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Short- and long-run heterogeneous investment dynamics

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Abstract In this paper, we model the dynamics of business investment taking into account asset-specific characteristics potentially affecting the reactivity of aggregate and disaggregate capital accumulation over the business cycle. We estimate Information and Communication Technologies (ICTs) and traditional investment (non-ICT) determinants within a Vector Error Correction Model testing the assumptions of the flexible accelerator and neoclassical model as well as the role of financial constraints and uncertainty. We evaluate our model on Italian data over the period 1980–2012, and we check our results also with Spanish and UK data. Our findings support the assumption that capital is heterogeneous since short- and long-run determinants are significantly different across the assets. Traditional assets experience stock adjustment costs while ICT investment incurs flow adjustment cost. In the short run, liquidity is a key determinant of investment independently of the asset type. In the long run, uncertainty significantly affects ICT. Finally, the results of the counterfactual exercises support the idea that ICT is a key policy variable to foster economic growth.

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Abbreviations

ICTs	Information and Communication Technologies
non-ICT	Traditional assets other than Information and Communication Technologies
VECM	Vector Error Correction Model

1 Introduction

The lack of private investment is currently one of Europe's biggest economic weaknesses. For two decades, investment has been too low undermining productivity, hampering the European growth potential, and damaging its competitiveness. The prolonged underinvestment together with inefficient and fragmented financial markets and the recent increasing political and economic uncertainty worsened the structural investment gap between Europe and the US. Since 2008, gross fixed investment has declined by around 15 per cent in the Euro area and the investment rate has dropped by around four percentage points. In the US, on the contrary, the investment rate has gradually recovered from its trough during the financial crisis, even if it is still below its pre-crisis level. Investment has been the main driver of the growth differential between the Eurozone and the US accounting for 20% and 21% of real GDP, respectively. Buti and Mohl (2014) estimate that a 5% point reduction in the investment rate leads to a decrease in potential growth of around 0.5%. Understanding what drives the low investment rates is thus key to assessing the future potential growth of the European economies (DIW 2014).

The macro and microeconomic literature tried to identify the main factors influencing capital accumulation, but none of them identified a comprehensive and flexible investment model suitable to address the above policy challenges. At the beginning, the accelerator model (Clark 1917, 1944; Koyck 1954), the neoclassical inter-temporal optimization model (Jorgenson 1963; Hall and Jorgenson 1967), and the q-model (Brainard and Tobin 1968; Tobin 1969) have been the benchmark models to explain aggregate investment behaviour. But, the macroapproach had a rather poor empirical performance that determined a shift from macro to microdata analysis to relax simplifying restrictions and deepen specific aspects, such as market imperfections (Hubbard 1998), the role of internal funds (Fazzari et al. 1988; Bond and Meghir 1994), non-convex adjustment costs (Caballero 1999), and fixed adjustment costs and irreversibility (Bertola and Caballero 1994; Caballero et al. 1995; Cooper and Haltiwanger 2006). A main finding of the micro research cited above is that capital is heterogeneous and that investment models need to take into account individual asset characteristics.

In this paper, we aim at identifying the main drivers of aggregate investment and of its key components, ICT (communication equipment, hardware and software) and non-ICT (machinery and equipment, and non-residential buildings), to account for capital heterogeneity in the time series macroeconometric framework. We focus in particular on the determinants of technological investments (ICT) emphasizing its strategic role in the policy agenda for innovation and growth.

In particular, we adopt the macroeconometric approach of the Vector Error Correction Model (VECM, Johansen 1995), to evaluate the assumptions of the flexible accelerator and neoclassical models as well as the role of financial constraints and uncertainty in explaining investment behaviour. Our approach allows for a different role played by financial constraints and uncertainty on the dynamics of the different types of investment, as it emphasizes the role of stock and flow adjustment costs under uncertainty (Bloom 2007) as well as that of asymmetric information and credit rationing particularly relevant for ICT (Hall and Lerner 2010).

In doing so, we take the macro investment models as testable null hypotheses rather than maintained hypotheses, in a sort of shift from micro analyses (mainly confirmatory) towards a mixture of confirmatory and exploratory macro analysis which reflects the epistemological pragmatism advocated in Colander et al. (2008), Hoover et al. (2008), and Morley (2010). The main advantage of our VECM-based models is their ability of accounting for macrotime series data features and regularities (see, e.g. Qin 2011), thus allowing to test the short- and long-run impact of uncertainty and financial constraints on investment dynamics in a comprehensive framework.

To our knowledge, this paper offers an original contribution to the macroeconomic modelling of investment as well as to the ICT literature looking at the short- and long-run determinants of technological capital accumulation. Traditionally, ICT capital accumulation has been widely investigated in the economic growth literature to explain its impact on productivity growth (Jorgenson and Stiroh 1999; Jorgenson 2001).

Very few studies have analysed ICT investment determinants (De Arcangelis et al. 2004; Guerrieri et al. 2011), and most of them focused on factors influencing ICT adoption in small and medium enterprises (Consoli 2012). More recently, O'Mahony and Vecchi (2005) and Venturini (2009) look at the long-run relationship between ICT capital and output growth, using panel cointegration techniques but with the goal of quantifying the impact of ICT capital accumulation on productivity growth. Overall, these studies do not provide any clear evidence about the driving factors of ICT investment dynamics, which is one of the main goals of the present paper.

We examine Italian business investment and capital stock by asset over the period 1980–2012. Italy is quite appealing as natural experiment of investment slowdown over the recent financial crisis because of its high uncertainty and liquidity constraints.[1] The Italian economy experienced also a prolonged productivity slowdown and an increasing gap in innovation investment with respect to the other EU countries, remarkably exacerbated by the financial turmoil. This makes Italy a very interesting candidate to investigate the short- and long-run determinants of ICT investment[2] widely recognized

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[1] Caivano et al. (2010) showed that in Italy financial factors may explain an investment decline of 9% points over the period 2008–2010. See also Gaiotti (2013).

[2] Italian GDP accounts for 17 per cent of the Euro Area GDP.

as a key driver of productivity growth. To check the robustness of our results, we test our model also for UK and Spain representing, respectively, a fast and a slow ICT adopter (Daveri 2002).

Our findings support the assumption that capital heterogeneity is a primary characteristic to be taken into account when modelling investment dynamics since short- and long-run determinants are significantly different across the assets. In particular, we show that the neoclassical stock adjustment mechanism is appropriate to explain the long-run dynamics of aggregate and non-ICT capital accumulation, but it does not fit with ICT stock dynamics. We discover instead that in the long run, ICT investments are driven by credit conditions and uncertainty and by strong complementarity with R&D. The assumption of capital heterogeneity and of a higher sensitivity of ICT compared to non-ICT is supported also by our counterfactual exercise aimed to assess the impact of different degrees of uncertainty and liquidity constraints on GDP growth.

Overall, our findings corroborate the notion that individual asset characteristics are relevant to interpret investment dynamics over the business cycle and that a macroinvestment model has to take capital heterogeneity into account to provide effective policy suggestions.

The paper is structured as follows. Section 2 discusses the relevance of ICT investment for the Italian and the EU growth agenda. Section 3 illustrates our model and empirical strategy, and Sect. 4 shows our empirical results. Section 5 is focused on policy implications while Sect. 6 concludes.

2 Why ICT investment matters

Extensive literature shows that information and communication technology is an asset that provides particularly large contributions to productivity growth (Oliner and Sichel 2000; Jorgenson and Stiroh 1999; Stiroh 2002; Oliner et al. 2007). This is why ICT is a key variable to assess the future potential growth of modern economies. Small ICT capital contribution coupled with a slower progress in productive efficiency is at the centre of the European debate about the EU productivity gap with respect to the US (Strauss and Samkharadze 2011). The disparities between innovation investments (ICT and R&D) are a concern also within Europe, with different countries showing divergent trends. Italy is an interesting example in this respect showing an increasing investment gap with respect to both fast (UK) and slow (Spain) ICT adopters. The Italian GDP shares of ICT persistently fell behind the Spanish and UK values (Fig. 1) even if at a different pace. In 1995, the GDP share of ICT investment was 6.9% both in Italy and in Spain and 8% in UK. Fifteen years later, the ICT shares jumped to 24% and 27% in Spain and UK, respectively, while in Italy it increased just up to 15%. The different pattern of Italian ICT investment shares, compared to UK and Spain, is a distinctive feature of the period starting in 2000 since before they followed comparable dynamics. As for the GDP shares of R&D, Italy and Spain trailed similarly converging to a tiny 0.7% at the end of the sample period, while UK shows a share always well above 1%.

The global economic and financial crisis contributed to exacerbate the investment gap between Europe and the US as well as within the EU economies. The financial fragmentation in most of the EU member countries significantly constrained the supply
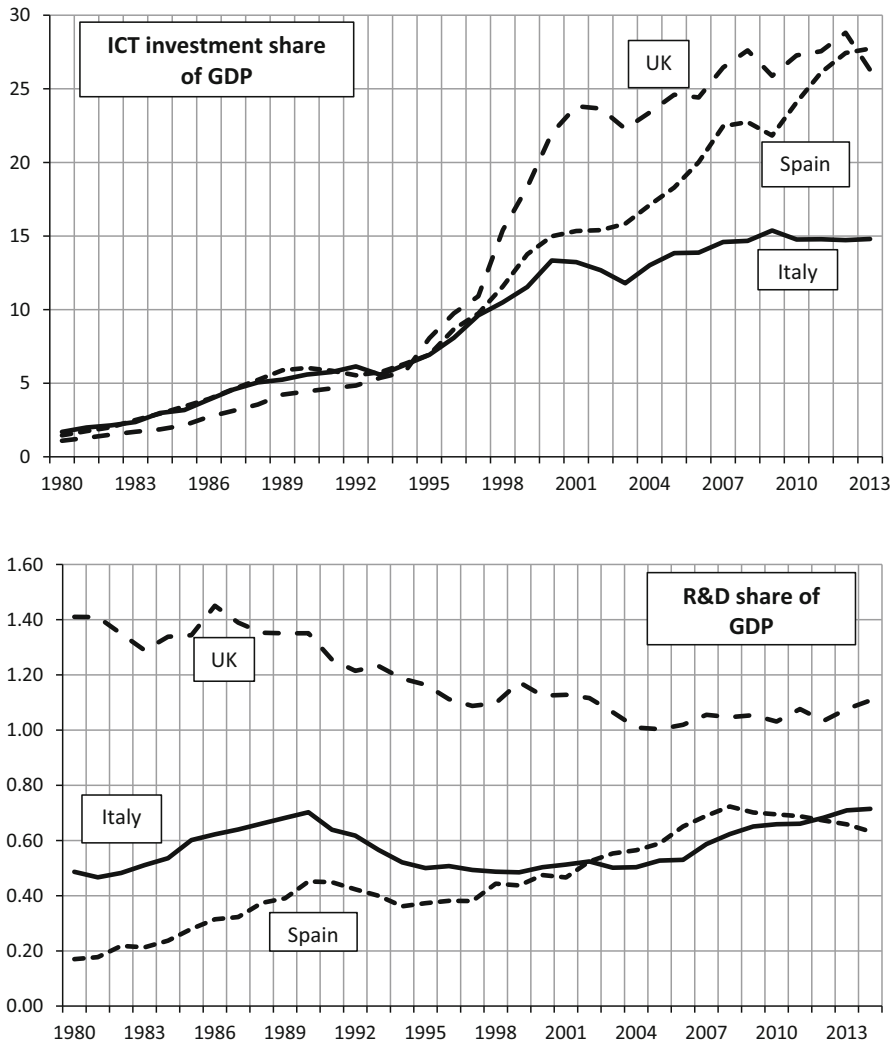
Fig. 1 ICT and R&D: Italy versus UK and Spain. *Sources*: ICT (EU KLEMS), GDP (Ameco), R&D (European Commission); see "Appendix 1"

of credit to the real economy, thus restraining investment activity.[3] Italy and Spain suffered more than the other EU members, since financing conditions of the private sector have been much less supportive in these countries than in the other European economies.

The high levels of economic and political uncertainty fostered by the crisis worsened the European investment environment amplifying the effects of credit constraints by

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[3] Garicano and Steinwender (2013) looking at Spanish firms have shown the effects of the credit constraints on the composition of investments towards investments that take shorter time to yield output .
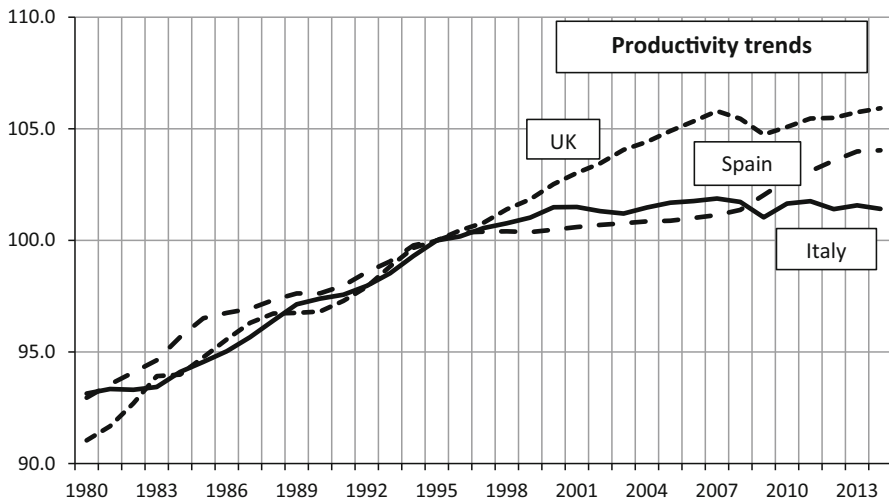
Fig. 2 Long-run productivity differential: Italy, UK, and Spain. *Source*: Ameco

raising the risks of irreversible investment decisions. The crises had a strong negative effect on total investment in all leading economies, but while in other EU countries there is evidence of an imminent recovery, the Italian investment gap has persistently broadened. Further, during the crisis, Italy experienced a relatively higher increase in the cost of capital that contributed to lower investment propensity and particularly propensity to ICT investment.

Years of underinvestment in innovation contributed to the structural decline of the Italian competitiveness. Since the second half of the 1990s, when most of the advanced countries were benefiting from the adoption of new business models and massive investment in new technologies (Daveri and Jona-Lasinio 2005), Italy experienced a sharp and prolonged productivity slowdown (Fig. 2).[4]

In 1995–2013, the rate of growth of productivity increased by 5.9% in UK,[5] 4.0% in Spain and a small 1.4% in Italy. The long-run trend shows that the Italian productivity decline is not the result of unfortunate business cycle fluctuations, but it is related to structural weaknesses (Daveri and Parisi 2015).

The prolonged lack of innovative investment coupled with the increasing productivity growth differential with respect to the other EU economies makes Italy a very good candidate to investigate the determinants of technological investment. The identification of the main drivers of ICT capital accumulation can provide critical insights to design strategic policy actions to revitalize long-term competitiveness enhancing investment in the slow growing economies, such Italy and Spain.

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[4] We keep UK and Spain as two reference countries for our comparative analysis since besides being fast and slow ICT adopters, they experienced different but superior productivity performances compared to Italy.

[5] See Pessoa and Reenen (2014) for a deep analysis of the UK productivity puzzle.

In what follows, we investigate the sensitivity of aggregate, ICT, and non-ICT investment to the business cycle taking into account the impact of uncertainty and financial constraints. The analysis is focused on the Italian economy in 1980–2012. Then we check the robustness of our findings looking also at Spain and UK over the same time period but resorting to a more aggregate data source.

3 The analytical framework

Our empirical strategy hinges from different macro- and microtheoretical models to identify short- and long-run determinants of technological and physical investment expenditure. We examine the characteristics of investment decisions distinguishing between aggregate (total business expenditure, *agg*) non-ICT (machinery and equipment, *me* and non-residential, *nres*), and ICT assets (*ict*).[6]

In the analysis, we make two core assumptions: the actual capital stock is dynamically related to 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 the findings by Bloom (2007), suggesting that R&D could incur flow adjustment costs, while investment in physical capital usually deserves stock adjustment costs, thus implying a different dynamics under uncertainty. Flow adjustment costs and uncertainty make R&D reacting with lags to recessions and highly persistently across the business cycle.

We assume that ICT has some features in common with R&D over the cycle. Since ICT is a mixture of tangible and intangible assets, we simply assume that the intangible component of ICT makes it closer to R&D than to ordinary physical assets. However, we take into account that R&D investment decisions can be affected by larger information asymmetries than ICT, so that R&D is more sensible to uncertainty and financial constraints (Hall and Lerner 2010).

We explore the driving adjustment mechanisms of aggregate and individual capital assets checking whether the neoclassical model holds independently of the asset category. If this is the case, the stock adjustment mechanism should be appropriate to explain the dynamics of aggregate, ICT and non-ICT investments. If instead the change in a specific investment category follows a flow adjustment mechanism, the neoclassical model does not hold and we need to check for additional investment determinants. We find ourselves in this position, and to account for capital heterogeneity, we augment the neoclassical framework including uncertainty and liquidity constraints. As we will show below, the distinction between stock and flow adjustment costs across the assets makes a material difference in shaping the response of investment to liquidity and uncertainty over the business cycle (Bloom 2007; Aghion et al. 2012).

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[6] 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, the empirical evidence about asset-specific investment determinants at macrolevel is scant. Very recently, Ketteni et al. (2015) investigate the impact of capital heterogeneity on productivity growth distinguishing between FDI, ICT, and non-ICT capital.

3.1 Background literature

We start from the flexible accelerator model (Clark 1944; Koyck 1954) according to which investments can be represented as:

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

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

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

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

where Y is the output, UC ^{j} is the cost of capital, ϕ_1^j and ϕ_2^j are parameters which, respectively, measure the elasticity of capital to output and its costs, and α_0^j is the total factor productivity (the intercept in the log-transformed function is $a_0^j = \log\alpha_0^j$); in general, variables in levels are labelled with uppercase letters, while lowercase letters label the corresponding log-levels, i.e. $y = \log Y$. In turn, the components of the cost of capital can be defined on the basis of the classical Hall and Jorgenson (1967) formula as (see, e.g. Caballero 1994):

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

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 in 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 price of investment in good j, and P_t is the output price.

The accelerator and the neoclassical models are nested in the general model obtained by substituting Eq. (2) in (1), according to alternative restrictions on the φ parameters. If $\phi_1^j = 1$ and $\phi_2^j = 0$, 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).

Even though k_t^{*j} is not observable, we can assume that k_t^j keeps pace with its target. Under this assumption, the differences between these two variables must be transitory (see, e.g. Caballero 1999). Let

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

where the unobservable u_t^j measures the transitory discrepancies due to adjustment costs. Substituting (2) in (4), we obtain a static relationship where the determinants of the desired capital stock explain the log-levels of its actual realizations:

$$k_t^j = a_0^j + \phi_1^j y_t + \phi_2^j uc_t^j + u_t^j \tag{5}$$

Given that the empirical literature suggests uncertainty and financial constraints as relevant determinants to explain in the short-run capital fluctuations (Hubbard 1998; Bloom et al. 2007; Gaiotti 2013),[7] the transitory discrepancies u_t^j between the target and the actual capital stock can be modelled as a function of liquidity constraints (*liq*), uncertainty (*unc*), and a miscellanea of other effects, v_t^j, that are bound to be serially correlated because of the omitted dynamics generated by the adjustment costs, in symbols:

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

Of course, the actual realizations of the variables belonging to Eqs. (5) and (6) derive from a process which is much more complex than the two simple equations listed above and, thus their empirical assessment must start from a multivariate framework (the unrestricted VAR model), where all the five variables of interest (i.e. capital stock, output, cost of capital, liquidity, and uncertainty) are a priori allowed to be endogenous, and where the specification of their short- and long-run dynamics and of the simultaneous direction of causality are not assumed to be known, as we indeed would have done if we would have estimated directly the parameters of Eqs. (5)–(6).

More explicitly, Eq. (5) represents a level relationship that, in the context of non-stationary variables, can be interpreted as a cointegration relationship. As such, it cannot be estimated directly, but its admissibility must be first assessed by testing the cointegration rank of the VAR model above and, in case of unit rank cointegration, we also have to test whether *liq* and *unc* variables can be excluded from the long-run relationship, as the theoretical model (5) does not predict them as long-run drivers.

Similarly, the process of adjustment, which *ex post* leads to the period-by-period discrepancy u_t^j, cannot be statistically modelled and estimated as expressed in Eq. (6), but must be rather obtained by a process of statistical reduction in the VAR which embodies the restrictions that identify the cointegrating Eq. (5) above, and where the short-term role of other determinants (such as liquidity constraints and uncertainty) is assessed through the weak exogeneity property. In fact, under the weak exogeneity assumption, u_t^j can drive only the adjustment process of the actual capital and not also the fluctuations of the other simultaneous variables in the VAR. Note that, in the absence of a clear theoretical guidance, we also have to find the best method to measure the transitory impulses of liquidity constraints and uncertainty, i.e. if they drive the adjustment process (6) in levels or in first differences.

As we will detail in the next section, the empirical steps outlined above can be accomplished in the context of the Vector Error Correction Model (VECM) approach of Johansen (1995), where a number of statistical issues (such as the cointegration rank and the weak exogeneity) can be easily implemented in a statistically sound environment. In other terms, the Johansen approach is the statistical tool that will

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[7] Among the macropapers, de Bondt and Diron (2008) find that financing constraints are relevant for aggregate investment, and Parigi and Siviero (2001) reveal the importance of business confidence (interpreted as a measure of uncertainty) to determine investment decisions.

enable us to carry out a mixture of confirmatory and exploratory macroanalyses in order to assess the usefulness and relevance of the classical theoretical drivers listed in Eqs. (5) and (6) to explain the patterns of aggregate investment and its components over time.

3.2 The VECM

The Johansen (1995) approach is sketched by the following general VECM representation in which, for simplicity, we omit the superscript j:

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

where Z is the $(n \times 1)$ vector of $nI(1)$ or $I(0)$ variables explained by the system, and Δ is the first-difference operator, C is the $(d \times 1)$ 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 in the variables, $\phi' Z_{t-1}$ is the $(r \times 1)$ vector of stationary (i.e. cointegrated of rank r) long-run level relationships 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), and ε is the $(n \times 1)$ vector of normal white noise stochastic errors.

Consider the case of asset j ($j = agg, me, nres$ and ict) and define the vector of the dependent variables as $Z^j = \left(k^j, y, uc^j, liq, unc \right)'$.[8] This model representation is appropriate to test the following assumptions both for aggregate capital stock and for the three individual assets:

1. Liquidity and uncertainty are weakly exogenous, and the neoclassical stock adjustment mechanism is driven in the long run by output and cost of capital;
2. Liquidity and uncertainty affect also the long-run relationship (i.e. they significantly contribute to the target in the long run), and the neoclassical stock adjustment mechanism is not suitable to explain asset-specific dynamics but, instead, the flow adjustment mechanism is.

If the cointegration rank of VECM (7) is $r = 1$, the first step of the analysis is to test the exclusion of *liq* and *unc* levels from the capital stock's long-run relationship by restricting the long-run parameters' vector to $\phi^j = \left(1, \phi_1^j, \phi_2^j, 0, 0 \right)'$; under the null hypothesis of these joint restrictions, the structural Eq. (5) cannot be rejected. These restrictions must be tested together with the weak exogeneity (see also Hausman 1978; Urbain 1992) of all the other variables in the system (7) by imposing additional zero restrictions on all the loading factors, except for that corresponding to the capital stock

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[8] Under the assumption of separate cointegration (Granger and Haldrup 1997), the estimation can be performed by three parsimonious subsystems (for $j = me, nres$ and ict) which can be modelled by asset in analogy with the aggregate case (i.e. $j = agg$).

equation, i.e.: $\pi^j = \left(\pi_1^j, 0, 0, 0, 0\right)$. If both sets of restrictions are not jointly rejected, then the VECM (7) can be reduced into the single equation (8), where capital stock is explained by an ECM model conditional on the simultaneous changes in all the other variables of the system:

$$\Delta k_t^j = \gamma_1^j + \gamma_2^j \Delta y_t + \gamma_3^j \Delta uc_t^j + \gamma_4^j \Delta liq_t + \gamma_5^j \Delta unc_t$$
$$+\gamma_{11}^j \Delta k_{t-1}^j + \gamma_{21}^j \Delta y_{t-1} + \gamma_{31}^j \Delta uc_{t-1}^j + \gamma_{41}^j \Delta liq_{t-1}$$
$$+\gamma_{51}^j \Delta unc_{t-1} + \pi_1^j \left(k_{t-1}^j - \phi_1^j y_{t-1} - \phi_2^j uc_{t-1}^j\right) + \varepsilon_t^j \quad (8)$$

The first row of Eq. (8) shows the contemporaneously conditioning explanatory variables, while the second row reports their corresponding lags (together with the lagged dependent variable); this first-order dynamics descend from the assumption that the VAR lag length is $p = 2$. These two rows of explanatory variables (together with the *iid* random shocks ε_t^j to capital stock) drive the impulses to the actual capital shock short-run fluctuations, measured by the changes in all the variables in VAR (including those in *liq* and *unc*). As such, they represent the statistically sound vision of Eq. (6) above because by definition all these dynamics effects are stationary (i.e. they are only transitory). Of course, a number of further significance tests can assess whether some of the γ parameters may be restricted to zero, and under the null of such zero restrictions, the corresponding short-run impulses would be cleared from the Eq. (8). For example, if under the null hypothesis H$_o$: $\gamma_4^j = \gamma_5^j = \gamma_{41}^j = \gamma_{51}^j = 0$, the effect of *liq* and *unc* is cleared also from the short-run dynamics of capital stock.

In the last row of Eq. (8), the equilibrium correction term is reported in brackets, and the loading factor π_1^j measures the speed at which target and actual capital stocks converge (the closer to zero, the slower the adjustment). In this formulation, consistent with the neoclassical stock adjustment model, the long-run parameters together with the log-levels of output and user cost define the target log-level of capital encapsulated in the VECM reduction:

$$k_t^{j*} = \phi_1^j y_t + \phi_2^j uc_t^j \quad (9)$$

which is the statistically sound estimate of the unobservable log-target definition in Eq. (2) above.[9]

If the reduction from the general VECM (7) to Eq. (8) is rejected by data, i.e. if assumption one does not hold because of the lack of cointegration and/or the rejection of the weak exogeneity restrictions, we must abandon the neoclassical stock adjustment mechanism and make other assumptions regarding the investment dynamics and determinants. One possibility is assuming a flow adjustment mechanism (Bloom 2007). This context, particularly suitable for R&D expenses, would imply to start

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[9] Once Eq (8) is solved for capital stocks, we can obtain the corresponding level of business investments adopting the perpetual inventory accounting identity: $I_t^j \equiv \Delta K_t^j + \delta^j K_{t-1}^j$, where investments are defined as the difference between the changes in the levels of capital stock and the amount of past capital depreciation (δ^j is the depreciation rate specific to asset j).

from the VECM (7) representation with $Z^j = (i^j, y, liq, unc)'$ where capital stock is replaced by investment to check whether assumption two holds.

4 The empirical results

In this section, we statistically describe the main characteristics of aggregate, ICT, and non-ICT dynamics in Italy over the period 1980–2012. Descriptive statistics are relevant to depict a complete picture of the driving factors of investments dynamics over the business cycle (for the US, Lee and Rabanal 2010). Then we present the results of the cointegration analysis and test the sensitivity of aggregate and disaggregate capital accumulation determinants in our newly defined investment/capital stock system of equations. The data description is in "Appendix 1".

4.1 Stylized facts over the cycle

Table 1 reports a number of classical business cycle time series indicators (see, e.g. Schlitzer 1995) to measure volatility, persistence, and comovement of each variable of interest (in general, X_t) with respect to the output gap, which is the reference variable labelled YG_t.

The growth rates of GDP and investment in machinery have approximately the same volatility of the output gap (the reference series) over the cycle, while non-residential investment are significantly less volatile. ICT investments and its main components, namely communication equipment (*ct*), hardware (*hw*), and software (*sw*), as well as R&D (*berd*), are twice more volatile than standard physical assets. According to the persistence indicators, all the variables in Table 1 are broadly stationary, albeit at different degrees.[10] Investment ratios are more persistent than the rate of growth of GDP and employment, with first-order autocorrelations equal to 0.7 or above. Non-residential buildings, software (*sw*), and R&D expenditure show the highest degree of persistence.[11] Finally, GDP growth and investment ratios in machinery and buildings are pro-cyclical and coincident (or slightly leading), while ICT and R&D are a-cyclical (hardware resembles machinery and equipment).

The descriptive analysis supports the idea that non-ICT and ICT (but also R&D) evolve and react differently over the business cycle and that the dynamics of aggregate business investment is substantially similar to non-ICT capital. Notice that ICT, as R&D, shows a relatively higher degree of persistency than machinery and equipment suggesting that a different adjustment mechanism might be at work.

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[10] The perpetual inventory method relating investment and capital stock, $I_t^j / K_{t-1}^j = \Delta K_t^j / K_{t-1}^j + \delta_t$, 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.

[11] For software and R&D, this finding is consistent with Bloom (2007).

Table 1 Time series analysis of GDP, employment, and investments (1980–2012)

| | Volatility[a] | Persistence[b] | | Comovement[c] $\rho^{(k)}_{XY}$ with k equal to: | | | | |
| | σ_X/σ_Y | ρ_1 | ρ_2 | Lagging | | Coincident | Leading | |
				-2	-1	0	1	2
Reference: output gap (YG)	1.00	0.63*	0.18			1.00		
$\Delta Y_t/\Delta Y_{t-1}$	1.12	0.40*	0.05	-0.33	-0.12	0.62*	0.60*	0.38*
I^{agg}_t/K^{agg}_{t-1}	0.57*	0.75*	0.37*	0.25	0.64*	0.93*	0.63*	0.26
I^{me}_t/K^{me}_{t-1}	0.99	0.72*	0.34	0.12	0.58*	0.88*	0.61*	0.24
$I^{nres}_t/K^{nres}_{t-1}$	0.40*	0.89*	0.67*	0.36	0.64*	0.67*	0.40*	0.15
I^{ict}_t/K^{ict}_{t-1}	2.89*	0.82*	0.67*	-0.30	0.00	0.31	0.28	0.22
I^{ct}_t/K^{ct}_{t-1}	2.72*	0.68*	0.4*	-0.30	-0.14	0.25	0.27	0.22
I^{hw}_t/K^{hw}_{t-1}	3.66*	0.66*	0.41*	-0.23	0.07	0.38*	0.20	0.04
I^{sw}_t/K^{sw}_{t-1}	7.31*	0.92*	0.85*	-0.19	-0.02	0.06	0.04	0.08
$I^{berd}_t/K^{berd}_{t-1}$	2.34*	0.84*	0.57*	-0.07	0.10	0.26	0.21	0.13

We focus on growth rates for GDP ($\Delta Y_t/Y_{t-1}$) and on investment ratios by asset (I^j_t/K^j_{t-1}, with $j = agg$ for aggregate, me for machinery-equipment, $nres$ for non-residential buildings, ict for information and communication technology). We also exploit the disaggregation in three components of ICT investments, namely ct (communication equipment), hw (hardware), and sw (software). Finally, we computed the same indicators for the ratio of R&D expenditure on its stock ($j = berd$). Details about data are in "Appendix 1"

[a] The volatility of each variable of interest, X_t, is measured by its standard deviation in terms of that of the output gap YG_t (i.e. σ_X/σ_{YG})

[b] The persistence of both X_t and YG_t is measured by the autocorrelation coefficients of the first- and second-order (ρ_1 and ρ_2)

[c] The comovements of X_t with the reference YG_t, reported in the last five columns, are measured by the correlation coefficients of X_t with up to the second lag/lead of YG_{t-k} ($\rho^{(k)}_{XY}$), where $k = -2, -1, 0, 1, 2$). With annual data, we assume that two lags are enough to account for all the relevant dynamics

* Denotes 5% significance in the volatility columns, while it denotes 5% significance from zero of the correlations in the persistence and comovement columns.

4.2 The cointegration analysis

The cointegration analysis has been performed using the Johansen's rank test based on VECM (7) at the aggregate level and by asset. The five-variables' vector includes the three components of the classical capital stock model together with a measure of uncertainty and a measure of liquidity constraints $Z^j = \left(k^j, y, uc^j, liq, unc\right)'$. The estimation results are reported in Table 2.

A significant cointegration relationship is identified for aggregate stock as well as for non-ICT capital while we do not find any cointegration relationship for ICT capital stock.[12] The identified cointegrated vectors support the relationship between desired capital stock and its classical determinants (output and user cost). In the long run, aggregate and non-ICT capital adjust to the desired stocks whose determinants are weakly exogenous.[13]

The long run desired capital stock elasticity to output (Table 2, VAR3) is very close to one in the aggregate specification, and significantly higher than (lower than) one for machinery and equipment (for non-residential buildings). The significantly negative parameter of the user cost elasticity rejects the accelerator model but supports the prediction of the flexible neoclassical model (assumption one).

The speed of adjustment of actual to desired capital stocks is rather slow, suggesting the presence of high adjustment costs, especially for non-residential buildings. The long-run estimates above reinforce the prediction of Caballero (1994) that with high adjustment costs, the standard deviation of the desired stocks is larger than the actual stocks (Table 2, last two rows).[14]

ICT capital stock behaves rather differently. The cointegration rank tests deliver the following 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, supports the assumption that the underlying long-run relationships in reduced form are a combination of target capital stock determinants and liquidity and uncertainty rather than the classical capital stock equations (assumption two).[15]

This model has been tested analysing individual ICT components and R&D. The analysis is reported in Table 3, in which the first two columns for aggregate ICT

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[12] The data congruence of VAR models has been assessed through a number of residuals' misspecification tests, which hardly ever reject the null of vector white noise errors. In the few cases of failure of the heteroscedasticity and/or the normality tests, the inclusion of one/two impulse dummies in the deterministic components prevents such rejections without qualitative changes in the results reported here without such dummies.

[13] Columns 1 to 6 show the remarkable similarity of test results and parameter estimates in VAR5 and VAR3 models. In the trace tests, the cointegration rank is always one at least at 5%, and the weak exogeneity is never 1% significant.

[14] In fact, the last two rows of Table 2 show that the ratio between desired and actual capital stock is relatively higher for non-residential building than for machinery and equipment.

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

Table 2 VECM modelling of capital stock: cointegration and weak exogeneity (1980–2012)

	Business (agg)		Machinery & equip. (me)		Non-resid. (nres)		ICT (ict)	
	VAR5	VAR3	VAR5	VAR3	VAR5	VAR3	VAR5	VAR3
VAR(p) settings:								
p (number of lags)=	2	2	2	2	2	3	2	3
Residuals' tests, p values:								
Autocorrelation third 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
$r \leq 1$	>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)

Table 2 continued

	Business (agg)		Machinery & equip. (me)		Non-resid. (nres)		ICT (ict)	
	VAR5	VAR3	VAR5	VAR3	VAR5	VAR3	VAR5	VAR3
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)	(0.020)	(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 [a]	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
Standard deviation of log-changes in:								
Desired (target) capital stock [b]	0.0348	0.0354	0.0549	0.0411	0.0502	0.0390	–	0.0478
Actual capital stock	0.0114	0.0114	0.0170	0.0170	0.0072	0.0072	0.0478	0.0478

Given the aforementioned problems in inferences because of overparameterization, we cross-validate results by assessing their consistency in the context of both VAR5 and VAR3. Dependent variables' vectors of VECM (7) are $Z^j = (k^j, y, uc^j, liq, unc)'$ for enlarged VAR5, and $Z^j = (k^j, y, uc^j)'$ for core VAR3.. Hence, for each asset, results from two different VAR specifications are reported: the 5 variables specification (VAR5) and the restrict one (VAR3) that does not include information on uncertainty and financial constraints

[a] In VAR5, tests for weak exogeneity also include restrictions to zero of liquidity and uncertainty long-run parameters

[b] "–" not available (i.e. no valid long-run relationship)

Table 3 VECM modelling of ICT capital stock, its components, and R&D: cointegration and weak exogeneity (1980–2012)

	ICT aggregate (ict)		Communication equip. (ct)		Hardware (hw)		Software (sw)		R&D (berd)	
	VAR5	VAR3	VAR5	VAR3	VAR5	VAR3	VAR5	VAR3	VAR5	VAR3
VAR(p) settings:										
p (number of lags)=	2	3	2	2	2	3	2	2	2	3
Residuals' tests, p values:										
Autocorrelation third order	0.2984	0.8008	0.7558	0.9423	0.5382	0.4015	0.8736	0.7407	0.663	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
$r \leq 1$	>0.0070	>0.1120	>0.1094	>0.1055	>0.021	>0.3338	>0.0111	>0.1723	>0.0559	>0.0846
Long-run parameter estimates:										
$\hat{\phi}_1$ (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)

Table 3 continued

	ICT aggregate (*ict*)		Communication equip. (*ct*)		Hardware (*hw*)		Software (*sw*)		R&D (*berd*)	
	VAR5	VAR3	VAR5	VAR3	VAR5	VAR3	VAR5	VAR3	VAR5	VAR3
Loading parameter estimates:										
$\hat{\pi}_1$ (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 [a]	0.0001	0.679	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	0.017

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

[a] In VAR5, tests for weak exogeneity also include restrictions to zero of liquidity and uncertainty long-run parameters

replicate the last two columns of Table 2 to ease the presentation. Results can be summarized in three main findings.

First, ICT components and R&D behave as aggregate ICT; hence, they react to different determinants compared to non-ICT physical capital. Second, the user cost of capital does not play any relevant role in the long run, as it is never significant and has opposite sign in eight cases out of ten. Third, the weak exogeneity of uncertainty and liquidity constraints in VAR5 is always strongly rejected. Therefore, we test an alternative VECM specification looking at ICT *investment* rather than ICT capital stock. We also check for the existence of possible complementarities between ICT and R&D augmenting Eq. (7) with the log-share of R&D on GDP (Table 4, *Model* (1)).

As for aggregate ICT, all variables (including uncertainty) are weakly exogenous: the disequilibria only feeds short-run changes in actual investments. The joint restrictions that the elasticity of investment to output is equal to one and that the elasticity to the user cost is equal to zero (i.e. the user cost plays a transitory role) are not rejected. Under these restrictions (*Model (2)*), in the long run, the ICT output ratio (in logs) is positively correlated with financial liquidity constraints and R&D, and negatively related to uncertainty. In particular, the long-run ICT elasticity to uncertainty is not significantly different from minus one, while the long-run effects of liquidity and R&D are smaller in absolute values. 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).

In the last three columns of Table 4, the analysis of ICT investment under *Model (2)* has been extended to its components: communication equipment (*ct*), software (*sw*), and hardware (*hw*). The results suggest that each asset performs as aggregate ICT. However, there are some interesting differences in the long-run parameters: liquidity does not exert a long-run effect on software, and R&D does not affect hardware. Software reacts strongly to uncertainty (almost double, if compared to the other ICT components) while hardware reveals the highest speed of adjustment. Finally, it is worth noting that the standard error of aggregate ICT equation is markedly lower than those of the three disaggregate equations: due to the statistical averaging of the individual shocks, the picture for aggregate ICT is clearer. Overall, our findings for ICT corroborate the hypothesis that as R&D, technological assets might incur flow adjustment costs under uncertainty (Bloom 2007).

4.3 The elasticities of the investment capital stock system

To characterize the different sensitivity of aggregate and disaggregate investment and capital stock, we first define an investment capital stock system of stochastic and deterministic equations where liquidity constraints and uncertainty interact with the traditional determinants of investment expenditure, output, and user cost (10–17 equations in "Appendix 2"). In the investment capital stock system, we evaluate short- and long-run composition effects comparing the sensitivity of total (*agg*) capital stock and investment (Eqs. 18–19) to capital stock and investment generated by the sum across the assets (*sum*, in Eqs. 20–22).

Table 4 VECM modelling ICT investment and its components: cointegration and weak exogeneity (1980–2012)

	ICT aggregate (ict)		ICT components Model (2)		
	Model (1)	Model (2)	ct	sw	hw
VAR ($p = 3$)					
Residuals' tests, (p values)					
Autocorrelation, third order	0.5374	0.2318	0.0749	0.6326	0.2678
Heteroscedasticity	0.5998	0.6065	0.2051	0.3054	0.4923
Normality	0.8539	0.0010	0.0333	0.5415	0.0059
Trace rank r tests, p values					
$r=0$	0.0124	0.0296	0.0010	0.0073	0.0130
$r \leq 1$	>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
	(0.984)	(–)	(–)	(–)	(–)
$\hat{\phi}_2$ (user cost)	0.279	–	–	–	–
	(0.890)	(–)	(–)	(–)	(–)
$\hat{\phi}_3$ (liquidity)	0.326	0.305	0.327	0.000	0.322
	(0.153)	(0.145)	(0.243)	(–)	(0.174)
$\hat{\phi}_4$ (uncertainty)	–1.061	–1.127	–0.898	–1.510	–0.667

Table 4 continued

	ICT aggregate (*ict*)		ICTcomponents		
	Model (1)	*Model (2)*	*Model (2)*		
			ct	*sw*	*hw*
	(0.373)	(0.166)	(0.253)	(0.808)	(0.167)
ϕ_5 (R&D)	0.576	0.632	0.429	0.476	0.000
	(0.258)	(0.297)	(0.254)	(0.562)	(–)
Loading parameter estimates:					
$\hat{\pi}_1$ (investment loading parameter)	−0.272	−0.271	−0.215	−0.133	−0.477
	(0.043)	(0.046)	(0.086)	(0.047)	(0.120)
Other loadings (restricted to zero)	0	0	0	0	0
Weak exogeneity, p values [a]	0.0713	0.7971	0.0224	0.0875	0.0731
Investment's equation:					
R^2	0.364	0.668	0.727	0.715	0.758
Standard error of the regression	0.0830	0.0599	0.0744	0.0860	0.0938
Conditioning cost of capital [b]	No	Yes**	Yes***	Yes**	Yes***

"–" means not estimated (excluded variables from VAR and/or standard errors of restricted parameters), p = 3

[a] Tests for weak exogeneity also include restrictions on the long-run parameters, when imposed

[b] Changes on user cost in t and $t-1$

** and ***, respectively, denote 5 and 1% significance on the basis of F tests

Second, we derive the steady-state solution of the system through its simulation 90 periods ahead where all the unmodelled variables are assumed to remain constant at the level of the last end-of-sample observation.

Finally, we calculate the short- and long-run elasticities of our variables by perturbing the determinants of the system. Table 5 reports the main results.

In the short run, the simulated output elasticities tend to significantly differ across the assets, while the user cost (i.e. the interest rates) elasticities do not diverge. In the long run, the estimated output elasticities validate the findings obtained by the cointegrated relationships (Tables 2 and 4).[16]

The zeros corresponding to the *agg* columns reveal that the aggregate modelling of capital stock excludes uncertainty and liquidity effects, that instead play a significant role in the individual asset specifications. In particular, the findings for physical investment (*nres* and *me*) show that in the short run an improvement in the liquidity conditions has an impact on investment that is about five times larger than the effect of a reduction in uncertainty. On the other hand, the identified long-run cointegration suggests that uncertainty permanently affects ICT investment (a 10% increase in uncertainty reduces the long-run business investment level by about 1%), while liquidity has an impact in the short run that vanishes in the long run.

4.4 An extension to Spain and UK

This section extends the previous framework to Spain and UK to check the robustness of the results we got with the Italian data. The expected advantage of this additional analysis is twofold. First, we can test whether our main findings are general or confined to a single country. Second, looking at UK and Spain can provide additional hints to interpret the productivity slowdown discussed in Sect. 2.

However, we cannot fully implement the analysis we developed above since data for Spain and UK are more scant compared to Italy whose information span more than 30 years. Therefore, in the following, we will forcedly focus on a subset of VECM applications aimed at inspecting the main results obtained for the Italian case. To this end, we resort to the EU KLEMS and Eurostat-EU Commission (AMECO) databases, as described in the lower part of "Appendix 1". We replicate the analysis with the new data also for Italy to allow for cross-country comparisons based on harmonized data sources.

In detail, we estimated the VECM (7) for $Z_c^j = \left(k_c^j, y_c, uc_c^j, liq_c, unc_c \right)'$, where j refers to non-ICT (*nict*) and ICT (*ict*) assets, to test for the existence of stock adjustment dynamics by country, with c equal to Italy, Spain, and UK (this is the VAR5 model in Tables 2 and 3 above). Further, for the same countries, we also use the VECM (7)

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[16] The slight difference between the long-run elasticities simulated in Table 5 and the corresponding estimates in Tables 2 and 4 is due to an approximation effect. In fact, the long-run estimates in Tables 2 and 4 are measured as ratios between changes in logs, while in Table 5 they are ratios between per cent deviations, i.e. $\frac{\Delta \log A}{\Delta \log B} \approx \frac{\frac{\Delta A}{A}}{\frac{\Delta B}{B}}$.

Table 5 Short- and long-run elasticities corresponding to the system steady-state solution

	Investment					Capital stock				
	agg	*sum (nres+me+ict)*	*nres*	*me*	*ict*	*agg*	*sum (nres+me+ict)*	*nres*	*me*	*ict*
Output										
Short run	2.560	3.495	3.249	4.056	0.110	0.447	0.301	0.119	0.593	0.035
	(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
	(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
	(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
	(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
	(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
	(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
	(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
	(0.035)	(0.046)	(0.097)	(0.055)	(0.000)	(0.015)	(0.015)	(0.018)	(0.023)	(0.000)

Obtained by perturbing 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 90 periods after the shock). Standard errors (in parentheses) are bootstrapped in stochastic simulations of the system (1000 replications). Simple zeros denote that the corresponding parameters in the system are restricted to zero, while "decimal zeros" suggest the numerical irrelevance of the elasticity

for $Z_c^j = (i_c^{ict} - y_c, liq_c, unc_c, berd_c)'$ to test for the existence of flow (investment) adjustment dynamics (see *Model* (2) in Table 4 above).[17]

The first column of Table 6 shows that our main findings for Italy are supported by the new estimates. In short, non-ICT capital follows the neoclassic stock adjustment mechanism (upper part of Table 6), while the same is not true for ICT capital stock (bottom part of Table 6). Table 6 confirms the results in Table 2 for aggregate non-ICT. Compared with Table 4, ICT investment instead is related to credit conditions, uncertainty, and R&D (ICT investment and R&D spending are confirmed to be complementary in the long run).

The use of a different database for Italy implies some caveats in the case of ICT. Results in Table 6 show different long-run (cointegrated) estimates mainly because the new proxies (the interest rate and the availability of internal funds) are quite different to the survey-based Italian indicator for credit constraints used in Tables 2, 3, and 4.[18] Overall, results in Tables 4 and 6 regarding the flow adjustment mechanism for Italian ICT show that Italian companies greatly base their investment financing on bank debt (see Bontempi 2002, 2016): high interest rates (in Table 6) and being credit constrained (in Table 4) both disincentive investment in ICT. The lower explanatory power in Table 6 compared to that in Table 4 (the R^2 falls from about 0.7 to 0.5) is due to the approximation of the user cost of capital and of the financial constraints.

Since previous caveats do not change the substance of the main findings shown in Tables 2, 3, and 4, we can use the results in the first column of Table 6 to compare the robustness of the Italian estimates with those for Spain and UK, in the last two columns.

In the non-ICT capital stock adjustment mechanism case, the "pure" Italian neoclassical model is fully confirmed for UK, but with a lower output elasticity and a stronger sensitivity to its user costs; external finance does not appear to be important. In the long run, in Spain, the neoclassical determinants are augmented by the significant contribution of liquidity and uncertainty, suggesting that the variability of the target non-ICT capital is higher in Spain than in Italy and UK. In the short run, the transitory effects of liquidity and uncertainty are smaller in Italy, UK shows a moderate sensitivity to uncertainty, whereas in Spain they are both very high.

In all the three countries, one of the main drivers of ICT flow adjustment mechanism is R&D, thus supporting the assumption of complementarity between the two assets. For Italy and UK, uncertainty plays a permanent role. In the UK, the highest sensitivity to interest rates is accompanied by the significant role of the internal funds (*liq*) to finance highly risky ICT investment projects as in the standard pecking order model of financing. As far as the financial determinants are concerned, Spain displays a picture in line with Italy. Overall, the dichotomy continental bank-based and Anglo Saxon-market-based countries is confirmed (see the European comparison in Gaud et al. 2007).

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[17] Regarding the specific measurements in the contest of countries' comparison, see the details in "Appendix 1".

[18] Note that these new proxies are necessary to be able to investigate the effect of credit conditions in Spain and the UK, for which a long time series of the degree of financial constraints indicator is not available.

Table 6 VECM modelling of non-ICT capital stock (high) and ICT investment (low), 1980–2012

Country, c	Italy	Spain	UK
Non-ICT capital stock adjustment mechanism			
VAR lag-order, p	1	2	2
Residuals' tests, p values:			
Autocorrelation third order	0.5038	0.1620	0.9409
Heteroscedasticity	0.0373	0.5955	0.8280
Normality	0.0083	0.1359	0.0902
Trace rank r test, p values:			
$r = 0$	0.0184	0.0000	0.0047
$r \leq 1$	0.1211	0.0758	0.1528
Weak exogeneity and other VECM restrictions, p values	0.1306	0.0550	0.6258
Long-run parameter estimates:			
Output	1.256***	1.031***	0.744***
User cost of capital	−0.060***	−0.252***	−0.177***
Liquidity[a]	0.000(−)	0.313***	0.000(−)
Uncertainty	0.000(−)	−0.019***	0.000(−)
Capital stock's equation:			
Loading parameter estimates	−0.101***	−0.216***	−0.103**
R^2	0.457	0.946	0.570
Standard error of the regression	0.0096	0.0040	0.0090
Residual correlation coefficient with liquidity shocks	0.034	0.274	0.026
Residual correlation coefficient with uncertainty shock	−0.038	−0.307	−0.169
ICT investment flow adjustment mechanism			
VAR lag-order, p	1	2	3
Residuals' tests, (p values)			
Autocorrelation, third order	0.7469	0.1987	0.1611
Heteroscedasticity	0.0781	0.8016	0.5828
Normality	0.8340	0.8528	0.5128
Trace rank r tests, p values			
$r = 0$	0.0003	0.0019	0.0485
$r \leq 1$	0.0898	0.0541	0.3480
Weak exogeneity and other VECM restrictions, p values	0.4138	0.1511	0.3209
Long-run parameter estimates:			
Interest rates[b]	−15.52***	−12.69***	−31.57***
Liquidity[a]	0.000(−)	0.000(−)	3.222**
Uncertainty	−0.334**	0.000(−)	−0.633***
R&D[c]	0.468**	0.782***	1.000(−)

Table 6 continued

Country, c:	Italy	Spain	UK
Investment's equation[c]			
Loading parameter estimates	−0.058*	−0.152***	−0.126***
R^2	0.496	0.671	0.849
Standard error of the regression	0.0689	0.0453	0.0517
Residual correlation coefficient with liquidity shocks	0.213	0.020	0.064
Residual correlation coefficient with uncertainty shock	−0.157	−0.222	−0.211
Residual correlation coefficient with R&D shock	0.018	0.086	0.175

[a] Ratio of the non-financial firms gross operating surplus to their value added (proxy of the availability of internal funds)

[b] Interest rates (proxy of the state of the financial markets)

[c] Logs of their share on GDP

5 Policy implications

Our analysis shows 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 and that they respond differently to macroeconomic shocks. This finding suggests that the identification of asset-specific policy design is crucial to better assess aggregate and disaggregate investments in the European outlook.

Further, the relatively higher reactivity of ICT supports the idea that in a period of economic downturn when the opportunity cost of a company's resources is reduced, there is increasing scope for innovation without sacrificing growth (Bhaumik 2011). Thus during a recession, the economic recovery might be stimulated fostering productivity enhancing investments, such as ICT, that are likely to generate higher returns compared to traditional assets.

In this section, we further investigate the advantages of modelling investment dynamics accounting for the heterogeneity of capital inputs. We develop a counterfactual exercise involving Italian investment by asset over the years 2008–2013,[19] to assess the impact of different degrees of uncertainty and financial conditions on GDP growth. We include the system of equations listed in "Appendix 2" in the framework of the Italian Statistical Institute Macroeconometric Model (MeMo-It)[20] to compare the current Italian economic performance with a simulated scenario where the level of uncertainty is equal to the average of France, Germany, and Spain[21] (the improvement

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[19] We extend our sample period to 2013 to look more deeply to the effects of the financial crises on Italian investment dynamics.

[20] 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 such as supply side, labour market, demand side, prices, and government. For more details, see Bacchini et al. (2013) and the summary in "Appendix 3". Of course, the three disaggregate investment equations above replace the pre-existing (aggregated) one.

[21] We selected three Euro area countries as a benchmark to look as much as possible to countries with a comparable structure of the financial markets.
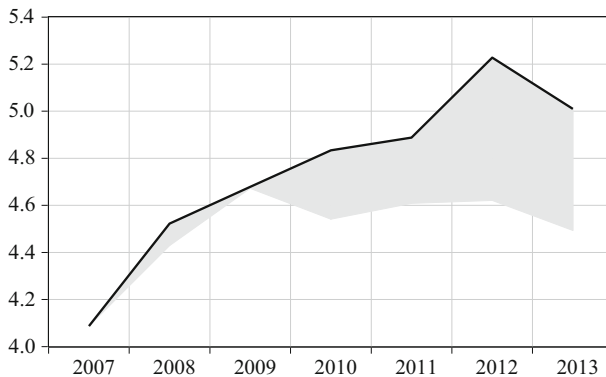
Fig. 3 Economic policy uncertainty index, log-levels. *Bold line* the Italian index; *grey shaded area* distance between the Italian index and the average of Germany, France, and Spain indexes

is the shaded area in Fig. 3), and the liquidity conditions are constantly improved in 2012–2013 (the measure of the improvement is the shaded area in Fig. 4).[22]

Since the financial turmoil in 2008, Italy experienced a deep recession. Subsequently, the risk of a sovereign debt defaults (in the middle of the Greek crisis) and endemic domestic political instability in the Italian economy fuelled uncertainty. In 2009, as in most of the other developed countries, the Italian GDP growth slowed down substantially (−5.5%), recovering in 2010 and 2011 (1.8 and 0.7%, respectively). In 2012, instead, even though in the euro area the recovery was moderately in progress (German GDP rose by 0.7 while French GDP remained at 0.0), Italy experienced another slowdown (GDP growth decreased by −2.6%).[23]

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 Euro area countries (summarized by the average of Germany, France, and Spain). The shaded area in Fig. 3 provides a broad idea of the degree of economic and political uncertainty that characterized the Italian economy over the period.

Further, the evolution of the financial conditions, measured by the ISTAT monthly business survey, reinforces the feelings of presence of liquidity constraints. In 2012, as reported in Fig. 4, in Italy, the level of liquidity was very close to the low level recorded in 2009.

Although we acknowledge that our results are surrounded by the usual caveats emerging from any macroeconometric counterfactual, the exercise shows in Table 7 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 (Table 7). GDP would have been

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[22] In particular, in the counterfactual the liquidity indicator is assumed to ignore the deep financing trough of 2012, by shifting back the observations for 2013 and 2014, as if the hole of 2012 never happened.

[23] The projection for 2013 is still negative (−1.9%); however, in Q4 2013, for the first time since Q2 2011, the growth rate has not been negative.
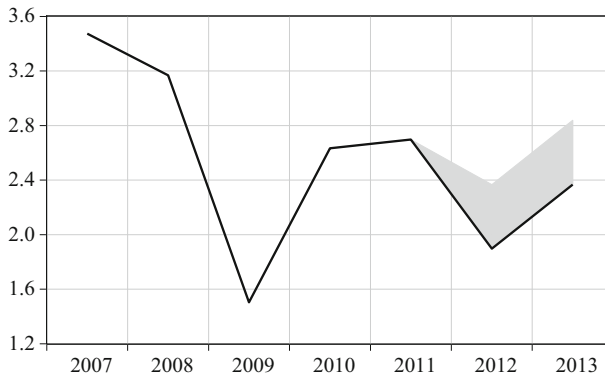
Fig. 4 Pattern of liquidity indicator, log-levels. *Bold line* the historical pattern; *grey shaded area* distance between the historical pattern and an alternative of less credit crunch in 2012–2013, whose liquidity levels are those of the historical figures one year later

Table 7 Price of the political uncertainty and financial conditions

	Uncertainty	Liquidity	Total
GDP	0.2	0.2	0.4
Business investments	2.1	2.5	4.8
ICT	15.0	9.3	25.7
Machinery & equipments	0.5	1.8	2.3
Non-residential buildings	0.5	1.2	1.7
Capital stock	0.6	0.6	1.2
Full time equivalent employees	0.1	0.1	0.2

% changes in 2013 with respect to the actual levels

raised by 0.4%, and employment by a slightly smaller amount (0.2%, corresponding to an increase in the number of full time employees by about 50 thousands).

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

6 Concluding remarks

In this paper, we modelled the dynamics of business investment taking into account asset-specific characteristics potentially affecting the reactivity of capital accumulation at the aggregate and disaggregate level over the business cycle. Our analysis corroborates the assumption that ICT and non-ICT investment decisions are driven by a different set of determinants, both in the long run and in the short run. Additionally,

our findings support the idea that tangible and intangible assets have different speed of adjustments to macroeconomic shocks because they incur in different adjustment costs. ICT, as other knowledge-based assets, incurs in flow adjustment costs thus being more sensitive to uncertainty (Bloom 2007).

We found that individual asset characteristics matter since disaggregate investments display an heterogeneous behaviour over the business cycle. 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 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 counterfactual exercise supports the idea that ICT is a key variable to stimulate economic growth. Simulation results show that better financial conditions and lower uncertainty could have helped the recovery of the Italian economy after the great recession, mainly through their impact on ICT. This finding is consistent with the empirical literature that 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).

Our analysis emphasizes the central role of investment-specific policy measures to lower economic growth differentials both inside the union and with respect to the US. Eurozone economies would benefit from a policy agenda aimed at stimulating those investment expenditures characterized by relatively higher output elasticity, such as ICT. To foster growth-enhancing investment, reforms to reduce uncertainty and improve financial conditions are mandatory. Future research developments will be devoted to test our investment capital stock system of equations on the Eurozone countries with the aim of building a new framework for investment policy programmes.

Appendix 1: Data sources

Italian (national) sources

Investments and capital stocks

Data for aggregate ($j = agg$) and disaggregate ($j = me, nres, ict$) capital stock and investments for the Italian case are drawn from ISTAT National Accounts (NA) and refer to the Italian business sector (i.e. they exclude public investments) over the period 1980–2012.

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 and the output gap

Output series (Y_t) is measured by GDP in volumes.

The *output gap* (YG_t) series is from the Ameco database of the European Commission. For the period

User cost of capital

In the user cost's formula (3), P_t is the GDP deflator; π_t^j is the rate of change in 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 corporate tax rate (τ_t) is obtained by the series of effective tax rates from the NA source. The cost of borrowing R_t^j is given by the average of the rate of interest of long-term government bonds (BTP) and ISTAT estimates of the rate of interest implicitly used in collecting information to compute capital stocks; the arbitrary risk premium (ψ^j) is set to zero. Finally, depreciation rates are obtained by reversing the formula of the perpetual inventory method, as $\delta_t^j = \left(I_t^j - \Delta K_t^j \right) / K_{t-1}^j$.

Financial constraints and uncertainty

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 Baker et al. (2016) over a period starting since 1997 (downloadable from http://www.policyuncertainty.com). Before 1997, unavailable uncertainty data are backward estimated by using the pattern of the GARCH component of the AR(2) representation of the GDP growth rate (over the period in which they overlap, the normalized data of the genuine uncertainty measure and of the estimated GARCH component evolve in a quite similar way).

R&D real spending and stock

Nominal R&D is measured by the total intramural R&D expenditure of the Italian business enterprise sector (source: Eurostat's Statistics on Research and Development). R&D in real terms (I_t^{berd}) 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, equal to about 0.4—see, e.g. Hall 2007, and Bontempi and Mairesse 2015). In steady state, the initial value of the capital

stock is proxied by $K_o^{berd} = I_o^{berd}/0.4$; although we acknowledge the crudeness of this assumption, its effect vanishes over a long time span like the one we have available.

Italy, Spain, and the UK data sources

EU KLEMS data are available for non-ICT and ICT capital stocks and investments over the period 1970–2009. These sources were updated with the corresponding growth rates from Eurostat source.

The uncertainty indicator and the R&D spending for Spain and the UK come from the same sources and procedures described above for Italy. All other series come from AMECO databank. In particular, R&D (*berd*) is measured by $\log \frac{I_c^{berd}}{Y_c}$, where $\frac{I_c^{berd}}{Y_c}$ is the ratio of R&D spending on GDP; the user cost (*uc*) cannot be fully asset-specific as it was in Tables 2 and 3 for Italy, because we had to proxy the inflation component of *uc* with the aggregate investment deflator. In addition, and more relevantly for the issues inspected, unavailable survey-based credit conditions (*liq*) are proxied here by two macrovariables: the interest rate (R_c, to proxy for credit market shocks), and the aggregate rate of gross operating surplus on the value added for the non-financial companies (gos_c, to proxy for the amount of internal funds).

Appendix 2: The investment capital stock system

The specification of the complete system for investments and capital stock is listed below. In the OLS estimate equations, the standard errors are reported in curly braces below each estimate. The use of OLS estimator is allowed by the weak exogeneity property emerged from the results in Sect. 4.2. Labels in capital letters denote variables in levels, while their logs are in small letters. Variables' definitions and data sources are reported in "Appendix 1".

Non-residential buildings (nres)

$$\text{UC}_t^{nres} \equiv \left(R_t^{nres} + \delta_t^{nres} - \Delta p^{nres} \right) \left(\frac{1 - c_t}{1 - \tau_t} \right) \frac{P_t^{nres}}{P_t} \tag{10}$$

$$\Delta k_t^{nres} = \underset{0.031}{0.068} + \underset{0.001}{0.003} \times \Delta liq_t + \underset{0.029}{0.107} \times \Delta y_{t-1} + \underset{0.136}{1.045} \times \Delta k_{t-1}^{nres} - \underset{0.121}{0.347} \times \Delta k_{t-2}^{nres}$$

$$- \underset{0.001}{0.002} \times \Delta uc_{t-2}^{nres} \underset{0.010}{-0.023} \times \left[k_{t-1}^{nres} - \left(\underset{0.088}{0.750} \times y_{t-1} - \underset{0.031}{0.100} \times uc_{t-1}^{nres} \right) \right] + \hat{\varepsilon}_t^{nres}$$

$$\tag{11}$$

$$I_t^{nres} \equiv \Delta K_t^{nres} + \delta K_{t-1}^{nres} \tag{12}$$

Machinery, plants, and equipments (me)

$$\mathrm{UC}_t^{me} \equiv \left(R_t^{me} + \delta_t^{me} - \Delta p^{me}\right)\left(\frac{1 - c_t}{1 - \tau_t}\right)\frac{P_t^{me}}{P_t} \tag{13}$$

$$\Delta k_t^{me} = \underbrace{-0.597}_{0.160} + \underbrace{0.015}_{0.002} \times \Delta liq_t - \underbrace{0.013}_{0.006} \times \Delta unc_t + \underbrace{0.482}_{0.060} \times \Delta y_{t-1} + \underbrace{0.518}_{0.061} \times \Delta k_{t-2}^{me}$$

$$- \underbrace{0.006}_{0.002} \times \Delta uc_{t-1}^{me} \underbrace{-0.087}_{0.023} \times \left[k_{t-1}^{me} - \left(\underbrace{1.402}_{0.055} \times y_{t-1} - \underbrace{0.266}_{0.022} \times uc_{t-1}^{me}\right) \right] + \hat{\varepsilon}_t^{me}$$

$$\tag{14}$$

$$I_t^{me} \equiv \Delta K_t^{me} + \delta K_{t-1}^{me} \tag{15}$$

Information and communication technology goods (ict)

$$\Delta i_t^{ict} = \underbrace{0.098}_{0.014} + \underbrace{0.113}_{0.026} \times \Delta liq_t + \underbrace{0.055}_{0.026} \times \Delta liq_{t-1} + \underbrace{0.044}_{0.026} \times \Delta liq_{t-2} - \underbrace{0.931}_{0.489} \times \Delta R_{t-1}$$

$$+ \underbrace{-0.115}_{0.032} \times \left[i_{t-1}^{ict} - \left(y_{t-1} - \underbrace{1.127}_{0.166} \times unc_{t-1} + \underbrace{0.632}_{0.297} \times \log\left(\frac{I_{t-1}^{berd}}{Y_{t-1}}\right) + \underbrace{0.305}_{0.145} \times liq_{t-1}\right) \right] + \hat{\varepsilon}_t^{ict}$$

$$\tag{16}$$

$$K_t^{ict} \equiv I_t^{ict} + (1 - \delta_t^{ict})K_{t-1}^{ict} \tag{17}$$

Aggregation through summation of the three business components (sum)

$$K_t^{sum} \equiv K_t^{nres} + K_t^{me} + K_t^{ict} \tag{18}$$

$$I_t^{sum} \equiv \frac{I_t^{nres} \times P_{t-1}^{nres} + I_t^{me} \times P_{t-1}^{me} + I_t^{ict} \times P_{t-1}^{ict}}{P_{t-1}^{sum}} \tag{19}$$

Aggregate modelling of business investments (agg)

$$\mathrm{UC}_t^{agg} \equiv \left(R_t^{agg} + \delta_t^{agg} - \Delta p^{agg}\right)\left(\frac{1 - c_t}{1 - \tau_t}\right)\frac{P_t^{agg}}{P_t} \tag{20}$$

$$\Delta k_t^{agg} = \underbrace{-0.081}_{0.021} + \underbrace{0.248}_{0.017} \times \Delta y_t + \underbrace{0.712}_{0.037} \times \Delta k_{t-1}^{agg} - \underbrace{0.009}_{0.002} \times \Delta uc_t^{agg}$$

$$\underbrace{-0.038}_{0.010} \times \left[k_{t-1}^{agg} - \left(\underbrace{1.141}_{0.058} \times y_{t-1} - \underbrace{0.170}_{0.044} \times uc_{t-1}^{agg}\right) \right] + \hat{\varepsilon}_t \tag{21}$$

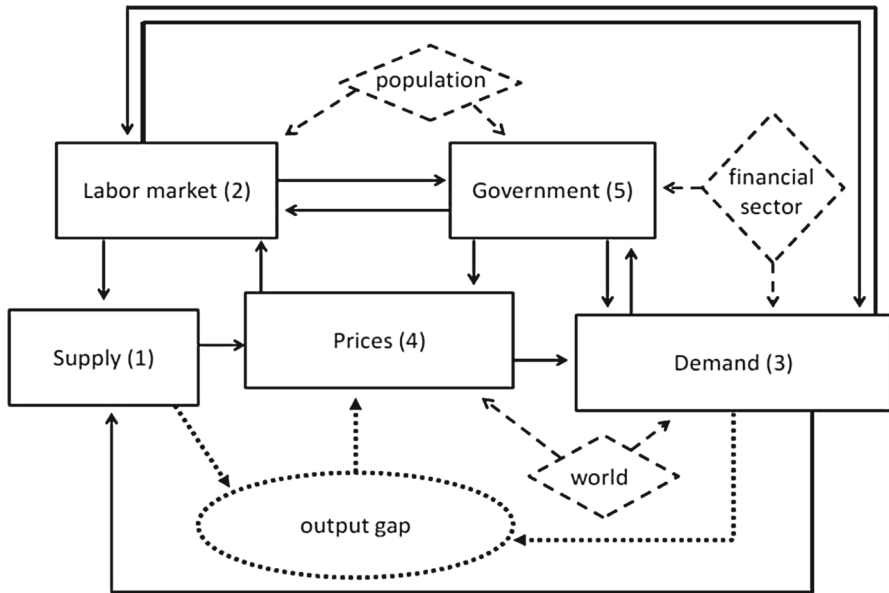$$I_t^{agg} \equiv \Delta K_t^{agg} + \delta K_{t-1}^{agg} \tag{22}$$

Fig. 5 MeMo.It building blocks

Appendix 3: MeMo.It—ISTAT macroeconometric model[24]

MeMo-It belongs to a suite of economic forecasting models developed by Istat, where it plays a fundamental role in the modelling framework ensuring the overall consistency in the system. The model is composed by 53 stochastic equations and 78 identities, and represents a New Keynesian economic system including households, firms, public administration, and a foreign sector. It is an annual model that uses two sets of external (exogenous) information over the forecasting period. The first set refers to the main variables that characterize the development of the international scenario, such as trade growth, exchange rates, ECB interest rates, and the oil price. The second set instead includes annual estimates of key GDP components obtained from short-term models based on monthly and quarterly data available at the time of forecast. The main characteristic of MeMo-It is that it is strongly grounded in empirical information (data-based model) in order to assess the data admissibility of the theoretical assumptions and does not assume explicit microfoundations of weak form. Further, it has been thought as a simple and easy tool to be introduced to the users, and it is timely updated with the most recent release of National Accounts. This allows to deliver updated forecasts always coherent with the last vintage of NA figures.

MeMo-It is substantially based on the New Keynesian approach where the supply side of the economy plays a central role. Accordingly, the underlying key assumption is that in the short run, the economic activity is mainly driven by the demand side, while in the long run the economic system converges to potential output given by

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[24] This section draws substantially from Bacchini et al. (2013).

the supply side. Prices react to the output gap and, in this way, they accounts for the disequilibrium of supply and demand.

The dotted arrows in the lower portion of Fig. 5 represent the interactions arising from such disequilibrium (between the supply and demand rectangles) with the output gap (in the oval circle) which, in turn, affects the prices rectangle. In turn, price changes feedback into demand variables rectangle and into wages in the labour sector rectangle. Real wages and employment affect income distribution and households consumption (in the demand rectangle). Consumption and incomes in the demand rectangle are the tax bases which, combined with (exogenous) rates, define different forms of taxation in the government rectangle. Direct taxation and public transfers generate income redistribution that affects the demand, while indirect tax and social security contributions influence prices and labour cost. Finally, investments and output in the demand rectangle interact with the supply side through the accumulation of capital stock (lower arrow), and employment in the labour market rectangle (upper arrow).

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