Second, will a profit increase – before interest and taxes – stimulate investments? Is there evidence that capital and R&D investment are affected differently by increased profit? Is there a reverse relationship between investment and profit? Third, will higher R&D expenditures lead to increased capital investments? Is there evidence of a two-way relationship between R&D and capital investment expenditures? Fourth, is there evidence of a bi-directional relationship between productivity and investment expenditures? Is there any difference in this possible two-way relationship between investment in knowledge and machinery and equipment?

The first two links consider capital market imperfections that introduce possible credit rationing. The theoretical literature suggest that presence of asymmetric information and moral hazard problem may be particular serious in the case of R&D investments. However, empirical results from recent studies shows that there are differences in financial constraints between new and old firms, between small and large firms, between high technological firms and other firms, and between countries as well.

The third correlation that we consider is the relationship between R&D-investment and capital investment. Using French data, Mairesse and Siu (1984) find no short-run relationship between R&D and capital investment. This result was confirmed more than two decades later by De Jong (2007). However, based on a panel of U.S. pharmaceutical firms, De Jong reports that R&D and capital investments are cointegrated and that a long-run bi-directional causality exits. Several other studies find that causality exists between R&D and physical investment and that it occurs in both ways also in a shorter perspective. Some papers indicate that R&D leads to increased physical investment but not the vise versa.

The final links re-examined in this paper concern investment and firm performance. It is a commonly held view that R&D and investments in machinery and equipment makes a vital contribution to firms’ performance (Griliches, 1988; Romer, 1990; Geroski, Machin and Van Reenen, 1993; Jones, 1995; Van Reenen, 1997). Firms invest in knowledge and capital in order to enhance their competitiveness and capability to earn profits. Ericsson and Pakes (1995) show that the stochastic outcome of a firm’s own investments in R&D together with physical capital, human capital, marketing and the competitive pressure from other firms within or outside the industry determine the sales performance, profitability and growth of the firm. In the paper we investigate whether there is a two-way causality between investment and productivity. Moreover, the possible differences between R&D and capital are explored. In general, the literature reports that tangible investments have a stronger impact on firm productivity than intangible investments.

With an upward biased "naive" pooled OLS-estimator and a downward biased within estimator as references to the preferred dynamic GMM-estimator, the following distinct results can be drawn from the study. First, the elasticity of productivity with respect to R&D and physical investment respectively is positive and statistically significant, even with proper controls for simultaneity and for permanent differences across firms. We also find some evidence that productivity leads to increased R&D and increased physical investment but this relationship is weaker than the causality in the opposite direction. Second, a two-way relationship between both categories of investment and profit exits, but the relationship is less strong than between investment and productivity. Third, physical investments are sensitive to both internal financing (profit) and external financing (expressed as leverage, or the ratio of debt over equity and debt) but R&D is only weakly affected by the finance conditions. One possible explanation for the latter is that we consider firms with 50 or more employees, while capital constraint is a problem mostly for smaller R&D firms. Third, R&D has a strong effect on productivity and profit. The reverse causality is weaker. The causality between physical capital and productivity is bidirectional, while increased profit leads to more capital but not the vise versa.

The paper begins with a brief review of the literature on (i) the correlation between finance and investments, (ii) the possible interdependence between capital and knowledge investments, and (iii) the correlation between these two categories of investments and firm performance (section 2). It then proceeds to describe the data set, which covers about 600 manufacturing firms over a nine-year period (section 3). This is followed by a presentation of the empirical dynamic GMM-model and the specification of the equation (section 4). The result section compares the GMM estimates with two simpler models. (Section 5). The paper concludes with a summary of the findings (section 6).

2. LITERATURE REVIEW

In recent years significant improvements in econometric modeling of causal relationships have been made. These include studies by Granger (1969), Sims (1972), Holz-Eakin, Newey and Rosen (1988), Arellano and Bond (1991), Arelleano and Bover (1995) and Blundell and Bond (1998) who offer new approaches for systematic testing and determination of causal directions among different indicators of interest.

The literature that we will briefly review below is based on either of the two main methods for investigating the causality in economic panel data, namely the Granger approach, and instrumental variable regressions using original or augmented Holz-Eakin, Newey and Rosen (1988)/ Arellano-Bond (1991) estimators.

2.1 Finance and investment

Ever since Modigliani and Miller (1958) demonstrated that there should be no role for liquidity variables such as cash flow or profit in the investment equation in a world of perfect capital markets, an extensive literature has examined the importance of firms' capital structure in the prevailing non-perfect world It is widely agreed that asymmetric information and other agency costs or moral hazard problems affect the relationship between a firm and external lenders. Likewise, it is broadly agreed that possible financing constraints imposed by less perfect capital markets hit intangible investments more severe than tangible investments. A third stylized fact related to the firms' financing decisions is that financial constraints are particularly pronounced in the case of small firms. While large firm more flexibly can choice to finance investment expenditures between retained earrings and issuance of equity or debt, small firms are mainly addicted to internal resources.

Motivated by the growing interest in innovation and growth, many recent empirical studies examining financial constraints compare ordinary and knowledge investments. Assessing the relationship between financial decisions and the investment in both fixed capital and R&D based on a sample of about 11,000 Belgian manufacturing firms over the period 1991-2000, Cincera (2002) confirms that small firms and ordinary investments are associated with financial constraints. However, in contrast to suggestions in the theoretical literature, R&D has not been found to be strongly affected by cash constraints. Similar results are reported by Audretch and Weigang (1999), Mulkay, Hall and Mairesse (2000) and others. Bond et al. (1999) report that financial constraints affect the decision to engage in R&D rather then the level of R&D-spending. One possible explanation for the weak link between fluctuation of internal financial resources and variation in research and development expenditures might be that the wages of the R&D personnel represents more than 50% of R&D expenditures and training, and the R&D-personnel is associated with high adjustments cost when firing and re-hiring.

Mixed results are presented by Harhoff (1998). Collating different models, Harhoff suggests that both R&D and physical capital are affected by financial constraints when the non structural accelerator and error-correction specifications are applied on a panel of 236 large manufacturing firms. Estimation based on the structural Euler equation, though, does not produce any evidence that R&D-investments are associated with cash flow.

Several other studies find positive impact of cash flow on both R&D and physical investments, though the relationship is more significant and stronger for physical investments. See for instance Hall (1992), Himmelsberg and Petersen (1994) and Hall and van Reenen (1999). Some works investigate whether the capital market of individual countries matter for the presence of capital constraints.

Comparing three panels of US, France and Japanese high technology companies, Hall et. al (1999) suggest that both R&D and physical capital investments are cash constrainted in the US only. Using other datasets and an alternative econometric methodology, Mulkay, Hall and Mairesse (2000) confirm a stronger presence of credit constraints on R&D-investments in the American economy than in Europe (France).

Chiao (2001) investigates the relationship between debt, R&D and physical investment in samples including firms in all industries, in science-based industries, and in nonscience-based industries, respectively. He shows that debt is a resource to finance both physical investment and R&D in nonscience-based industries, but debt is only a resource to finance physical investment but not R&D in science-based industries. The latter is in contrast to Hall (1992) who suggested that leverage ratios and R&D investments are strongly negatively correlated among R&D intensive firms in the U.S.

Brown et al. (2007) study a panel of 1,347 U.S. publicly traded firms from seven high-tech industries over the period 1990-2004. They find that for young firms, the estimated effect of both cash flow and external equity finance are and quite large and highly significant.

Binz and Czarnitski (2008) investigate whether the presence of financial constraint is associated with difference in uncertainty between routine R&D and cutting-edge R&D. Using a German panel data of 354 different firms over the period 1993-2002, the authors find that R&D of a more risky nature is difficult to finance by external resources.

2.2 R&D and physical capital.

Empirical investigations of the relationship between R&D and other investments report that the volatility of R&D expenditures (mainly scientists and engineers) is smaller than variations in physical capital (acquisition of new machinery and equipment). A a large body of literature studying the causal relationship between these two has been anything but unambiguous (See for instance Jong 2007).

Lach and Schankerman (1989) belong to the group of work suggesting a positive and bi-directional relationship. Investing the interaction among research and development, capital investment, and the stock market performance at for 191 firms in science-based industries they find that granger causality between current R&D and current physical investment occur in both ways. Moreover, the authors show that previous R&D affect current physical investment, and previous physical investment also affect current R&D.

Lach and Rob (1996), however, suggest that R&D granger-causes capital investment, but capital investment does not stimulate R&D investment. Chiao (2001) suggest that the granger causality between capital investment and R&D is bi-directional only in the short run.

De Jong (2007) examines the relationship between capital investment and R&D in a panel of 36 pharmaceutical firms. This study suggests that capital investment does not Granger-cause R&D and vice versa in the short run. However, a long-run causality test shows that R&D and capital investment are cointegrated and the causality runs in both directions. This implies that capital investment depends on the success of the R&D effort over time. Moreover, contemporaneous increased investment stimulates R&D in the next period, possible in order to support the success of the current products.

In the work by Ciao (2001) he found that the contemporary relationship between R&D and physical investment is positively reciprocal, particularly in science-based industries.

2.3 The two-way relationship between investment and performance

In the past, empirical researchers have confirmed a significant positive relationship between investments and sales performance, productivity and profit (Cohen and Klepper 1996, Griliches, 1998, Sutton, 1998). Three kind of relationships are possible: (i) investment in physical capital and R&D influence subsequent firm performance, (ii) firm performance influence subsequent investment, and (iii) investment and performance are influenced simultaneous by a third factor.

In contrast to overwhelming evidence that investments are good predictors of firm performance, at least in the level dimension[1], the literature is rather thin and less conclusive on both the reverse causality and the simultaneous influence from for instance the business cycle on R&D and profit.

Early contributions by Minasian (1962) and Scherer (1965) suggested that R&D exerts an influence on subsequent profit, while Brown (1957) showed that R&D and profit may be inversely related over the business cycle. Grabowski (1968) reported that current profit is positively related to future R&D investments.

Motivated by more efficient estimators, extended longitudinal data and new insights on specification issues a new wave of research continued to investigate the two-way relationship between investment and performance. Addressing specification issues when estimating the returns to R&D, Griliches (1979) highlights the important of a relevant time-lag structure since current research and development may not have an effect on measured productivity until several years later. Applying a distributed lag model on a sample containing 111 firms over a 16 year period, Branch (1974) found that R&D influences future profitability, and that R&D is influenced by past profitability. Using productivity as the output measure, more recent studies have questioned the positive bi-directional relationship between R&D and performance. In a study on Finnish data, Rouvinen (2002) suggest that R&D Granger causes productivity but not the vise versa. Franzen (2003) find that the causality mainly runs from R&D to productivity rather than the other way around, when using dynamic and augmenting

[1] However, regarding the R&D-productivity link the relationship is only robust across firms. In their survey of the literature, Klette and Kortum (2004) report a fragile and typically insignificant relationship between firms' R&D and their productivity growth.

error correction models on panel data from 22 manufacturing sectors in OECD-countries during the period 1972-94, in an autoregressive framework.

Mairesse and Hall (1996) apply a GMM methodology on two large panels of approximately 1,000 France and U.S. manufacturing firms covering over half of R&D spending in each country. Investigating the importance of R&D and physical capital on firm sales as a proxy for productivity, their results suggest the presence of simultaneity due to demand and liquidity shocks.

2.4 Expected relationships

In an attempt to summarize the robust findings from literature reviewed above, Figure 1 in the Appendix provides expected sign of the causal relationships that we will re-estimate in this paper. First we assume that increased leveraged is followed by a reduction in both R&D capital investment. We then expect that both increased R&D and capital should be positively correlated to productivity and profit as well, while the reverse causality is ambiguous. Finally, we a priori do not expect any strong correlation between knowledge investments and investments in machinery, equipment and other tangible assets.

It should be noted, however, that many past and recent empirical applications of panel data methods to micro-data on the issues discussed above essentially suffer from three kind of problems: (i) non-representative datasets, (ii) limitations in time series observations on various key variables and (iii) weak instruments in GMM-estimations where series are highly autoregressive, or non-stationary variables in short panels using the Granger approach. This motivates research efforts that can shed further light on the dynamic process of firm growth.

3. DATA

The data source used is this study covers the period 1992-2000. The initial data set consist of 11,367 observations on manufacturing firms in Sweden with 50 or more employees. The censoring is motivated by the data availability. The R&D data have been taken from the Swedish R&D surveys carried out by statistics Sweden. This survey is essentially a census for all manufacturing firms with 50 or more employees. Production, financial and education data have been merged with the R&D data, using unique company identification numbers. In the estimation procedure we further restrict the data to only R&D firms. This selection might produce selection bias but a robustness check using the heckman selection model is a first step showed no substantial differences to the reported results.

It should be noted that R&D-information at the firm level only are colleted biannually in Sweden. Hence, in the present case, we have R&D figures for the odd years 1993, 1995, 1997 and 1999. In the official register data, Statistics Sweden report estimated R&D expenditures for even years. This computation is done with several different methods. In the case of smaller firms in our population, missing values for year t are substituted by the reported $t\text{-}1$ value. The result of this procedure is reflected in row 1 of Table A displayed in the Appendix. It reports that 40 percent of all firms have identical R&D expenditures during two successively number of years.

The basic dataset is merged with administrative data. The economic variables are those commonly used in the literature that we are referring to in the present study. They included value added (VA), profit expressed as earnings before taxes (EB), physical capital as a stock measure (K), capital structure (CS) and number of employees (L). All variables are expressed in logarithm and in per employee terms. The definition of the variables and the way the variables have been trimmed is reported in Tables 2, Panel A and Panel B. Value added per employee (labour productivity), profit, capital stock and R&D have been deflated by the consumer price index. Net capital in volume has been computed by a perpetual inventory method with a constant rate of depreciation $(1-\delta)\ K_{t-1}+I_t$, where δ is 0.15. Due to log transformation issues, we only employ the profit variables when positive profit is observed.

Table 3 gives means and standard deviations for the variables used in the study. It also report summary statistics for the non R&D firms included in the original sample. Comparing R&D firms and non-R&D firms it is clear from the table that the R&D firms are more productive and profitable than other firms, the capital stock is larger, they are less leveraged and have more employees.

Table 3 reports pairwise correlations for R&D firms. As could be expected, profit and productivity are highly correlated. The capital stock has a stronger association with both performance measures than R&D. The leverage coefficient confirms that the relative size of interest cost correlates is negatively with profit and productivity.

Fig 2 (See Appendix) displays the lag structure of the capital stock, R&D and gross investment in machinery and equipment. The correlation between the three capital variables and their own lags shows that the flow of investment is considerable more volatile than the two other. In the econometric analysis we use capital stock but the flow of R&D.

There is an issue of accumulation and depreciation of the firms' knowledge capital. The literature has convincingly shown that the impact of current R&D on current productivity depends crucially on past R&D. Griliches (1979), and others argue that the stock of R&D is preferable to flow in the production function. In this case, the accumulation of knowledge capital should be treated in the same way as that of physical capital, using the ”perpetual inventory” process as a common framework. One problem with the perpetual-inventory model, discussed by Klette (1997) is that we need a long history of the firms' R&D expenditures in order to construct the knowledge capital stock. In many cases, like the present, limitation on the R&D observations is acute. We therefore use the flow measure.[2]

[2] The calculation of the capital stock is based on information on tangible assets provided by Statistics Sweden. We use this as a proxy for gross capital stock and calculate the growth as the difference between gross investment and and depreciation.

4. METHODOLOGY

Time series of cross sectional firm observations are typically quite short which brings about the issue of efficient estimators and estimation of individual heterogeneity effects. Consistent estimation of model parameters requires a sufficient number of time period observations for each firm.

Our panel is unbalanced, with some firms having more observations than others. In the estimation procedure, we are looking for an estimator for a typical “Arellano-Bond” situation: (i) “small T, large N” panels; (ii) a linear functional relationship; (iii) a left hand side variable explained by its own lagged values; (iv) some regressors may be endogenous; (v) fixed individual effects; and (vi) heteroskedasticity and autocorrelation within individuals, but the idiosyncratic disturbances are uncorrelated across individuals.

Unfortunately proposed estimators such as system generalized method of moments (GMM), although theoretically attractive, often are empirically complicated to apply and can easily generate invalid estimates. Crucial is the information provided by the test statistics and Roodman (2006) suggests that inferior estimators such as the OLS panel data estimator or the likewise “dynamic panel biased” within estimator both can be helpful when specifying the GMM-estimator; a good estimate of the true parameter estimate of a one-lag of the dependent variables should lie in the range between the OLS and the FE values.

The Arellano-Bover (1995)/Blundell-Bond (1998) estimator that we will employ assumes that the first differences of instrumenting variables used are uncorrelated with the fixed effects. This is an important improvement of the original Arellano-Bond model since it allows the introduction of more instruments. Moreover, the methodology offers forward orthogonal deviations, as an alternative to differencing. The advantage with forward orthogonal deviations is that it preserves sample size in our unbalanced sample which includes gap.

In this paper we employ the asymptotically more efficient two-step system GMM estimator augmented with a finite-sample correction to the two-step covariance matrix derived by Windmeijer (2000) in order to correct for downward biased standard errors. The GMM-estimator should correct for simultaneity bias coming from the endogeneity of variables and the presence of correlated firm-specific effects and the general model is the following:

$$y_{it} = \alpha y_{i,t-n} + \beta_1' x_{it} \ldots + \beta_n' x_{it-n} + \varepsilon_{it} \tag{1.1}$$

$$\varepsilon_{it} = \mu_i + \nu_{it} \tag{1.2}$$

$$E[\mu_i] = [\nu_i] = [\mu_i \nu_{it}] = 0 \tag{1.3}$$

where y_{it} is an observation firm [i] in period [t] 1992-2000, x_{it} is covariates commonly used in the literature we refer to in this paper. The error term ε_{it} consists of two variables: $[\mu_i]$ is an unobserved individual-specific time-invariant effect which allows for heterogeneity in the means of $[y_{it}]$ series across individuals, and [ν_{it}] is the traditional error term. We assume that [ν_{it}] are independent across individuals.

The first of our two benchmark models, included for the specification issue discussed above, is the "naive" OLS panel data estimator. One problem in applying OLS to equation (1), is that $y_{i,\ t}$-1 is endogenous to the fixed effect in the error term, which gives rise to "dynamic panel bias." By construction, the unobserved panel-level effects are correlated with the lagged dependent variables. The effect will be that the correlation with the error term inflates the coefficient estimate for the lagged dependent variable by attributing power that actually belongs to the fixed effect. One way to correct for endogeneity is to transform (difference) the data to remove the fixed effects. But the resulting Within Group estimator does not eliminate dynamic panel data bias as has been shown by Nickell (1981), Judson and Owen (1999), Bond (2002), Roodman (2006) and others. Instead the resulting estimates will be biased downwards.[3]

Specification of the model

We will specify six versions of equation (1.1), but the general model is the same for all regressions. In specification (2) , the logarithm of current labour productivity is estimated as a function of two lagged values of the logarithm of productivity (VA), current and two lagged values of the logarithm of research expenditures (R), current and two lagged values of the logarithm of the capital stock (K), current and two lagged values of the logarithm of the capital structure (CS), current and two lagged values of the logarithm of the employment (CS) nine year dummies (T) and 13 industry dummies (IC)

$$\begin{aligned} VA = \alpha_1 VA_{i,t-1} + \alpha_2 VA_{i,t-2} + \beta_1 R_i + \beta_1 R_{i,t-1} + \beta 2 R_{i,t-2} + \gamma_1 K_i + \gamma_1 K_{i,t-1} + \gamma_2 K_{i,t-2} \\ + \varsigma_1 CS_i + \varsigma_1 CS_{i,t-1} + \varsigma_2 CS_{i,t-2} + \zeta_1 L_i + \xi_1 L_{i,t-1} + \zeta_2 L_{i,t-2} + T + IC_i \end{aligned} \tag{2}$$

Compared to specification (2), in the third specification, we substitute VA for R, and R for VA. Otherwise specification (3) is identical with specification (2). In specification (4) the left-hand side variable is K, explained by its own past realizations, current and two lagged values of the logarithm of research expenditures (R), and current and two lagged values of the capital structure (CS). In the same manner as above, specification (5) explains profitability as a function of K and R.

$$\begin{aligned} R = \alpha_1 R_{i,t-1} + \alpha_2 R_{i,t-2} + \beta_1 VA_i + \beta_1 VA_{i,t-1} + \beta 2 VA_{i,t-2} + \gamma_1 K_i + \gamma_1 K_{i,t-1} + \gamma_2 K_{i,t-2} \\ + \varsigma_1 CS_i + \varsigma_1 CS_{i,t-1} + \varsigma_2 CS_{i,t-2} + \zeta_1 L_i + \xi_1 L_{i,t-1} + \zeta_2 L_{i,t-2} + T + IC_i \end{aligned} \tag{3}$$

[3] Roodman (2006) shows that "Under the Within Group transformation, the lagged dependent varibale becomes $y^*_{i,\ t-1}=y_{i,\ t-1}$ - 1/T-1(y_{i2} +…+y_{iT}) while the error becomes $\nu^*_{i,\ t-1}=\nu_{i,\ t-1}$ - 1/T-1(ν_{i2} +…+ν_{iT})…The problem is that the $y_{i,\ t-1}$ term in $y^*_{i,\ t-1}$ correlates negatively with the -1/T-1($\nu_{i,\ t-1}$) in $\nu^*_{i\ t}$ while, symmetrically , the -1/T-1($y_{it)}$ and ν_{it} term also move together."

$$K = \alpha_1 K_{i,t-1} + \alpha_2 K_{i,t-2} + \beta_1 VA_i + \beta_1 VA_{i,t-1} + \beta 2 VA_{i,t-2} + \gamma_1 R_i + \gamma_1 R_{i,t-1} + \gamma_2 R_{i,t-2}$$
$$+\varsigma_1 CS_i + \varsigma_1 CS_{i,t-1} + \varsigma_2 CS_{i,t-2} + \zeta_1 L_i + \xi_1 L_{i,t-1} + \zeta_2 L_{i,t-2} + T + IC_i \quad (4)$$

$$EB = \alpha_1 EB_{i,t-1} + \alpha_2 EB_{i,t-2} + \beta_1 K_i + \beta_1 K_{i,t-1} + \beta 2 K_{i,t-2} + \gamma_1 R_i + \gamma_1 R_{i,t-1} + \gamma_2 R_{i,t-2} +$$
$$\zeta_1 L_i + \xi_1 L_{i,t-1} + \zeta_2 L_{i,t-2} + T + IC_i \quad (5)$$

Specifications (6) and (7) include both capital structure (issuing of debt) and profit in the same equations when explaining R&D and physical capital respectively. It should be noted that the general lag structure in equations 2-7 is changed when it is required due to the presence of autocorrelation.

$$R = \alpha_1 R_{i,t-1} + \alpha_2 R_{i,t-2} + \beta_1 EB_i + \beta_1 EB_{i,t-1} + \beta 2 EB_{i,t-2} + \gamma_1 K_i + \gamma_1 K_{i,t-1} + \gamma_2 K_{i,t-2}$$
$$+\varsigma_1 CS_i + \varsigma_1 CS_{i,t-1} + \varsigma_2 CS_{i,t-2} + \zeta_1 L_i + \xi_1 L_{i,t-1} + \zeta_2 L_{i,t-2} + T + IC_i \quad (6)$$

$$K = \alpha_1 K_{i,t-1} + \alpha_2 K_{i,t-2} + \beta_1 EB_i + \beta_1 EB_{i,t-1} + \beta 2 EB_{i,t-2} + \gamma_1 R_i + \gamma_1 R_{i,t-1} + \gamma_2 R_{i,t-2}$$
$$+\varsigma_1 CS_i + \varsigma_1 CS_{i,t-1} + \varsigma_2 CS_{i,t-2} + \zeta_1 L_i + \xi_1 L_{i,t-1} + \zeta_2 L_{i,t-2} + T + IC_i \quad (7)$$

5. RESULT SECTION

This section reports the results. Table 4 displays the productivity equation. In Table 5 the elasticity of R&D is reported. Table 6 report the relationship between capital investments and its determinants. Table 7 presents the profit equation. In Tables 8 and 9 the two investment functions are re-specified and both capital structure and gross profit are included among the covariates. Table 10, finally, gives the summary results. Test statistics for the GMM-estimates are provided in Panel B of the Tables 4-9.

5.1 Productivity equation

Table 4 exhibits three regression results and standard errors on equation (1.1) when the dependent variable is log value added per employee. The first column reports the pooled OLS-regression. The second shows the within-estimates. Column 3 displays the GMM-estimates. Our main interest is how productivity if affected by R&D and physical capital and the focus is on the system GMM-estimator. The other two estimators are presented for specification issues and will only be commented in this respect. Additional covariates in the regressions are capital structure and employment. Industry dummies and a time trend are also included in the regression but not reported in the table.

As a first check of how well the GMM-model has been specified, we use the “Rule of thumb” suggested by Roodman (2006): Good estimates of the true parameter for the first lag of the dependent variable should lie in the range between the parameter estimates of this variable using the naive OLS and the fixed effects model. Row 1 shows that the first lag of productivity enters with highly significant coefficients in all three equations within the range 0.15-0.67. These results are consistent with the literature suggesting that productivity differences are highly persistent. Section four provides evidence that the within estimate (0.15) is downward biased while the OLS estimate (0.67) is biased upward. The GMM estimate is 0.46 and fulfils the requirement to be to between the two benchmark coefficients.

We now turn to the investment coefficients. The literature has shown the central role played by knowledge and capital in firms' production function. If one ignores the non-significant first-lag coefficients, Column 3 suggests that productivity is an increasing function of both tangible and intangible investments. The system GMM estimates indicate that the contemporaneous marginal effect is somewhat stronger for physical capital (0.064) as compared to R&D (0.017). However, the coefficient estimate indicates that R&D has a more persistent effect on productivity. While the second-lag coefficient for R&D is positive significant at the 5% level, its counterpart for capital is only weakly significant.

We now consider Panel B and the test statistics. The first order serial correlation test does not point to any misspecification of the model. The second order test is just outside the critical value to be satisfactory. The Sargan test for the additional instrument implied by the GMM-system is significant at the 1% level. Like-wise, the GMM overidentification test, suggested by Hansen (1982), does not indicate that the econometric model is misspecified.

5.2 R&D equation

Table 5 presents regression results for the R&D equation. Comparing the first lag of the dependent variable in the GMM-model with the two other models gives a first rough indication that the model is not misspecified. Column 3, Rows 2-3 reports quite sizeable estimates for the lagged R&D variable. Hence, among firms with 50 or more employees, current engagement in R&D is a good predictor of future R&D-ambitions. Comparing with the productivity equation, Table 4 suggests that the persistency of R&D is stronger than that of productivity.

While Table 4 reported that R&D causes productivity Table 5 shows that the reverse causality is weak. The coefficient estimates for the immediately effect and for the second lag of productivity are not statistically different from zero. The one-year lagged productivity variable is positive but only weakly significant.

Contemporaneous change in physical capital is positively related to R&D investment supporting the idea that innovation in form of ideas must be embodied in new machinery and equipment in order to generate sales, productivity and profit. However, capital estimates reported in Table 5 indicates that the effect is transitory. The lagged capital variables show that tangible investment year 1 have no influence on R&D year 2 and year 3. We also see that the capital structure variable report that R&D

investment is not sensible to issuing debt or increased costs for interest payment. Finally, the test statistics presented in table B is satisfactory suggesting that the equation is not misspecified.

5.3 Capital Investment.

Table 6 reports that the specification of the GMM-equation is just outside the Roodman-criteron when the capital equation is considered, but test statistics displayed in Panel B is entirely satisfactory.

Similar to R&D and productivity, the coefficient estimate for one-year and two-year lagged values of the capital stock indicates high degree of persistency. Moreover, increased R&D is inversely related to capital, although only the second-lag of the knowledge variables is statistically significant.

The contemporaneous increased leverage ratio is strongly positively related to capital investment, suggesting that firms finance their capital investment by issuing debt. But the raised debt year 1 has a negative influence on the capital investment year 2 although it decays rapidly. When lagging two periods, the elasticity of capital investment with respect to the capital structure is not significantly different from zero.

5.4 Profitability

The regression result for the profit equation is displayed in Table 7. The Roodman test and the test statistics in Panel B don't suggest that the model has to be re-specified. Row 1 shows that the current level of profit is highly correlated with the profit level last year.

The panel-data literature reports that increased investment levels suggest positive expectations on future profitability. This finding is partly confirmed by our regression results. Looking at our two investment variables intimates that R&D is stronger predictor of profit than capital. When capital is considered, only the current level is significant, but nearly outside any acceptable levels of significance. In contrast, the R&D-variable suggest that increased knowledge investments lead to higher profit with a lag of one year.

5.5 Investment as a faction of internal and external financing

While Tables 4 and 5 show the influence of issuing debt on investment, Tables 8 and 9 re-specify the two investment equations presented above by including profit among the determinants. The test statistics are satisfactory in both cases and we can therefore put our attention on the coefficient estimates.

Starting with the R&D-equation, Table 8 report that the firms' R&D-efforts do not vary, or vary only weakly (at the 10% level) with changes in the profitability. Similarly to the findings reported in Table 5, the coefficient estimates for capital structure shown in Table 8 confirm the unsuitability of debt at a source of finance for R&D investment.

Interestingly, Table 9 shows a difference in responses to increased profitability between capital and R&D investments. Our results give support to works by Bond, Harhoff, Van Reenen 1999, Cinera 2002 and other suggesting that R&D is a long term commitment not expected to be seriously affected by temporary financial constraints. In contrast, capital investment is sensitive to both external financing and internal financial sources through retained profitability.

6. SUMMARY

This paper starts by reviewing empirical applications of panel data methods to micro-data on the links between finance, investments and firm performance. The literature shows inconsistent results and partly they can be related to data limitations and methodological problems. In both cases continuing research efforts are motivated, that can shed further light on the dynamic process of firm growth.

The empirical study focuses on four possible causal relationships by asking the following questions: First, will higher interest expenditures due to increased leverage leave less room for investment expenditures? Is there evidence that capital and R&D investment are affected differently by increased leverage? Second, will a profit increase – before interest and taxes – stimulate investments? Is there evidence that capital and R&D investment are affected differently by increased profit? Is there a reverse relationship between investment and profit? Third, will higher R&D expenditures lead to increased capital investments? Is there evidence of a two-way relationship between R&D and capital investment expenditures? Fourth, is there evidence of a bi-directional relationship between productivity and investment expenditures? Is there any difference in this possible two-way relationship between investment in knowledge and machinery and equipment?

By applying a system GMM estimator on 5,289 firm observations from Swedish manufacturing firms over the 1992-2000 period, the main empirical finding can be summarized as follows. First, physical investments are sensitive to changes in both profitability and external debts while R&D is only weakly affected by the firm's finance conditions. One possible explanation for the latter is that we consider firms with 50 or more employees, while capital constraint is a problem mostly for smaller R&D firms. Second, no robust correlation between knowledge investments and ordinary investments can be established. Third, R&D has a strong effect on productivity and profit. The reverse relationship is fragile and typically insignificant. The causality between physical capital and productivity is bidirectional, while increased profit leads to more capital but not the vise versa.

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TABLE SECTION

Table 1 Variables, trimming and summary statistics

Panel A: There variables we used were the following:

• VA:	Log value added per employee
• EB:	Earnings before interest and taxes
• RD:	Log R&D per employee
• CS	Capital structure; total debt/(equity + total debt)
• K:	Net capital in volume computed by a perpetual inventory method with a constant rate of depreciation (1-δ) $K_{t-1}+I_t$, where δ is 0.15.
• L:	Log number of employees

The economic variables are expressed in 100 000 Swedish crowns (1 Swedish crown is about 9.50 Euro)

Panel B: The variables have been trimmed in the following way:

• VA:	The observation is dropped if value added is negative. Value added is upward censored to 0.8*sales
• EB:	Profit is downward censored to -1.0* sales times -1, Profit is upward censored to 0.6 * sales.
• R:	R&D is upward censored to two times sales if R&D. The observation is dropped if R&D/emp is larger than 200 billion Swedish crowns).
• CS	Capital structure is downward censored to 0 and upward censored to 1.

Table 2: Summary Statistics over the period 1992-200

	R&D Firms			Non R&D Firms		
	OBS	Mean	Std. dev	OBS	Mean	Std. dev
VA	5,289	6.10	0.48	6,078	5.97	0.49
EB	4,344	4.48	1.15	4,852	4.14	1.16
K	5,289	5.47	0.98	6,078	5.28	1.10
R	5,289	2.63	1.66	6,078	0.00	-
CS	5,289	0.70	0.19	6,078	0.73	0.19
L	5,289	5.40	1.09	6,078	4.69	0.74

Notes: VA: log value added per employee; EB: log earnings before interest per employee; K: Log capital stock per employee; R: Log R&D per employee; CS: Capital structure, Log employment per employee

The data contain all manufacturing Swedish firms with 50 or more employees. Panel C split these group into our investigated R&D firms and the rest of the firm.

Table 3: Pairwise correlation ober the period 1992-2000.

	VA	EB	K	R	CS	L
VA	1.000					
EB	0.748	1.000				
K	0.370	0.319	1.000			
R	0.203	0.235	0.010	1.000		
CS	-0.164	-0.176	-0.094	-0.027	1.000	
L	0.158	0.123	0.247	0.224	0.071	1.000

Notes: VA: log value added per employee; EB: log earnings before interest per employee; K: Log capital stock per employee; R: Log R&D per employee; CS: Capital structure, Log employment per employee.

Table 4: Regression results.
Dependent Variable: Productivity; log value added per employee (VA)

Panel A: Parameter estimates						
	OLS "Naive"		OLS FE		GMM	
N	2,978		2,298		2,298	
	Coeff	StDev	Coeff	StDev	Coeff	StDev
VA, t-1	**.573*****	.019	**.151*****	.023	**.464*****	.078
VA, t-2	.202***	.020	-.102***	.023	.014	.057
R, t-0	.006	.007	.000	.008	.017**	.011
R, t-1	-.016**	.007	-.033***	.008	-.007	.006
R, t-2	.015**	.007	-.016**	.008	.016**	.006
K, t-0	.039**	.016	.005	.019	.064***	.021
K, t-1	-.035*	.019	-.000	.019	-.005	.028
K, t-2	.048***	.015	.024	.018	.035*	.019

Panel B: GMM-test statistics	
Instruments for first difference equation:	Standard: year and industri dummies GMM-type: Lag (1/.). (L.VA, R, L, K, CS)
Instruments for level equation:	Standard: year and industri dummies GMM-type: Diff (L.VA, R, L, K, CS)
AR (1)	.005 [a]
AR (2)	.085 [b]
Sargan overid	.000 [a]
Hansen overid	.340 [a]
Diff.-in-Hansen test of exogeneity of instruments	
Diff.-in-Hansen test of exogeneity of instruments	
-Excluding groups	.171 [a]
-Difference	.869 [a]
2. Ivstyle	
-Excluding groups	.229 [a]
-Difference	.910 [a]

Notes: The table focuses on the relationship between productivity and R&D and physical capital respectively. Additional covariates in the model are capital structure and employment. Variables in the model are VA log value added per employee, R: log R&D- investment per employee, K: log Capital stock per employee, L: log employment, CS: capital structure (debt/(equity + debt)), industry dummies and year dummies. In order to save space, the coefficient estimates for the two latter is not reported

As a first check of the specification of the GMM-model, we use the "Rule of thumb" suggested by Roodman (2006): Good estimates of the true parameter for the first lag of the dependent variable should lie in the range between the parameter estimates of this variable using the naive OLS and the Fixed effects model. See VA, $_{t-1}$ in Row 1.

Test statistics (a) satisfactory, (b) less satisfactory, (c) unsatisfactory

Table 5: Regression results.
Dependent Variable: R&D; log R&D per employee (R)

Panel A: Parameter estimates						
	OLS "Naive"		OLS FE		GMM	
N	2,978		2,978		2,978	
	Coeff	StDev	Coeff	Coeff	Coeff	Corr. StDev
R, t-1	**.563*** **	.017	**.102*** **	.021	**.515*****	.054
R, t-2	.307***	.017	.027	.021	.178***	.042
VA, t-0	.046	.047	.001	.054	.017	.062
VA, t-1	.213***	.056	.120**	.060	.123*	.072
VA , t-2	-.148***	.053	-.068	.061	-.080	.055
K, t-0	.091**	.041	.102**	.050	.143**	.071
K, t-1	-.070	.051	-.052	.051	-.010	.047
K, t-2	-.014	.040	-.041	.047	-.004	.042
CS, t-0	.121	.168	.322	.198	.342	.211
CS, t-1	.142	.223	.039	.212	.062	.218
CS, t-2	-.318*	.111	-.071	.189	.011	.1658

Panel B: GMM-test statistics	
Instruments for first difference equation:	Standard: year and industri dummies GMM-type: Lag (1/.). (L.R, VA, L, K, CS)
Instruments for level equation:	Standard: year and industri dummies GMM-type: Diff (L.P, P, L, K, CS)
AR (1)	.000 [a]
AR (2)	.428 [a]
Sargan overid	.000 [a]
Hansen overid	.318 [a]
Diff.-in-Hansen test of exogeneity of instruments	
-Excluding groups	.696 [a]
-Difference	.028
2. Ivstyle	
-Excluding groups	.443 [a]
-Difference	.109 [a]

Notes: The table reports on the determinants to R&D (R). The explanatory variables in the model are log value added per employee (VA), log capital stock per employee (K), log employment, capital structure (CS) expressed as (debt/(equity + debt)). The log of employment, industry dummies and year dummies are also included. In order to save space, the coefficient estimates for the three latter are not reported

As a first check of the specification of the GMM-model, we use the "Rule of thumb" suggested by Roodman (2006): Good estimates of the true parameter for the first lag of the dependent variable should lie in the range between the parameter estimates of this variable using the naive OLS and the Fixed effects model. See row two from the bottom of panel A.

Test statistics (a) satisfactory, (b) less satisfactory, (c) unsatisfactory

Table 6: Regression results.
Dependent Variable: Physical Capital; log variable capital stock per employee (K)

Panel A: Parameter estimates						
	OLS "Naive"		OLS FE		GMM	
N	2,978		2,978		2,978	
	Coeff	StDev	Coeff	Coeff	Coeff	Corr. StDev
K, t-1	**.750*****	.017	.**325*****	.020	.**756*****	.030
K, t-2	.150***	.017	-.042	.020	.058*	.029
K, t-3					.098****	.029
VA, t-0	.050**	.020	.006	.022	.017	.044
VA, t-1	.069**	.024	.075***	.025	.109***	.030
VA, t-2	-.039*	.023	-.041	.025	-.050	.034
R, t-0	.017**	.008	.018**	.008	-.006	.010
R, t-1	-.008	.008	.012	.008	-.015	.010
R, t-2	-.009	.008	-.004	.008	-.029**	.011
CS, t-0	.306***	.073	.350***	.083	.294***	.122
CS, t-1	-.485***	.097	-.445***	.088	-.471***	.136
CS, t-2	.073	.075	-.011	.078	-.020	.093

Panel B: GMM-test statistics	
Instruments for first difference equation:	Standard: year and industri dummies GMM-type: Lag (1/.). (L.K, P, R, L, CS)
Instruments for level equation:	Standard: year and industri dummies GMM-type: Diff (L.K, P, R, L, CS)
AR (1)	.000 [a]
AR (2)	.178 [a]
Sargan overid	.000 [a]
Hansen overid	.288 [a]
Diff.-in-Hansen test of exogeneity of instruments	
-Excluding groups	.367 [a]
-Difference	.253 [a]
2. Ivstyle	
-Excluding groups	.318 [a]
-Difference	.305 [a]

Notes: Table focuses on the relationship between capital stock, productivity, R&D and capital structure. As a first check of the specification of the GMM-model, we use the "Rule of thumb" suggested by Roodman (2006): Good estimates of the true parameter for the first lag of the dependent variable should lie in the range between the parameter estimates of this variable using the naive OLS and the Fixed effects model. See row two from the bottom of panel A.

Variables in the model are VA: log value added per employee, R: log R&D- investment per employee, K: log Capital stock per employee, L: log employment, CS: capital structure (debt/(equity + debt)), industry dummies and year dummies.

Test statistics (a) satisfactory, (b) less satisfactory, (c) unsatisfactory

Table 7: Regression results.
Dependent Variable: Profit; log earnings before interest and taxes per employee (EB)

Panel A: Parameter estimates						
	OLS "Naive"		OLS FE		GMM	
N	2,978		2,298		2,298	
	Coeff	StDev	Coeff	StDev	Coeff	Corr. StDev
EB, t-1	**.549*****	.022	**.086*****	.027	**.377*****	.058
EB, t-2	.182***	.021	-.070	.026	.023	.039
K, t-0	.004	.049	-.029	.060	.106*	.064
K, t-1	.049	.060	-.055	.061	.090	.068
K, t-2	.030	.046	-.108*	.058	-.025	.053
R, t-0	-.028	.020	-.073***	.025	.007	.029
R, t-1.	.035	.022	-.013	.023	.048**	.021
R, t-2	.054***	.020	-.013	.023	.029	.027

Panel B:GMM-test statistics	
Instruments for first difference equation:	Standard: year and industri dummies GMM-type: Lag (1/.). ()
Instruments for level equation:	Standard: year and industri dummies GMM-type: Diff (L.π, R, K, L, CS)
AR (1)	.000 [a]
AR (2)	.212 [a]
Sargan overid	.000 [a]
Hansen overid	.152 [a]
Diff.-in-Hansen test of exogeneity of instruments	
Diff.-in-Hansen test of exogeneity of instruments	
-Excluding groups	.072 [b]
-Difference	.763 [a]
2. Ivstyle	
-Excluding groups	.172 [a]
-Difference	.284 [a]

Notes: Table focuses on the relationship between Profit and Physical Capital and Profit and R&D respectively.

As a first check of the specification of the GMM-model, we use the "Rule of thumb" suggested by Roodman (2006): Good estimates of the true parameter for the first lag of the dependent variable should lie in the range between the parameter estimates of this variable using the naive OLS and the Fixed effects model. See row two from the bottom of panel A.

Variables in the model are EB: log profit before interest and taxes per employee, R: log R&D- investment per employee, K: log Capital stock per employee, L: log employment, CS: capital structure (debt/(equity + debt)), industry dummies and year dummies

Test statistics (a) satisfactory, (b) less satisfactory, (c) unsatisfactory

Table 8: Regression results.
Dependent Variable: R&D; log R&D per employee (R)

Panel A: Parameter estimates						
	OLS "Naive"		OLS FE		GMM	
N	2,978		2,978		2,978	
	Coeff	StDev	Coeff	Coeff	Coeff	Corr. StDev
R, t-1	**.575*****	.020	**.109*****	.024	**.659*****	.038
R, t-2	.283***	.020	.752	.024	.290***	.032
EB, t-0	-.031	.023	-.077***	.026	-.013	.026
EB, t-1	.102***	.020	.035	.028	.072*	.037
EB, t-2	.004	.023	-.000	.027	-.024	.032
K, t-0	.080	.051	.096	.062	.032	.066
K, t-1	-.051	.063	-.040	.063	-.052	.066
K, t-2	-.032	.049	-.018	.060	-.082	.051
CS, t-0	.267	.205	.434*	.244	.162	.240
CS, t-1	-.010	.272	.055	.254	.138	.243
CS, t-2	-.208	.200	.076	.221	-.079	.201

Panel B:GMM-test statistics	
Instruments for first difference equation:	Standard: year and industri dummies GMM-type: Lag (1/.). (L.R, π, L, K, CS)
Instruments for level equation:	Standard: year and industri dummies GMM-type: Diff (L.R, π, L, K, CS)
AR (1)	.000 [a]
AR (2)	.178 [a]
Sargan overid	.000 [a]
Hansen overid	.288 [a]
Diff.-in-Hansen test of exogeneity of instruments	
-Excluding groups	.367 [a]
-Difference	.253 [a]
2. Ivstyle	
-Excluding groups	.318 [a]
-Difference	.305 [a]

Notes: Table focuses the impact of (i) Profit, (ii) Capital Stock and (iii) Capital Structure on R&D investments. The estimated coefficients of the first lag of the dependent variables indicate if the GMM estimates are somewhere between the biased Naive OLS estimate or the biased Fixed effect estimate. See R, t-1.

Variables in the model are EB: log earnings before interest and taxes per employee, R: log R&D- investment per employee, K: log Capital stock per employee, L: log employment, CS: capital structure (debt/(equity + debt)), industry dummies and year dummies.

Test statistics (a) satisfactory, (b) less satisfactory, (c) unsatisfactory

Table 9: Regression results.
Dependent Variable: Physical Capital; log variable capital stock per employee (K)

Panel A: Parameter estimates						
	OLS "Naive"		OLS FE		GMM	
N	2,978		2,978		2,978	
	Coeff	StDev	Coeff	Coeff	Coeff	Corr. StDev
K, t-1	**.723*** **	.021	**.292*****	.025	**.723*****	.032
K, t-2	.166	.020	-.013	.025	.167***	.024
EB, t-0	.000	.009	-.005	.011	.023	.015
EB, t-1	.040	.011	.035***	.011	.063***	.019
EB, t-2	.003	.009	.018	.011	.019	.013
R, t-0	.014	.000	.016	.010	-.011	.012
R, t-1	-.011	.010	.008	.010	-.008	.013
R, t-2	-.007	.009	-.009	.010	-.021*	.011
CS, t-0	.395***	.086	.290***	.101	.244*	.132
CS, t-1	-.514***	.114	-.429***	.105	-.403***	.088
CS, t-2	.074	.085	.009	.092	.065	.073

Panel B:GMM-test statistics	
GMM-test statistics	
Instruments for first difference equation:	Standard: year and industri dummies GMM-type: Lag (1/.). (L.K, π P, R, L, CS)
Instruments for level equation:	Standard: year and industri dummies GMM-type: Diff (L.K, π, R, L, CS)
AR (1)	.000 [a]
AR (2)	.240 [a]
Sargan overid	.000 [a]
Hansen overid	.066 [b]
Diff.-in-Hansen test of exogeneity of instruments	
-Excluding groups	.168 [a]
-Difference	.068
2. Ivstyle	
-Excluding groups	.284 [a]
-Difference	.002 [c]

Notes: Table focuses the impact of (i) Profit, (ii) R&D and (iii) Capital Structure on Physical capital investment, i.e growth of the Capital Stock. The estimated coefficients of the first lag of the dependent variables indicate if the GMM estimates are somewhere between the biased Naive OLS estimate or the biased Fixed effect estimate. See K, t-1.

Variables in the model are EB: log earnings before interest and taxes per employee, R: log R&D- investment per employee, K: log Capital stock per employee, L: log employment, CS: capital structure (debt/(equity + debt)), industry dummies and year dummies.

Test statistics (a) satisfactory, (b) less satisfactory, (c) unsatisfactory

Appendix:

Table A: Identitical R&D expenditures

Successively number of years	Number of firms	Fraction of all R&D firms
2	2,144	40.5%
3	1,171	22.1%
4	666	12.6%
5	380	7.2%
6	197	3.7%
7	111	2.1%
8	55	1.0%
9	23	0.4%

Fig 1: What can we expect based on the literature?

Relationship			Expected sign based on the literature
Capital structure	$\longrightarrow$	Physical capital	(ar): Contemporaneous change in debt can be followed by an increase or a decrease in capital investments.
Capital structure	$\longrightarrow$	R&D	(ar): If changes in capital structure towards more debt is following by reduction in R&D the relationship might be either one of simultaneity or transitory.
R&D	$\longrightarrow$	Profit	(+): Changes in R&D suggest positive expectations on profitability.
Profit	$\longrightarrow$	R&D	(ar) The estimated effect of profit on R&D is often not statistically different from zero.
Physical capital	$\longrightarrow$	Profit	(+): A larger capital stock will be associated with a higher level of profit.
Profit	$\longrightarrow$	Physical capital	(ar) The profitability estimate can be expected to be positive but with a weak degree of significance.
Physical capital	$\longrightarrow$	R&D	(ar): The elasticity of R&D with respect to physical capital is ambiguous.
R&D	$\longrightarrow$	Physical capital	(ar): The elasticity of capital with respect to R&D is ambiguous.
R&D	$\longrightarrow$	Productivity	(+): The estimates associated with current and lagged values of R&D on productivity are estimated to be positive
Productivity	$\longrightarrow$	R&D	(ar): Weak or no evidence is expected that productivity causes R&D.
Physical capital	$\longrightarrow$	Produc-tivity	(+):The estimates associated with physical on productivity are estimated to be positive
Productivity	$\longrightarrow$	Physical capital	(ar): We are not expecting to provide strong evidence that changes in productivity will stimulate growth of the capital stock.

Notes: Ambiguous results (ar)

Fig 2: Correlation between (i) Capital Stock, K, K $_{t-1}$… K $_{t-8}$, (ii) Capital Investment, κ , κ_{t-1}…, κ_{t-8} and (iii) R&D, R, R $_{t-1}$… R $_{t-8}$