Short- and long-run ICT and Non-ICT investments: the role of uncertainty and liquidity constraints

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Abstract

In this paper, we model ICT (communication equipment, hardware and software) and Non-ICT (machinery and equipment, and non-residential buildings) business investment components taking into account asset specific characteristics potentially affecting the reactivity of capital accumulation over the business cycle. We estimate a VECM model to test, in a unique framework, the flexible accelerator model (Clark, 1944, and Koyck, 1954), the neoclassical model of Hall and Jorgenson (1967) and the role of financial constraints and uncertainty, as well as complementarity effects between different types of investments. We empirically test our approach on annual Italian data for the period 1980-2012. Our results suggest that the long-run relationship with standard macro determinants (output and user cost) holds for aggregate business capital stock as well as for individual Non-ICT assets but not for ICT. Liquidity is a key determinant of investment behaviour independently of the asset type only in the short run, while it plays a role in the long-run for ICT. Also uncertainty has a permanent effect on ICT. The simulation results support the idea that ICT is a key policy variable to foster the economic recovery.

JEL Classification: C52, C53, E22, E50
Keywords: Uncertainty, Liquidity constraints, Model Evaluation, Disaggregate Capital stocks and Investments, ICT, Cointegration.

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1. Introduction[1]

Aggregate investment is a key policy variable in the macroeconomic debate. This is the reason why, since the seminal work of Clark (1917) up to the most recent contributions of Bloom et al. (2007) and Bachmann et al. (2013), the macro and micro economic literature have tried to identify the key determinants of investment behaviour. Nevertheless, today there is still a weak empirical support for an inclusive macro or micro theoretical model able to provide effective policy suggestions. At the macro level, in particular, little is known about the role of financial constraints and uncertainty in explaining investment dynamics of asset specific business expenditure (de Bondt and Diron, 2008).

In this paper, we try to fill this gap testing the flexible accelerator model (Clark, 1944, and Koyck, 1954), the neoclassical model of Hall and Jorgenson (1967) and the role of financial constraints and uncertainty in a unified Vector Error Correction Model (VECM) where we examine business investment decisions distinguishing between Non-ICT physical capital (machinery and equipment, and non-residential buildings) and ICT capital (Information and Communication Technologies). The adoption of individual asset specifications turns out to be particularly relevant to address sound policy suggestions.

In the analysis we make two core assumptions: the actual capital stock is dynamically related with the determinants of the desired stock (Caballero, 1999); and ICT and non-ICT capital may incur in different adjustment costs thus responding differently to macroeconomic shocks.

The second hypothesis is based on Bloom (2007) who suggests that investment in knowledge capital (R&D) typically incurs flow adjustment costs, while investment in physical capital usually deserves stock adjustment costs, thus implying a different dynamics under uncertainty.

Our findings, based on Italian business investment and capital stock by asset over the period 1980-2012, support the assumption that physical assets (Non-ICT) and technological advanced assets (ICT) respond differently to macroeconomic fluctuations. We detect a cointegration relationship for business capital both at the aggregate level and for its Non-ICT components (machinery and equipment, and non-residential). But, we do not find any evidence of a long run relationship for ICT capital *stock* nor for any of its main components (communication equipment, hardware and software). This result coupled with the evidence of a cointegration relationship identified for ICT *investment* and its assets, reinforce the hypothesis that ICT, as other knowledge based assets (R&D), incurs in flow adjustment costs instead of stock adjustment costs. This results is consistent with the assumption that ICT and R&D share some common characteristics/determinants as they are both inputs to innovation[2].

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[2] Few papers have tried to assess the complementarity between ICT and R&D with opposite results (Polder et al. (2009), Cerquera and Klein (2008)).

More generally, we find that the flexible neoclassical model can explain the long-run dynamics of Non-ICT capital, while ICT investment flows are driven liquidity constraints, uncertainty and R&D. Interestingly, financial constraints are a key determinant for short run investment decisions independently of the asset characteristics. The same holds for output in the long run.

Finally, our policy simulations for the Italian economy in 2008-2013 suggest the following: a lower level of uncertainty and better financial conditions could have accounted for a cumulate increase of nearly 5% in total business investment with respect to its level in 2013, and 1.2% in capital stock, thus increasing the GDP by 0.4%. ICT investment is the main driver of this results.

The paper is structured as follows. Section 2 surveys the basics of the macro and micro theoretical and empirical literature on investment models. Section 3 illustrates our model and the empirical strategy, and section 4 shows the estimation results. Section 5 is focused on policy implications while section 6 concludes.

2. Modelling investment expenditure: macro and micro findings

Investment decisions have short- and long-run characteristics that have to be taken into account when modeling investment behavior (Bernanke, 1980). Generally, macro theoretical models assumed a long run perspective focusing on the idea that an investment occurs when expected returns over the life of the project exceed its costs (Hall and Jorgenson, 1967; Eisner, 1967; Tobin and Brainard, 1977). This perspective has been helpful to describe investment over the long-run but not very useful to explain its short-run fluctuations.

The macro structural models were empirically tested since the beginning of the 1970's. Clark (1979) provided an extensive analysis of the output-based and security-value models using U.S. macro data. He found that the econometric performance of both classes of models was reasonable to explain U.S. investment in machinery and equipment in the mid 1970's, with a slightly better performance of the accelerator model. Few years later Gordon (1986) went back to the standard approach to estimate structural investment equations arguing that this method led to an overstatement of the endogeneity of investment spending. He found that structural models may be useful to identify a list of explanatory variables that might play a role in investment equations, but they identify structural parameters only because they impose strong and arbitrary simplifying assumptions and exclusion restrictions. The underlying idea, still valid today, is that since economic aggregates play multiple roles in explaining investment behavior, the observed estimated coefficients represent the contribution of a number of structural parameters that cannot be separately identified (Hassett and Hubbard, 1996). Thus it is possible only to estimate reduced form equations. For these reasons, Gordon proposed a mixed methodology combining the VAR approach with the estimation of reduced-form equations as suggested by the traditional theory (Chirinko, 1983).

The modest empirical performance of macroeconomic models and the need to analyze investment properties at higher frequencies determined a shift from macro to micro data analysis (Caballero, 1999). As largely demonstrated, the most popular empirical implementation, the *q*-model of Brainard and Tobin (1968), and Tobin (1969), has a low performance since it produces estimated coefficients for the Q variable (the measured shadow value of capital) which imply unrealistically high marginal adjustment costs and therefore implausibly slow adjustment speeds (Whited, 1994). The *q*-model is seriously misspecified because it does not allow for market imperfections (Hubbard, 1998), non-convex adjustment costs (Caballero, 1999), and fixed adjustment costs and irreversibility (Bertola and Caballero, 1994, Caballero et al., 1995, and Cooper and Haltiwanger, 2006) which may differently affect individual capital inputs and be more relevant for intangibles than for tangibles, or for buildings than for equipment.[3] So, aggregation of capital inputs fails to consider that capital is heterogeneous and that firms use many types of capital assets in the production process. The assumption of capital homogeneity might be responsible for the poor empirical performance of the neoclassical inter-temporal optimization investment model (Chirinko, 1993).

A possible solution to deal with capital heterogeneity is that of relying on the structural model based on the Euler equation which can be extended more straightforwardly than the *q*-model to the case of more than one quasi-fixed factor (Bontempi et al., 2004). A system of equations for each type of investment, in which an Euler equation holds for each type of capital, can accommodate the case of interrelated adjustment costs, provided one is willing to specify the form of the adjustment cost function (Shapiro, 1986, uses a system of Euler equations with interrelated adjustment costs). Given the critiques to the restrictions (symmetric, quadratic costs of adjustment) implied by the theory in the Euler equation model (Whited, 1998), its empirical implementation to deal with heterogeneity and markets' imperfections is that of augmenting the standard equation in intuitively appealing ways. For example, Bond and Meghir (1994) extend it to financial variables. Bond et al. (2003) also deal with liquidity constraints. They compare the Euler-equation specification with a reduced-form error-correction model, in which the long-run representation of the capital stock levels is specified to be consistent with a simple model of the firm's demand for capital, but in which the short-run investment dynamics are guided by specification search, rather than imposed a priori. Dynamic reduced forms are also used by Bloom et al. (2007) and by the literature on dynamic factor demand models (see *e.g.* Pindyck and Rotemberg, 1983, who estimate the Euler equations disaggregated for equipment and structure). Remarkable is also the result of Eberly et al. (2012), according to which the best predictor of current investment at the firm level is lagged investment.

Together with dynamics, output and the user cost of capital, other determinants have been shown to be important for investments. As noted by Pindyck (1991), irreversible investment is especially sensitive to

[3] A further problem derives from difficulties in measuring average Q as the ratio of the stock market value of the firm to the replacement cost of its assets. The book value of a company usually does not capture intangibles: the expenditures for R&D, advertising, and the like are expensed rather than treated as assets, even though they are expected to yield future profits. And if stock market is not strongly efficient a firm's market value can differ from its fundamental value because the stock market fails to properly value tangibles and, to a higher extent, intangibles (Bond and Cummins, 2000 and 2001).

uncertainty about future cash flows, interest rates, or the ultimate cost of the investment. The theoretical relationship between uncertainty and investment is ambiguous: predictions are different according to the assumptions on adjustment costs, firms' profit function and managers' or investors' utility functions. As we move away from perfect competition and constant returns to scale towards a concave marginal revenue product of capital and asymmetric adjustment costs (irreversibility), the relationship is supposed to be negative (Bernanke, 1983, McDonald and Siegel, 1986, Pindyck, 1988, Bertola, 1988, Dixit and Pindyck, 1994). The empirical evidence based on micro-level data is prevalently focused on tangible investments (Leahy and Whited, 1996, Guiso and Parigi, 1999, Bloom et al., 2007, Bontempi et al., 2010, Bianco et al., 2013; for a survey Carruth et al., 2000, and Greasley and Madsen, 2006). While few exceptions looking at R&D and uncertainty are: Goel and Ram (2001) on a panel of OECD countries, Czarnitzki and Toole (2007, 2011, 2013) on German firms, Stein and Stone (2012) on US firms, and Bontempi (2014) on Italian firms. Since the effect of uncertainty is usually negative, if a policy goal is to stimulate investment, a stable environment and policy credibility may be more important than tax incentives or interest rates.

When assessing the impact of uncertainty on capital accumulation, it is important to include also the financial variables, because the negative effect of uncertainty on investment might proxy for credit constraints and/or agency costs: inherently riskier firms may find it more difficult to finance their spending and hence they may plan a lower amount of investments. Therefore, capital market imperfections and the role of internal funds are shown to be relevant in the literature on physical capital, since Fazzari et al. (1988). Investment in R&D is usually considered even more affected than tangibles by financial constraints (e.g. Himmelberg and Petersen, 1994, Czarnitzki and Hottenrott, 2009). Hall and Lerner (2010) describe some of the unique characteristics of R&D investment that could explain why external finance for R&D might be more expensive than internal finance.

Up to now, there is no strong empirical support for one specific model, neither from the macro nor from the micro literature. Given the weak empirical performance of structural models (Hayashi, 1982; Summers, 1981), the investment literature agreed on the idea that these models are useful to identify key determinants of investment but they have little power to explain aggregate investment behavior (Hasset and Hubbard, 1996). This is the reason why our empirical strategy hinges from different theoretical models/specifications adopting a mixed approach to model the behaviour of business investment and its main components.

3. The empirical approach

To explore the explanatory power of different determinants of capital accumulation we examine the characteristics of investment decisions both at the aggregate level (total business expenditure, *agg*) and by assets (machinery and equipment, *me,* non-residential, *nres*, and information and communication technologies, *ict*). The comparison of the quantitative results at the aggregate and disaggregate level can be helpful to assess whether asset specific characteristics matter for modelling and policy purposes.[4]

The accelerator model of Clark (1917) and the neoclassical intertemporal optimisation model of Jorgenson (1963) have been the first benchmark models to explain investment behaviour. As both models descend from theories of investment conditional on the level of output, following Caballero (1999) we can see them as nested in the definition of the flexible accelerator (Clark, 1944, and Koyck, 1954):

$$I_t^j = \sum_{k^j=1}^{n^j} \beta_k^j \Delta K_{t-k}^{*j} \tag{1}$$

where I^j is the investment, K^{*j} is the desired stock of capital, and β^j are parameters; superscripts j = *agg*, *me*, *nres*, and *ict* denote different types of investments.

Given that K^{*j} is unobservable, we can define it, in the spirit of Eisner (1969), as a function of income and substitution effects, the latter measured by the neoclassical cost of capital:

$$K_t^{*j} = \alpha_0^j Y_t^{\phi_1^j} UC_t^{\phi_2^j} \quad \text{or, in logs} \quad k_t^{*j} = a_0^j + \phi_1^j y_t + \phi_2^j uc_t^j \tag{2}$$

where Y is the output, ϕ^j are parameters, and UC^j is the cost of capital, which can be defined on the basis of the classical Hall and Jorgenson (1967) formula as (see e.g. Caballero, 1994):

$$UC_t^j = \left(R_t^j + \delta_t^j - \pi_t^j + \psi^j\right) \left(\frac{1-c_t}{1-\tau_t}\right) \frac{P_t^j}{P_t} \tag{3}$$

where R_t^j is the cost of the borrowing; δ_t^j is the depreciation rate, π_t^j is the rate of change of investment prices; ψ^j is an arbitrary risk premium; c_t is the rate of investments' subsidies; τ_t is the corporate tax rate; P_t^j is the prices of investment in good *j*, and P_t is the product price.

The accelerator and the neoclassical models are nested in the general model obtained by substituting equation (2) in (1), according to alternative restrictions on the ϕ parameters. If $\phi_1^j=1$ and $\phi_2^j=0$ (1) we have the accelerator model; if $\phi_1^j=1$ and $\phi_2^j=-1$ we have the flexible neoclassical model of Hall and Jorgenson (1967). Broadly speaking, if an estimate of ϕ_2^j (i.e. if the user cost) is significantly negative in explaining the desired stock of capital, the accelerator model is questioned in favour of the neoclassical model.

Even though k_t^{*j} is not observable, we can model k_t^j as trying to keep pace with it. Thus, differences between these two variables should only be transitory (see for example Caballero, 1999). Let

$$k_t^j = k_t^{*j} + u_t^j \tag{4}$$

[4] Several empirical studies have been focused on traditional assets, such as machinery and equipment, to observe their relation with the business cycle (see e.g. Lee and Rabanal, 2010). However to our knowledge there is no evidence of any analysis by asset at macro level such as that one described in this section.

where u_t^j is the stationary residual measuring transitory discrepancies due to adjustment costs. Substituting (2) in (4) we obtain the relationship, where the traditional determinants of the desired capital stock explain directly its actual realizations.

$$k_t^j = a_0^j + \phi_1^j y_t + \phi_2^j uc_t^j + u_t^j \qquad (5)$$

Besides output and user cost, the empirical evidence suggests that the short-run fluctuations in capital accumulation u_t^j can also be substantially related to the effects of uncertainty and liquidity (Hubbard, 1998, Bloom et al. 2007).[5] As a result, the transitory discrepancies emerging between desired and actual capital stock can be modeled in (6) as a function of financial constraints (*liq*), uncertainty (*unc*) and a miscellanea of other effects ν_t^j which are possibly autocorrelated because of the omitted dynamics due to adjustment costs.

$$u_t^j = f^{\,j}(liq_t, unc_t) + \nu_t^j \qquad (6)$$

Despite equations (5) and (6) are useful to respectively summarize long- and short-run movements of the capital decisions, both of them are unavoidably mixed in the data generation process. Therefore, in order to explore long- and short-run fluctuations in a comprehensive framework, we adopt the Vector Error Correction Model (VECM) approach of Johansen (1995). In this context, we can cope with the issues of estimating the number of long-run relationships (i.e. the cointegration rank), and of testing for the weak exogeneity of a subset of variables in a multivariate framework, where all the variables of interest are *a priori* endogenous. More explicitly, the VECM approach freely estimates and tests for all the basic ingredients of equations (5) and (6), without imposing the rank to be one (see Johansen, 1995) and capital stock's driving forces to be exogenous (see Granger and Lin, 1995), as the dynamic single-equation approaches do.[6]

The Johansen approach is sketched by the following general VECM representation (for simplicity we omit the superscript *j*):

$$\Delta Z_t = \Gamma_0 C_t + \sum_{k=1}^{p-1} \Gamma_k \Delta Z_{t-k} + \pi\left(\phi' Z_{t-1}\right) + \varepsilon_t \qquad (7)$$

where: Z is the $(n\times1)$ vector of n I(1) or I(0) variables explained by the system, and Δ is the first-difference operator; C is the $(d\times1)$ vector of d deterministic terms (such as intercept and linear trend), Γ_0 is the corresponding $(n\times d)$ matrix of parameters, and p is the lag-order of the underlying unrestricted VAR; Γ_k are the p $(n\times n)$ matrixes of parameters measuring the short-run fluctuations on the basis of lagged changes of the variables; $\phi' Z_{t-1}$ is the $(r\times1)$ vector of stationary (i.e. cointegrated of rank r) long-run level-relationships

[5] Among the others, De Bondt and Diron (2008) find that financing constraints are relevant for the aggregate investment. Parigi and Siviero (2001) results remark the significance, for investment decisions, of the business confidence, which they interpret as a measure of expectations on accumulation and of uncertainty.

[6] See e.g. Stock and Watson (1993) dynamic OLS, and Pesaran et al. (2001) autoregressive distributed lags models.

among the variables of interest, and ϕ is the ($n \times r$) matrix of cointegration parameters; π is the ($n \times r$) matrix of loading factors (measuring the speed of adjustment towards the long-run/target relationships among the variables in levels); ε is the ($n \times 1$) vector of normal white noise stochastic errors.

In VECM (7), the weak exogeneity of some variables in vector Z can be tested to assess whether partial systems (in which some variables - the weakly exogenous ones - are not endogenously determined within the system) are appropriate for valid inferences and parameters' estimates.

In terms of modelling the aggregate capital stock by using the determinants listed in equations (5) and (6), we define the vector of the dependent variables as: $Z^{agg} = \left(k^{agg}, y, uc^{agg}, liq, unc\right)'$. If we assume, for simplicity, in VECM (7) that: p=2, r=1, and that this unique long run relationship identifies the target capital stock, we have the following representation (8).

$$\begin{pmatrix} \Delta k_t^{agg} \\ \Delta y_t \\ \Delta uc_t^{agg} \\ \Delta liq_t \\ \Delta unc_t \end{pmatrix} = \Gamma_0 C_t + \begin{pmatrix} \gamma_{11} & \gamma_{12} & \cdots & \cdots & \gamma_{15} \\ \gamma_{21} & \gamma_{22} & \cdots & \cdots & \gamma_{25} \\ \cdots & & \cdots & & \cdots \\ \cdots & & & & \cdots \\ \gamma_{51} & \gamma_{52} & \cdots & \cdots & \gamma_{55} \end{pmatrix} \begin{pmatrix} \Delta k_{t-1}^{agg} \\ \Delta y_{t-1} \\ \Delta uc_{t-1}^{agg} \\ \Delta liq_{t-1} \\ \Delta unc_{t-1} \end{pmatrix} +$$
$$\begin{pmatrix} \pi_1 \\ \pi_2 \\ \cdots \\ \cdots \\ \pi_5 \end{pmatrix} \left(k_{t-1}^{agg} \quad - \phi_1 y_{t-1} \quad - \phi_2 uc_{t-1}^{agg} \quad - \phi_3 liq_{t-1} \quad - \phi_4 unc_{t-1}\right) + \begin{pmatrix} \varepsilon_t \\ \varepsilon_t \\ \cdots \\ \cdots \\ \varepsilon_t \end{pmatrix} \tag{8}$$

In VECM (8), the exclusion of liquidity and uncertainty from capital stock's long run relationship implies two restrictions on the long run parameters:

$$\phi_3 = \phi_4 = 0 \tag{9}$$

Apart from the capital stock, the weak exogeneity of all the other variables in (8) implies four restrictions on the loading parameters:

$$\pi_2 = \pi_3 = \pi_4 = \pi_5 = 0 \tag{10}$$

If restrictions (9) and (10) are both not rejected, then the VECM (8) can be reduced into the single-equation (11), where the aggregate capital stock is explained by an EqCM model which is conditional on the simultaneous changes in all the other variables of the system:

$$\begin{aligned} \Delta k_t^{agg} = {} & \gamma_1 + \gamma_2 \Delta y_t + \gamma_3 \Delta uc_t^{agg} + \gamma_4 \Delta liq_t + \gamma_5 \Delta unc_t + \\ & \gamma_{11} \Delta k_{t-1}^{agg} + \gamma_{21} \Delta y_{t-1} + \gamma_{31} \Delta uc_{t-1}^{agg} + \gamma_{41} \Delta liq_{t-1} + \gamma_{51} \Delta unc_{t-1} + \\ & \pi_1 \left(k_{t-1}^{agg} - \phi_1 y_{t-1} - \phi_2 uc_{t-1}^{agg}\right) + \varepsilon_t \end{aligned} \tag{11}$$

The conditioning (weak exogenous) explanatory variables are listed in the first row of equation (11), while the second row reports the corresponding lags. In the last row, the equilibrium correction term is reported in squared brackets. There, the long run parameters contribute to the definition of the target level of capital:

$$k_t^{agg*} = \phi_1 y_t + \phi_2 uc_t^{agg} \tag{12}$$

Given the solution of the capital stock equation (11), we obtain the corresponding level of business investments by exploiting the perpetual inventory accounting identity:

$$I_t^{agg} \equiv \Delta K_t^{agg} + \delta K_{t-1}^{agg} \tag{13}$$

in which investments are defined as the difference between the change in levels of capital stock and the amount of past capital depreciation (δ is the depreciation rate).

If we aimed to model the Italian business capital at the disaggregate level in the VECM context, we would first need to model a vector of nine variables (i.e. six asset-specific variables - stocks and user costs - plus output, liquidity and uncertainty), and then to define the overall business stock as the sum of the three disaggregate stocks. However, this approach is not recommendable, as it would certainly imply the curse of dimensionality problem. Alternatively, the issue of modelling the business stock at the disaggregate level without incurring in the inefficient inferences of large systems can be tackled by exploiting the notion of separation in cointegrating systems (see e.g. Granger and Haldrup, 1997). In fact, under the assumption of separate cointegration, the statistically unmanageable complexity of the complete system can be summarized by the three parsimonious sub-systems which, in analogy with the aggregate case, are modelled by asset, i.e. $Z^j = \left(k^j, y, uc^j, liq, unc\right)'$, for j = *me*, *nres* and *ict*.

In other words, under the assumption of separate cointegration, we will accomplish all the steps mentioned above both at aggregate level and by each asset category.

4. The empirical results

4.1. Stylised facts over the cycle

In this section we report the main stylized facts of our variables of interest over the cycle by using the output gap as the reference variable. In particular, we focus on growth rates for GDP and employment (i.e. $\Delta Y_{it} / Y_{it-1}$ and $\Delta E_{it} / E_{it-1}$) and investment ratios on capital stock by asset (i.e. I_t^j / K_{t-1}^j, where as usual j = *agg* for total, *me* for machinery and equipments, *nres* for non residential buildings and *ict* for information and communication technologies).[7]

We computed, over the period 1980-2012, a number of classical business-cycle time-series indicators (Schlitzer, 1995) to measure volatility, persistence, and co-movement of each variable of interest (in general, X_t) with respect to the output gap (labelled as Y_t). In particular, the volatility of X_t is measured in

[7] In addition, we also exploited a fine level of disaggregation for three components of the *ict* investments, namely for j = *ct* (communication equipment), *hw* (hardware) and *sw* (software). Finally, we also computed the same indicators for the ratio of R&D expenditure on its stock, i.e. j = *berd*. Details about data sources are in Appendix A1.

the first column of Table 1 by its standard deviation in terms of that of Y_t (i.e. σ_X / σ_Y). The persistence of both X_t and Y_t is measured by the autocorrelation coefficients of the first and second order (ρ_1 and ρ_2)[8] respectively reported in the second and the third columns of Table 1. The co-movements of X_t with the reference Y_t are reported in the last five columns of Table 1 , and measured by the correlation coefficients of X_t. with up to the second lag/lead of Y_{t-k} ($\rho_{XY}^{(k)}$, where k= -2, -1, 0, 1, 2).[9]

Table 1 here

As far as the terminology of the cyclical co-movements is concerned, X_t is said to be (*i*) anti- or counter-cyclical if $\rho_{XY}^{(k)}$ is significantly negative; (*ii*) a-cyclical if $|\rho_{XY}^{(k)}|$ is not significantly different from zero, (*iii*) pro-cyclical if $\rho_{XY}^{(k)}$ is significantly positive. In addition, X_t is labeled as leading, coincident, or lagging the cycle of Y_t if the largest estimate of $|\rho_{XY}^{(k)}|$ is reached when k>0, k=0, or k<0, respectively.

The main results can be summarised as follows. Regarding volatility, it must be emphasized that the output gap, and the growth rate of GDP and of investment in machinery are about equally volatile over the cycle, while employment and investment in buildings are significantly less volatile. As a result, being machinery and buildings the most important items of the business investment, total investments have a standard deviation slightly lower than that of the output gap. On the other hand, technological investment and its main components, as well as R&D, have a volatility which is more than twice that of physical assets. The persistence indicators suggest that all the variables in Table 1 are stationary, albeit at different degrees.[10] Investment ratios are more persistent than output and employment growth rates, with first order autocorrelations equal to 0.7 or above. The highest degree of persistence is reached by non-residential buildings, by *ict* components (software) and R&D expenditure. Finally, GDP growth, employment and investment ratios in machinery and buildings are pro-cyclical and coincident (or slightly leading), while *ict* assets and R&D expenditure are a-cyclical (hardware is the only *ict* asset showing a similar behaviour, although considerably less pronounced, as that of machinery and equipments). Such broad ICT a-cyclcality of investment ratios can be interpreted in the light of previous discussion about the role played by capital stock in ICT (and R&D) investment decisions: ICT goods are short lived and, therefore, their very high and a-cyclical depreciation rates tends to dominate the cyclical pattern of the growth rate of the capital stock. However, the levels of investment by asset are related with the economic cycle, and in fact they are all coincident (sometimes lagging), as reported in squared brackets which highlight the larger correlation of the output gap with the Hodrick and Prescott (HP) filtered log-levels of GDP, employment and investments by

[8] We estimate autocorrelations up to the second order to discriminate the case of non invertible MA(1) processes, where the first-order autocorrelation is significant and the second-order one is zero, with that of the AR processes, where the first- and the second-order autocorrelations are both significant (and very large, if the AR is strongly persistent).

[9] With annual data, we assume that two lags are enough to account for all the relevant dynamics.

[10] Given the permanent inventory identity relating investment and capital stock, the relationship $I_t^j / K_{t-1}^j = \Delta K_t^j / K_{t-1}^j + \delta_t$ implies that the investment ratios in Table 1 are linked to the growth of the capital stocks. Unreported unit root tests show that log-levels of capital stocks are I(1), as their first differences always reject the null of unit roots.

asset with lambda equal to 6.25). The ICT goods comovements are smaller than those of the other investment goods because of their larger volatility.

Overall, while the traditional HP-filtered levels give the usual picture of broadly coincident ICT investments, their ratios over stocks induce fluctuations that cannot be seen as evidence of choices taken over peaks and troughs but, rather, random realizations due to the factor of scale in the denominator which usually is not much screened and targeted by economic agents.

Therefore, the descriptive analysis confirm the assumption that there are two broad categories of business investments showing different cyclical characteristics: Non-ICT physical assets (machinery and buildings) on one side, and innovation assets on the other (ICT and R&D). Obviously, the dynamics of aggregate business investment, given the large weight of traditional tangible assets, is substantially similar to the dynamics of Non-ICT capital.

4.2. The cointegration analysis

As introduced in Section 3, the tests for cointegration have been performed using the Johansen's rank-test based on the VECM (7) at both the aggregate level and by asset. If we represent the vector of the dependent variables of the VECM (7) as $Z^j = \left(k^j, y, uc^j, liq, unc\right)'$, at the aggregate level we set *j* = *agg*, while at the disaggregate level we set three VECM one for each asset, with *j* = *me*, *nres* and *ict*. In Table 2, the representation above is labelled as VECM5 because the variables jointly modelled in the VAR are five. We report results also for smaller systems defined as VAR3, where $Z^j = \left(k^j, y, uc^j\right)'$, i.e. where *liq* and *unc* are excluded. The VAR5 constitutes the enlarged view of the system, which relates capital, output and user cost (i.e. the three components of the classical capital stock model) with the additional determinants emerging from the recent empirical literature (i.e. liquidity and uncertainty), while the VAR3 focuses only on the three classical determinants. Given the aforementioned problems in inferences because of over-parameterization, we cross-validate results by assessing their consistency in the context of both VAR5 and VAR3.

Table 2 here

The upper part of Table 2 lists the basic information about VAR settings. As far as lags are concerned, we set either two or three; the intercept is the only deterministic component in order to adequately represent drifting patterns under the null of no-cointegration. The data congruence of VAR models has been assessed through a number of residuals' mis-specification tests, which hardly ever reject the null of vector white noise errors.[11]

In the following rows of Table 2 both the trace rank tests and the estimates of the long run parameters are reported. Overall, the outcomes are coherent with the dichotomy emerged from the cyclical

[11] In the few cases of failure of the eteroschedasticity and/or the normality tests, the inclusion of one/two dummies in the deterministic components prevents such rejections without qualitative changes in the results reported here.

analysis. On one hand, a cointegration relationship is clearly detected in the first six columns of Table 2 for aggregate (*agg*), machinery (*me*) and non residential stocks (*nres*), on the other hand there is no evidence of cointegration for *j=ict*. The identified cointegrated vectors support the relationship of desired capital stock with its classical determinants (output and user costs) for *j = agg, me,* and *nres*.

Columns 1 to 5 (i.e. excluding the *ict* case), show the remarkable similarity of test results and parameter estimates in VAR5 and VAR3 models thus strongly supporting the above view. In the trace tests, the cointegration rank is always one at least at 5%, and the weak exogeneity is never 1% significant. Therefore, the systems adjust in the long run to desired stocks whose determinants are weakly exogenous and forcing.

The long run elasticity of desired capital stock to output is very close to one for aggregate capital, and significantly higher than (lower than) one for machinery and equipment (for non residential buildings). Being significantly negative, the estimates of the elasticity of capital to user cost reject the accelerator model, but they are also significantly higher than minus one as the flexible neoclassical model would predict. As for the elasticity to output, the capital stock elasticity to user cost in the aggregate case lays between the estimates for machinery and for buildings. The speed of adjustment of actual to desired capital stocks is quite slow, suggesting dynamics with relevant adjustment costs, especially for the non residential buildings.

The capital stock targets, which correspond to the long run estimates above, support the prediction of Caballero (1994) that - in presence of relevant adjustment costs - the standard deviations of the desired stocks must be larger than the actual ones. The last two rows of Table 2 show that the variability of the business target stock is about three times that of the actual stock; for machinery and equipment this ratio is slightly lower (suggesting lower adjustment costs than the aggregate), and for non residential buildings it is clearly higher than that of the actual one (about five-six times, denoting the highest adjustment costs).

As anticipated above, the *ict* behaviour is completely different. Although the performance of the unrestricted VARs is not much different than those of the previous cases, the cointegration rank tests deliver opposite results: the rank is larger than one in VAR5 and zero (no cointegration) in VAR3. As far as VAR5 results are concerned, the cointegration finding that $r>1$, together with the strong rejection of the weak exogeneity restrictions,[12] leads to the idea that the underlying long run relationships in reduced form are a combination of target capital stock determinants with liquidity and uncertainty, and that have little to do with desired capital stock equations. [13] This explanation is further corroborated by the lack of cointegration in VAR3, where liquidity and uncertainty variables are excluded.

The finding that, among capital assets, only *ict* fails to detect a long run relationships between capital stock, output and user cost can be investigated inside *ict* components by estimating VAR5 and VAR3 models

[12] Note that in VAR5 columns the labelled "weak exogeneity" test not only refers to the restrictions in (10), but also to the exclusion of the liquidity and uncertainty long run effects, as listed in (9).

[13] This interpretation is also supported by wrong-signed and quite imprecise long run ϕ_1 and ϕ_2 estimates in the VAR5 where the restrictions to identify the long-run capital stock equation are imposed.

where, respectively, $Z^j = \left(k^j, y, uc^j, liq, unc\right)'$ and $Z^j = \left(k^j, y, uc^j\right)'$ for j = *ct* (communication equipment), *hw* (hardware), and *sw* (software). Further, the same analysis is also carried out by using partially estimated R&D variables: $Z^{berd} = \left(k^{berd}, y, uc^{berd}, liq, unc\right)'$ and $Z^{berd} = \left(k^{berd}, y, uc^{berd}\right)'$. Even though the latter data are of lower quality than those officially released by ISTAT, it is interesting to compare the features of R&D modelling in the context of VECM (7) with those emerging from the use of the three *ict* components.

The results, detailed in the annexed Table A1, deliver three main findings. First, they clearly suggest that the identification scheme, adopted for business, machinery and buildings capital stocks, is not able to explain *ict* dynamics. This outcome is confirmed both for aggregate *ict* and within its components, as well as for R&D. Second, the levels of the user cost of capital do not play any relevant role in the systems, as they are never significant and have wrong signs in six cases out of eight. Third, the marginalisation of the liquidity and uncertainty data generation process by jointly imposing the restriction listed in (9) and in (10) to VAR5 parameters is always strongly rejected. The relationships between investment decisions, output, liquidity and uncertainty are not limited to explain the short run fluctuations, as we have seen for business, machinery and buildings, but might also play a role in shaping *ict* developments in the long run.

Overall, these results - coupled with those in previous section - suggest that the failure of the classical stock adjustment models in explaining the dynamics of *ict* assets is related to the assumption that technological investment dynamics respond differently to macroeconomic shocks because, as other knowledge based assets (R&D), they experience flow adjustment costs (Bloom, 2007). Whereas Non-ICT tangible assets incur in stock adjustment costs.

In order to overcome these *ict* modelling failures, the first adaptation of the previous approach consists in replacing capital stocks with investment flows. In addition, given the availability of data flows regarding R&D expenditure, we added the log-share of R&D on GDP (*rd*) in order to asess for possible complementarity between R&D and ICT goods. As a result, the enlarged VECM (7) for *ict* will explain the following vector of variables: $Z^{ict} = \left(i^{ict}, y, uc^{ict}, liq, unc, rd\right)'$, where *i* denotes investment flows and all the other variables are the same as above. Cointegration results are reported along the columns of Table 3.

Table 3 here

Column (1) shows that the replacement of the stock with the flow of *ict* investment induces weak exogeneity of all the variables of interest apart of investment, leading to the identification of its long.-run relationship with the levels of the other variables. The cointegration rank is equal to one at 5%, because the test for cointegration rank r ≤2 is close to be 10% significant. This mild evidence of a second long run relationship is not exploited here because it is probably due to a (little informative) long run relationship between R&D share and the constant term representing its steady state value. In fact, at the univariate level, the unit root statistic - testing for the null of being I(1) - in the case of the R&D share on GDP is around 10%, as this variable fluctuates with a very persistent AR(2) dynamics. In this context, the imposition of rank one (and not two) cannot bias the cointegration vector parameters' estimates. The identification of only the long run relationship explaining the ICT investment determinants and not of also that for R&D can be explained both in the light of R&D data features mentioned above, and of possible nonlinearity of the R&D nexus with its determinants, as suggested in Bloom (2007). At the present stage, the lacking information set is the main reason preventing us from deepening the issue of non-linear cointegration.

The restriction to one of the elasticity of investment to output and to zero that to user cost in column (2) is not rejected, as their unrestricted estimates are very imprecise. Under this restriction, the ratio of *ict* investment to output (in logs) is positively related in the long run to liquidity and R&D, and negatively related to uncertainty. These results can be further inspected in a smaller VECM in column (3), where the weakly exogenous user cost only plays a short run role as conditioning variable (in changes), and the vector of the endogenous variables becomes: $Z^{ict} = \left(i^{ict}, y, liq, unc, rd\right)'$. Results confirm the cointegration relationship between the ratio of *ict* investment to output (in logs) uncertainty, liquidity and R&D share. All the long run estimates have the expected signs and are significant. It is worth noting the remarkable constancy of the latter estimates with those from the larger VAR.

In the cointegrated VAR models estimated in columns (1)-(3) all the variables (including - most importantly - uncertainty) are weakly exogenous: the disequilibria only feed short run changes in actual investments and not in the other VAR variables. The long run elasticity of *ict* investment to uncertainty is negative and not significantly different from one, while the long run effects of liquidity and R&D are smaller and positive; the user cost only play a transitory role. The speed of adjustment of actual to target *ict* investments is estimated around 0.27 (i.e. about one-quarter of the discrepancy between desired and actual investment is closed after one year), denoting flow adjustment costs which are considerably lower than the stock adjustment costs experienced in business, machinery-equipments and buildings cases.[14]

In columns (4) to (6) the results for *ict* in column (3) are replicated by each of its three components (communication equipments *ct*, software *sw*, and hardware *hw*, respectively). This fact suggests that the *ict* findings in columns (1)-(3) are not simply the outcome of an aggregation effect between heterogeneous goods, but that all the *ict* components share the same behaviour as that of the the aggregate *ict* investment. Some differences in the long run parameters deserve to be noted: liquidity does not exert a long run relationship on investments in software, while R&D does not drive investments in hardware. The investments in software reactivity to uncertainty is almost the double than those of the other two items. The speed of adjustment of investments in hardware is largely the highest of the three groups.

Finally, it is worth noting that the standard error of the aggregate ICT equation in column (3) is markedly lower than those of the three disaggregate equations in columns (4)-(6): because of the statistical averaging of the individual shocks, the aggregate ICT picture is clearer, as the long run estimates have lower

[14] As for capital stock targets, *ict* investment targets show standard deviations which are larger than the actual ones. For example, with reference to column (5) long run estimates, the variability of the *ict* investment target is almost four times that of the actual *ict* investment (0.282 against 0.078). This fact suggests adjustment costs for *ict* investment which is in line with that of the capital stock in machinery and much lower than that of the stock in buildings.

standard errors. The latter fact suggest that, despite point estimates are quite different, their estimation intervals are not.

The joint vision of the results in Tables 2 and 3 suggests the following summary. A long run relationship for Non-ICT capital stocks is found only for machinery and equipment and buildings, i.e. for the largest share of tangible goods, in the context of the flexible neoclassical model. While technologically advanced (*ict*) assets show a different relationship which explains the desired investment flows on the basis of output, liquidity, uncertainty and R&D expenditure. Overall, the output effects always play a role in explaining long run fluctuations of both capital and investments, while the liquidity effects play a role in shaping the short run dynamics of Non-ICT capital stocks, and also the long run of ICT investments. In the same way, the desired levels of machinery and buildings stocks are not affected in the long run by uncertainty, which is rather a relevant explanatory variable of the desired levels of *ict* investments. Vice-versa regarding the role played by user costs.

Regarding the issue of modelling at aggregate/disaggregate level, we found considerable heterogeneity between aggregate (business) investments and their three disaggregate components (machinery, buildings and ICT), as only machinery and buildings (i.e. the Non-ICT items) behave as the aggregate, while ICT model is deeply different: the target variable is investment (and not capital) and output is the only long run determinant of the ICT investment which is in common with Non-ICT capital stock (the other being liquidity, uncertainty and R&D).

However, if we look inside the aggregate ICT, the heterogeneity mentioned above tends to vanish, as the determinants of the three ICT components (i.e. communication equipments, software and hardware) broadly behave as the aggregate ICT, although with different (but imprecisely estimated) point estimates of the long-run parameters. In this context, the aggregate ICT model can be seen as an "average" specification which - enjoying a sort of statistical averaging effect - better explains the ICT investments behaviour. Of course, it remains open the issue of keeping the track of the aggregate ICT estimates as soon as new data are available, because the aggregate ICT model can be subject to breaks if the distribution of the single ICT items does not remain constant over time (see e.g. Theil, 1954, Forni and Lippi, 1997, and - for an application to the money demand function - Hsiao et al., 2004).

In short, neglecting investment heterogeneity is much costly at the stage of ICT/Non-ICT modelling, rather than at the stage of modelling aggregate ICT and its components.

4.3. The elasticities of the investment-capital stock system

The process of reduction of the cointegrated VARs discussed above leads to four estimated dynamic relationships listed in the appendix A3 together with the nine identities which, overall, constitute the investment-capital stock system. The analysis of the four residuals of the OLS estimated equations holds up the hypothesis of non-autocorrelation, normality and homoscedasticity. Note that the use of the OLS estimator is allowed by the weak exogeneity property emerging from the results in the previous section.

In order to better understand and compare investment and capital stock elasticity to output, user cost, uncertainty, liquidity and R&D (i.e. the forcing variables of the system) at both aggregate and disaggregate level, Table 4 reports the short- and the long-run elasticities, listed in bold along the rows, obtained by perturbating output, uncertainty, liquidity, interest rates and R&D of the steady state solution of the whole system in the appendix A3. In turn, the steady state solution is numerically obtained through the simulation of the system about 90 periods ahead with constant exogenous variables, i.e. all the unmodelled variables. Finally, the standard errors of the elasticity (reported below each elasticity row) are computed on the basis of stochastic simulations in which the residuals are bootstrapped (1000 replications). Along the different columns, investments and capital stocks refer to both the disaggregate items, to their aggregation, and to the aggregate level equations.

Table 4 here

The zeros corresponding to the *agg* columns highlight that the aggregate modelling of the relationships of the capital stock with its determinants admits the exclusion of both uncertainty and liquidity effects, while such effects play a significant role by asset, leading to aggregate (by summation) significant effects at business investment and capital stocks levels (see the *sum* columns). In general, by comparing *agg* and *sum* results, we note that the estimated elasticities tend to significantly differ in the short-run, apart from the role played by the user cost (i.e. the interest rates). Following the *sum* outcomes, an improvement in the liquidity conditions has an elasticity about five times larger than that corresponding to less uncertainty. However, due to the long run cointegration between *ict* investment and uncertainty, the uncertainty effect is permanent (a 10% increase in uncertainty reduces the long run business investment level by about 1%), while the liquidity effect always vanishes in the long-run.

Given that steady state investments and capital stocks are linked by the proportional relationship: $I^* = \delta\ K^*$, the long-run elasticies to output of both investment and capital stock are very close, and much similar to those estimated by the cointegrated relationships in Table 2. However, the short run elasticity of investment to output for buildings and machinery exhibits cyclical overshoots which are typical of the accelerator model.

Overall, the specification by asset assumes a particular relevance for policy design, as the results in Table 4 suggest a high degree of heterogeneity emerging from the disaggregate behaviours. Liquidity and uncertainty play a role only at the disaggregate level: they are key determinants of machinery and equipment capital accumulation, while liquidity, more than uncertainty, also influences the short run behaviour of non residential buildings. Uncertainty has permanent effects on the pattern of ICT investment.

5. Policy implications

Our findings show that the dynamics of Non-ICT and ICT capital is subject to a different set of drivers, both in the short and in the long run since they respond differently to macroeconomic shocks. From a policy perspective this is a relevant result suggesting the need to define asset specific policy designs.
Further, the relatively higher reactivity of ICT supports the idea that in a period of economic downturn, policymakers should definitely stimulate productivity enhancing investments, such as those in knowledge based assets. More generally, during a downturn, the opportunity cost of a company's resources is reduced so that it has a greater opportunity to reorganise production and other business processes, thus increasing the scope for innovation without sacrificing growth (Bhaumik, 2011).

We check the above idea testing the effect of uncertainty and firm's liquidity constraints on the Italian growth performance looking at their impact on the dynamics of Non-ICT and ICT capital accumulation. Financial constraints and uncertainty[15] are explored also to address the growth differential of the Italian economy compared to the average of the other euro area countries.

Since the financial turmoil in 2008, the Italian economy has been characterized by a double-dip recession and then since 2009 the risk of a sovereign debt defaults in Italy (in the middle of the Greek crisis) and endemic domestic political instability fuelled uncertainty. In 2009, as in most of the other EU economies, the Italian GDP growth experienced a substantial drop (-5.5%), recovering in 2010 and 2011 (1.8% and 0.7% respectively). In 2012, instead, while in the euro area the recovery continued somewhat (German GDP rose by 0.7 while French GDP remained at 0.0), in Italy the GDP fell down again (-2.6%)[16].

The risk of sovereign debt defaults is clearly represented by the Italian index of economic policy uncertainty showing the markedly higher level of uncertainty experienced since 2008, as compared to the other European countries (summarised by the average of Germany, France and Spain). The shaded area in Figure 1 provides a broad idea of the Italian-specific uncertainty.

Figure 1 here

Further, the financial conditions, measured by the ISTAT monthly business survey, reinforce our assumption. In 2012, as reported in Figure 2, the level of liquidity was very close to the low level recorded in 2009.

To assess the macroeconomic effects of a change in the level of uncertainty and liquidity conditions on the Italian economic performance, we included the system of equations listed in appendix A3 in the

[15] In periods of recession high level of uncertainty and low level of liquidity could negatively influence behavioural responses of firms and consumers as shown in e.g. Romer (1990) and Bloom (2009). The economic rationale of this effect lies in a number of theoretical underpinnings, based on the channel of real- and growth-options, of the risk premia and of the precautionary savings (for an updated survey, see Bloom, 2013)

[16] The projection for 2013 are still negative (-1.9%), however in Q4 2013, for the first time since Q2 2011 the growth rate has not been negative.

framework of the ISTAT Macroeconometric Model (MeMo-It) [17]. We used this modified model to build up a counterfactual exercise - over the period 2008-2013 - where the actual Italian economic performance is compared with a simulated scenario where the level of uncertainty is equal to the average of France, Germany and Spain (the improvement is the shaded area in Figure 1), and the liquidity conditions are constantly improved in 2012-2013 (the measure of the improvement is the shaded area in Figure 4). [18]

Figure 2 here

Before looking at our empirical findings, we recognize that our results are surrounded by the usual caveats emerging from any macro-econometric counterfactual[19].

Table 5 shows that over the years 2008-2013, a lower level of uncertainty and better financial conditions could account for a cumulate increase of almost 5% in business investments with respect to their level in 2013, and 1.2% in capital stock. GDP would have been raised by 0.4%, and the employment by a slightly smaller amount (0.2%, corresponding to an increase in the number of full time employees by about 50 thousands).

Table 5 here

Remarkably, Non-ICT and ICT investments react differently to uncertainty and liquidity changes. Although ICT investment is more sensitive to uncertainty, also the financial conditions play a relevant role: smaller uncertainty coupled with higher level of liquidity would make them increase by a cumulate 25% in six years. Both investments in machinery and equipment and in non-residential buildings react to both shocks, with a higher sensitivity to the financial conditions (improving by 2.3% and 1.7% respectively).

Historically, the double-dip recession operated a disruptive selection on firm investment decisions, by severely affecting ICT capital that in 2012 showed a stronger slowdown than that of machinery and equipment.

6. Concluding remarks

In this paper, we modelled the dynamics of business investment components taking into account asset specific characteristics potentially affecting the reactivity of capital accumulation over the business cycle. Our analysis confirms that ICT and Non-ICT investment decisions depend on a different set of determinants, both in the long and in the short run. This finding support the evidence provided by Bloom (2007) that

[17] MeMo-It is an annual model composed by 53 stochastic equations and 78 identities, and represents a New Keynesian economic system including households, firms, public administration, and a foreign sector. MeMo-It is structured into five main blocks supply side, labor market, demand side, prices, and Government. For more details see Bacchini et al. (2013). Of course, the three disaggregate investment equations replace the pre-existing (aggregated) one.

[18] We are aware of the limits of the counterfactual analysis but, as in other studies (for Italy, see Caivano et al., 2011), we use it to illustrate the driving force that could be significant for policy design.

[19] Actually, the retrospective analysis of historical events is based on a number of assumptions about both the counterfactual pattern of the variables of interest we just described and, of course, the Lucas-Sims critiques about the lack of structural stability of MeMo-IT type models'. However, we think that our exercises may shed further light on the macroeconomic effects of uncertainty shocks.

knowledge based assets incurring in flow adjustment costs respond differently to macroeconomic shocks, as compared to tangible assets. Individual investment characteristics assume particular relevance for policy design since they have highly heterogeneous behaviours. In the short run, liquidity constraints and uncertainty are key determinants of Non-ICT capital accumulation, while ICT investment is driven by the interest rate and the financial constraints. In the long run instead, uncertainty and output have permanent effects on ICT, while Non-ICT tangible capital is affected by output and the user cost as suggested by the flexible neoclassical model.

Our simulation results support the idea that ICT is a key variable to assess sound policy measures to stimulate economic growth. The empirical literature widely demonstrated that ICT investment generates higher returns to growth than the other capital assets thus producing higher level of GDP (Jorgenson and Stiroh, 2000, Jorgenson and Vu, 2007).

We tested out model on the Italian data over the period 2008-2012. The simulation results show that better financial conditions and lower uncertainty could have helped the recovery of the Italian economy after the Great Recession.

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Appendix A1 - Data sources

Data refer to Italian business investment and capital stock by asset over the period 1980-2012.
Aggregate and disaggregate capital stock and investments data are drawn from the ISTAT National Accounts (NA). Series are available at both current prices and in volumes (chained index). Non-residential capital stock (*nres*) is the difference between business capital stock (*agg*), machinery and equipment (*me*) and ICT (*ict*).
From the NA source, we can compute the series of capital stock and investments in volume, respectively K_t^j and I_t^j, and the corresponding series of investment deflators P_t^j, obtained as ratios between investments at current prices and those in volumes.
Output series is measured by GDP in volumes; P_t is the GDP deflator; π_t^j is the rate of change of investment prices (measured by $\Delta \log P_t^j$). The rate of investments' subsidies (c_t) is the ratio between Government subsidies to investments and the value of business investments in the previous year.
The cost of borrowing R_t^j is given by the average of the rate of interest of long terms Government bonds (BTP) and ISTAT estimates based on the information collected to compute capital stocks; the risk premium is set to zero.
By reversing the formula of the perpetual inventory method we can compute the depreciation rates: $\delta_t^j = \dfrac{I_t^j - \Delta K_t^j}{K_{t-1}^j}$.
The degree of financial constraints (*liq*) is from the Istat monthly business survey where it is asked to the firms: "how do you judge the current level of liquidity (quite good, normal, bad)?". The index of economic policy uncertainty (*unc*) is from Backer et al. (2013) and is downloadable from http://www.policyuncertainty.com.
Nominal R&D (I_t^{berd}) is measured by the total intramural R&D expenditure of the Italian business enterprise sector; source: Eurostat's Statistics on Research and Development is. R&D in real terms is obtained by deflating its values with the GDP deflator. In order to compute the R&D stock, we used the perpetual inventory method with constant depreciation rate (assumed, as customary, to be equal to about 0.4 - see e.g. Hall, 2007, and Bontempi and Mairesse, 2014). In steady state, the initial value of the capital stock is proxied by $K_o^{berd} = I_o^{berd} / 0.4$. Although we acknowledge that this is a very crude method, it is just an early estimate subject to possible improvements.
The *output gap* series is from the Ameco database of the European Commission.

Appendix A2 - VECM modelling of three *ict* subsectors

Table A1 here

Appendix A3 - The complete system specification

The specification of the complete system for investments and capital stock is listed below. In the OLS estimates equations, the standard errors are reported in curly braces below each estimate. Labels in capital letters denote variables in levels, while their logs are in small letters. Variables' definitions and data sources are reported in the appendix A.1.

Non-residential buildings (bui)

$$UC_t^{bui} \equiv \left(R_t^{bui} + \delta_t^{bui} - \Delta p^{bui}\right) \left(\frac{1-c_t}{1-\tau_t}\right) \frac{P_t^{bui}}{P_t} \tag{A1}$$

$$\begin{aligned}\Delta k_t^{bui} = {} & \underbrace{0.068}_{0.031} + \underbrace{0.003}_{0.001} \times \Delta liq_t + \underbrace{0.107}_{0.029} \times \Delta y_{t-1} + \underbrace{1.045}_{0.136} \times \Delta k_{t-1}^{bui} - \underbrace{0.347}_{0.121} \times \Delta k_{t-2}^{bui} \\ & - \underbrace{0.002}_{0.001} \times \Delta uc_{t-2}^{bui} \quad \underbrace{-0.023}_{0.010} \times \left[k_{t-1}^{bui} - \left(\underbrace{0.750}_{0.088} \times y_{t-1} - \underbrace{0.100}_{0.031} \times uc_{t-1}^{bui} \right) \right] + \hat{\varepsilon}_t^{bui}\end{aligned} \tag{A2}$$

$$I_t^{bui} \equiv \Delta K_t^{bui} + \delta K_{t-1}^{bui} \tag{A3}$$

Machinery, plants and equipments (me)

$$UC_t^{me} \equiv \left(R_t^{me} + \delta_t^{me} - \Delta p^{me}\right) \left(\frac{1-c_t}{1-\tau_t}\right) \frac{P_t^{me}}{P_t} \tag{A4}$$

$$\begin{aligned}\Delta k_t^{me} = {} & \underbrace{-0.597}_{0.160} + \underbrace{0.015}_{0.002} \times \Delta liq_t - \underbrace{0.013}_{0.006} \times \Delta unc_t + \underbrace{0.482}_{0.060} \times \Delta y_{t-1} + \underbrace{0.518}_{0.061} \times \Delta k_{t-2}^{me} \\ & - \underbrace{0.006}_{0.002} \times \Delta uc_{t-1}^{me} \quad \underbrace{-0.087}_{0.023} \times \left[k_{t-1}^{me} - \left(\underbrace{1.402}_{0.055} \times y_{t-1} - \underbrace{0.266}_{0.022} \times uc_{t-1}^{me} \right) \right] + \hat{\varepsilon}_t^{me}\end{aligned} \tag{A5}$$

$$I_t^{me} \equiv \Delta K_t^{me} + \delta K_{t-1}^{me} \tag{A6}$$

Information and communication technology goods (ict)

$$\begin{aligned}\Delta i_t^{ict} = {} & \underbrace{0.098}_{0.014} + \underbrace{0.094}_{0.026} \times \Delta liq_t + \underbrace{0.067}_{0.025} \times \Delta liq_{t-1} + \underbrace{0.050}_{0.025} \times \Delta liq_{t-2} - \underbrace{1.124}_{0.492} \times \Delta R_{t-1} + \\ & \underbrace{-0.143}_{0.037} \times \left[i_{t-1}^{ict} - \left(y_{t-1} - \underbrace{0.993}_{0.220} \times unc_{t-1} \right) \right] + \hat{\varepsilon}_t^{ict}\end{aligned} \tag{A7}$$

$$K_t^{ict} \equiv I_t^{ict} + (1-\delta_t^{ict})K_{t-1}^{ict} \tag{A8}$$

Aggregation through summation of the three business components (sum)

$$K_t^{sum} \equiv K_t^{bui} + K_t^{me} + K_t^{ict} \tag{A9}$$

$$I_t^{sum} \equiv \frac{I_t^{bui} \times P_{t-1}^{bui} + I_t^{me} \times P_{t-1}^{me} + I_t^{ict} \times P_{t-1}^{ict}}{P_{t-1}^{sum}} \tag{A10}$$

Aggregate modelling of business investments (agg)

$$UC_t^{agg} \equiv \left(R_t^{agg} + \delta_t^{agg} - \Delta p^{agg}\right) \left(\frac{1-c_t}{1-\tau_t}\right) \frac{P_t^{agg}}{P_t} \tag{A11}$$

$$\begin{aligned}\Delta k_t^{agg} &= \underbrace{-0.081}_{0.021} + \underbrace{0.248}_{0.017} \times \Delta y_t + \underbrace{0.712}_{0.037} \times \Delta k_{t-1}^{agg} - \underbrace{0.009}_{0.002} \times \Delta uc_t^{agg} \\ &\underbrace{-0.038}_{0.010} \times \left[k_{t-1}^{agg} - \left(\underbrace{1.141}_{0.058} \times y_{t-1} - \underbrace{0.170}_{0.044} \times uc_{t-1}^{agg} \right) \right] + \hat{\varepsilon}_t\end{aligned} \tag{A12}$$

$$I_t^{agg} \equiv \Delta K_t^{agg} + \delta K_{t-1}^{agg} \tag{A13}$$

Tables and figures

Tab. 1 – Time series analysis of GDP, employment, and investments (1980-2012) [(a)]

	Volatility[(b)]	Persistence[(c)]		Comovement[(d)]				
	σ_X / σ_Y	ρ_1	ρ_2	$\rho_{XY}^{(k)}$ with k equal to:				
				-2	-1	0	+1	+2
				Lagging		Coincident	Leading	
Reference: Output gap	1.00	0.63 *	0.18			1.00		
$\Delta Y_t \ / Y_{t-1}$	1.12	0.40 *	0.05	-0.33	-0.12	**0.62** * **[0.76]** *	0.60 *	0.38 *
$\Delta E_t \ / E_{t-1}$	0.67 *	0.54 *	0.13	-0.23	0.26 * **[0.58]** *	**0.71** *	0.53 *	0.28
$I_t^{agg} / K_{t-1}^{agg}$	0.57 *	0.75 *	0.37 *	0.25	0.64 *	**0.93** * **[0.66]** *	0.63 *	0.26
- I_t^{me} / K_{t-1}^{me}	0.99	0.72 *	0.34	0.12	0.58 *	**0.88** * **[0.66]** *	0.61 *	0.24
- $I_t^{nres} / K_{t-1}^{nres}$	0.40 *	0.89 *	0.67 *	0.36	0.64 * **[0.57]** *	**0.67** *	0.40 *	0.15
- $I_t^{ict} / K_{t-1}^{ict}$	2.89 *	0.82 *	0.67 *	-0.30	0.00	0.31 **[0.52]** *	0.28	0.22
-- I_t^{ct} / K_{t-1}^{ct}	2.72 *	0.68 *	0.40 *	-0.30	-0.14	0.25 **[0.38]** *	0.27	0.22
-- I_t^{hw} / K_{t-1}^{hw}	3.66 *	0.66 *	0.41 *	-0.23	0.07	**0.38** * **[0.45]** *	0.20	0.04
-- I_t^{sw} / K_{t-1}^{sw}	7.31 *	0.92 *	0.85 *	-0.19	-0.02 **[0.33]** *	0.06	0.04	0.08
$I_t^{berd} / K_{t-1}^{berd}$	2.34 *	0.84 *	0.57 *	-0.07	0.10	0.26 **[0.34]** *	0.21	0.13

(a) Regarding volatility, * denotes 5% significance from one of the variance rations. Regarding persistence and comovement, * denotes 5% significance from zero of the correlations (the highest significant comovement is in bold). In squared brackets, the highest comovement of each HP filtered log-level with the output gap is reported; from high to low: GDP, employment, business investment, machinery and equipments, non residential buildings, ICT, telecommunication equipments, hardware, software, and R&D.

(b) Standard deviations of each variable relative to that of the output gap.

(c) Autocorrelations of the first- and the second-order.

(d) Correlations between each variable in t and the output gap in $t+k$, with k = -2, -1, 0, +1, +2.

Tab. 2 – VECM modelling of capital stock: cointegration and weak exogeneity (1980-2012) [(a)]

Investment asset (j=):	Business VAR5	(*agg*) VAR3	Machinery& Equipments VAR5	(*me*) VAR3	Non resid. buildings VAR5	(*nres*) VAR3	ICT VAR5	(*ict*) VAR3
VAR(p) settings:								
- deterministic terms	const	const	const	const	const	const	const	const
- p (number of lags)=	2	2	2	2	2	3	2	3
Residuals' tests, p-values:								
- autocorrelation 3rd order	0.6953	0.2080	0.3641	0.2335	0.1904	0.0530	0.2984	0.8008
- heteroscedasticity	0.1422	0.0005	0.3008	0.0019	0.0040	0.0877	0.2235	0.0013
- normality	0.2068	0.0128	0.5647	0.0042	0.0181	0.3390	0.0070	0.1120
Trace rank r test, p-values:								
r=0	0.0211	0.0105	0.0461	0.0111	0.0225	0.0393	0.0000	0.1457
r<=1	>0.1417	>0.0600	>0.1020	>0.0788	>0.0624	>0.0634	>0.0070	>0.1120
Long run parameter estimates:								
$\hat{\phi}_1$ (output)	1.156	1.141	1.427	1.402	0.946	0.750	3.337	2.080
	(0.050)	(0.058)	(0.061)	(0.055)	(0.070)	(0.088)	(0.472)	(1.074)
$\hat{\phi}_2$ (user cost)	-0.164	-0.170	-0.295	-0.266	-0.067	-0.100	1.043	0.053
	(0.050)	(0.044)	(0.070)	(0.022)	(0.027)	(0.031)	(0.531)	(1.272)
Loading parameter estimates:								
- $\hat{\pi}_1$ stock's loading parameter	-0.068	-0.068	-0.097	-0.106	-0.038	-0.033	-0.100	-0.061
	(0.014)	(0.020)	(0020)	(0.022)	(0.010)	(0.011)	(0.019)	(0.019)
- other loadings (restricted to zero)	0	0	0	0	0	0	0	0
- weak exogeneity, p-values [(b)]	0.0264	0.2145	0.2772	0.1804	0.0189	0.0891	0.0001	0.6790
Stock's equation:								
- R^2	0.831	0.803	0.763	0.718	0.914	0.913	0.817	0.840
- standard error of the regression	0.0056	0.0062	0.0099	0.0104	0.0025	0.0026	0.0233	0.0222
Sstandard deviation of log-changes in:								
- desired (target) capital stock [(c)]	0.0348	0.0354	0.0549	0.0411	0.0502	0.0390	--	--
- actual capital stock	0.0114	0.0114	0.0170	0.0170	0.0072	0.0072	0.0478	0.0478

[(a)] Dependent variables' vectors of VECM (7): $Z^j = \left(k^j, y, uc^j, liq, unc\right)'$ for enlarged VAR5, $Z^j = \left(k^j, y, uc^j\right)'$ for core VAR3. [(b)] In VAR5, tests for weak exogeneity also include restrictions to zero of liquidity and uncertainty long run parameters. [(c)] "--" not available (i.e. no valid long run relationship).

Tab. 3 – VECM modelling *ict* investment and its components: cointegration and weak exogeneity (1980-2012) [(a)]

	(1)	(2)	(3)	(4)	(5)	(6)
Investments by assets, j=		*ict*	*ict*	*ct*	*sw*	*hw*
VAR order. *p*	3	3	3	3	3	3
Residuals' tests, (p-values)						
- autocorrelation, 3rd order	0.5374	0.5256	0.2318	0.0749	0.6326	0.2678
- heteroscedasticity	5998	0.5993	0.6065	0.2051	0.3054	0.4923
- normality	0.8539	0.8549	0.0010	0.0333	0.5415	0.0059
Trace rank *r* tests, p-values						
r=0	0.0124	0.0124	0.0296	0.0010	0.0073	0.0130
r<=1	>0.1164	>0.1164	>0.0778	>0.0775	>0.0618	>0.0700
Long run parameter estimates:						
$\hat{\phi}_1$ (output)	1.3273	1.000	1.000	1.000	1.000	1.000
	(0.984)	(--)	(--)	(--)	(--)	(--)
$\hat{\phi}_2$ (user cost)	0.279	0.000	--	--	--	--
	(0.890)	(--)	--	--	--	--
$\hat{\phi}_3$ (liquidity)	0.326	0.350	0.305	0.327	0.000	0.322
	(0.153)	(0.151)	(0.145)	(0.243)	(--)	(0.174)
$\hat{\phi}_4$ (uncertainty)	-1.061	-1.157	-1.127	-0.898	-1.510	-0.667
	(0.373)	(0.148)	(0.166)	(0.253)	(0.808)	(0.167)
$\hat{\phi}_5$ (R&D)	0.576	0.569	0.632	0.429	0.476	0.000
	(0.258)	(0.252)	(0.297)	(0.254)	(0.562)	(--)
Loading parameter estimates:						
- $\hat{\pi}_1$ investment loading parameter	-0.272	-0.270	-0.271	-0.215	-0.133	-0.477
	(0.043)	(0.043)	(0.046)	(0.086)	(0.047)	(0.120)
- other loadings (restricted to zero)	0	0	0	0	0	0
- weak exogeneity, p-values [(b)]	0.0713	0.1770	0.7971	0.0224	0.0875	0.0731
Investment's equation:						
- R^2	0.364	0.371	0.668	0.727	0.715	0.758
- standard error of the regression	0.0830	0.0826	0.0599	0.0744	0.0860	0.0938
- conditioning cost of capital [(c)]	No	No	Yes **	Yes ***	Yes **	Yes ***

[(a)] "--" means not estimated (excluded variables from VAR and/or standard errors of restricted parameters). [(b)] Tests for weak exogeneity also include restrictions on the long run parameters, when imposed. [(c)] Changes of user cost in *t* and *t-1*; ** and *** respectively denote 5% and 1% significance on the basis of F tests.

Tab. 4 – Short- and long-run elasticities corresponding to the system steady state solution [(a)]

Elasticity of:	Investment					Capital stock				
	agg	*sum*	*bui*	*me*	*ict*	*agg*	*sum*	*bui*	*me*	*ict*
Elasticity to:										
Output										
- short-run	**2.560**	**3.495**	**3.249**	**4.056**	**0.110**	**0.447**	**0.301**	**0.119**	**0.593**	**0.035**
standard error	0.028	0.045	0.038	0.064	0.011	0.004	0.004	0.001	0.009	0.003
- long-run	**1.149**	**1.214**	**0.740**	**1.432**	**1.000**	**1.149**	**1.021**	**0.740**	**1.431**	**1.002**
standard error	0.029	0.043	0.054	0.058	0.102	0.012	0.011	0.010	0.024	0.090
Uncertainty										
- short-run	**0**	**-0.014**	**0**	**-0.005**	**-0.122**	**0**	**-0.006**	**0**	**-0.012**	**-0.039**
standard error	0	0.001	0	0.000	0.012	0	0.000	0	0.000	0.004
- long-run	**0**	**-0.078**	**0**	**0.000**	**-1.019**	**0**	**-0.025**	**0**	**0.000**	**-1.018**
standard error	0	0.008	0	0.000	0.107	0	0.002	0	0.000	0.096
Liquidity										
- short-run	**0**	**0.091**	**0.068**	**0.097**	**0.108**	**0**	**0.008**	**0.002**	**0.014**	**0.034**
standard error	0	0.001	0.001	0.002	0.011	0	0.000	0.000	0.000	0.003
- long-run	**0**	**0.023**	**0.000**	**0.000**	**0.294**	**0**	**0.007**	**0.000**	**0.000**	**0.295**
standard error	0	0.002	0.000	0.000	0.031	0	0.001	0.000	0.000	0.027
Interest rates [b]										
- short-run	**-1.130**	**-1.027**	**-1.416**	**-0.883**	**-0.916**	**-0.163**	**-0.126**	**-0.072**	**-0.194**	**-0.289**
standard error	0.011	0.014	0.017	0.015	0.094	0.002	0.002	0.001	0.003	0.030
- long-run	**-1.307**	**-1.280**	**-1.306**	**-1.419**	**0.000**	**-1.304**	**-1.320**	**-1.309**	**-1.419**	**0.000**
standard error	0.035	0.046	0.097	0.055	0.000	0.015	0.015	0.018	0.023	0.000
R&D [b]										
- short-run	**0**	**0.006**	**0**	**0**	**0.069**	**0**	**0.001**	**0**	**0**	**0.022**
standard error	0	0.001	0	0	0.007	0	0.000	0	0	0.002
- long-run	**0**	**0.048**	**0**	**0**	**0.620**	**0**	**0.015**	**0**	**0**	**0.620**
standard error	0	0.005	0	0	0.066	0	0.001	0	0	0.058

([a]) Obtained by perturbating the steady state solution of the four explanatory variables listed along the rows. The short-run elasticity is computed one period (year) after the shock, the long run corresponds to the last simulation year (i.e. about 80 periods after the shock). Standard errors are boostrapped in stochastic simulations of the system. Simple zeros denote that the corresponding parameters in the system are restricted to zero, while "decimal zeros" suggest the numerical irrelevance of the elasticity.

([b]) Semi-elasticity, i.e. % change in investments and capital stocks corresponding to an increase of 100 basis points in the interest rates.

Table 5 The price of the political uncertainty and financial conditions [a]

	uncertainty	*liquidity*	*total*
GDP	0.3	0.2	0.4
Business investments	2.3	2.3	4.7
- ICT	16.2	7.3	24.6
- Machinery & equipments	0.5	1.8	2.3
- Non-residential buildings	0.6	1.2	1.7
Capital stock	0.7	0.6	1.2
Full time equivalent employees	0.1	0.1	0.2

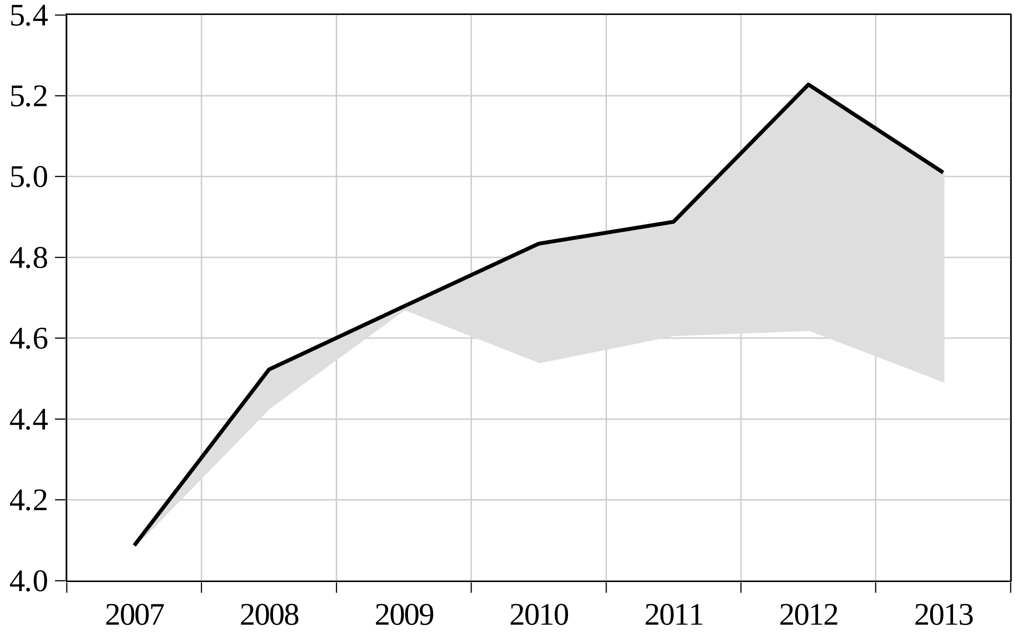
([a]) % changes in 2013 with respect to the actual levels.

Tab. A1 – VECM modelling of *ict* capital stock, its components and R&D: cointegration and weak exogeneity (1980-2012) [(a)]

	ICT VAR5	(*ict*) VAR3	Communic. equipments VAR5	(*ct*) VAR3	Hardware VAR5	(*hw*) VAR3	Software VAR5	(*sw*) VAR3	R&D VAR5	(*berd*) VAR3
VAR(*p*) settings:										
- deterministic terms	const	const	const	const	const	const	const	const	const	const
- *p* (number of lags)=	2	3	2	2	2	3	2	2	2	3
Residuals' tests, p-values:										
- autocorrelation 3rd order	0.2984	0.8008	0.7558	0.9423	0.5382	0.4015	0.8736	0.7407	0.6630	0.1316
- heteroscedasticity	0.2235	0.0013	0.1780	0.2692	0.6673	0.3327	0.7280	0.2294	0.6626	0.2914
- normality	0.0070	0.1120	0.0004	0.0000	0.6031	0.0736	0.0001	0.0000	0.2900	0.0199
Trace rank *r* test, p-values:										
r=0	0.0000	0.1457	0.0202	0.1554	0.0000	0.1439	0.0015	0.0929	0.0036	0.0108
$r<=1$	>0.0070	>0.1120	>0.1094	>0.1055	>0.021	>0.3338	>0.0111	>0.1723	>0.0559	>0.0846
Long run parameters:										
$\hat{\phi}_1$ (output)	3.337	2.080	2.923	2.351	2.375	1.710	2.122	2.283	0.728	0.641
	(0.472)	(1.074)	(0.515)	(0.559)	(0.396)	(0.498)	(0.0919)	(0.809)	(0.200)	(0.206)
$\hat{\phi}_2$ (user cost)	1.043	0.053	0.333	-0.152	0.037	-0.408	2.722	2.433	0.674	0.670
	(0.531)	(1.272)	(0.401)	(0.404)	(0.252)	(0.310)	(0.798)	(0.711)	(0.469)	(0.507)
Loading parameters:										
- $\hat{\pi}_1$ stock's loading parameter	-0.100	-0.061	-0.099	-0.096	-0.207	-0.202	-0.076	-0.085	-0.134	-0.145
	(0.019)	(0.019)	(0031)	(0.036)	(0.040)	(0.046)	(0.021)	(0.020)	(0.028)	(0.040)
- other loadings (restricted to zero)	0	0	0	0	0	0	0	0	0	0
- weak exogeneity, p-values [(b)]	0.0001	0.6790	0.0023	0.0945	0.0016	0.1664	0.0027	0.2106	0.0006	0.0093
Stock's equation:										
- R^2	0.817	0.840	0.625	0.601	0.655	0.678	0.937	0.935	0.840	0.851
- standard error of the regression	0.0233	0.0222	0.0218	0.0232	0.0373	0.0368	0.0229	0.0235	0.0173	0.0170

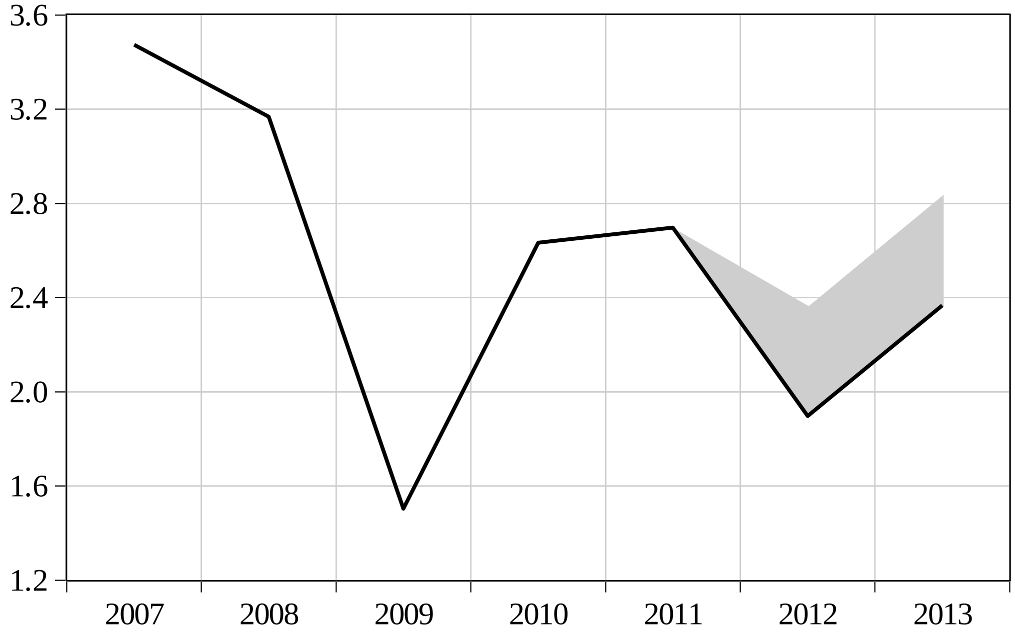
[(a)] Dependent variables' vectors of VECM (7): $Z^j = \left(k^j, y, uc^j, liq, unc\right)'$ for enlarged VAR5, $Z^j = \left(k^j, y, uc^j\right)'$ for core VAR3. [(b)] In VAR5, tests for weak exogeneity also include restrictions to zero of liquidity and uncertainty long run parameters.

Fig. 1 – The economic policy uncertainty index, log-levels [a]



([a]) Bold line: the Italian index; grey shaded area: distance between the Italian index and the average of Germany, France and Spain indexes.

Fig. 2 – The pattern of liquidity indicator, log-levels [a]



([a]) Bold line: the historical pattern; grey shaded area: distance between the historical pattern and an alternative of less credit crunch in 2012-2013, whose liquidity levels are those of the historical figures one-year later.