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RESEARCH PAPER

Profits, Innovation, Investment. Exploring the Virtuous Circle

Giuseppe Simone[1] · Rinaldo Evangelista[2] · Mario Pianta[3]

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Abstract
The article explores the dynamic relationships between profits, product innovation and capital investments. A virtuous circle model is proposed where product innovation and investment are the key drivers of profits, which in turn support technological change and capital accumulation. In our model industries are characterised by two different trajectories for innovation and investments—either 'embodied' in machinery and equipment, aiming at cost competitiveness, or knowledge-related and aiming at technological competitiveness. The model is empirically tested on 40 manufacturing and service industries in six major European countries. The empirical analysis confirms that product innovations and capital investments are distinct drivers of profit growth. A virtuous circle between profit, innovation and investment is mainly found in the industries characterised by strategies of technological competitiveness.

Keywords Profits · Product innovation · Capital accumulation · Technological change · Industry-level analysis · System of simultaneous equations · Virtuous circles

JEL Classification C3 · C33 · L16 · O3 · O14

1 Introduction

Technological change and capital accumulation are key drivers of firms' growth and economic development. They allow innovative firms and industries to gain monopolistic profits, providing resources for further accumulation. The relationship between technological change and investment has a key role in many heterodox economic approaches but has received limited empirical attention (Evangelista 1999), with a

✉ Mario Pianta
mario.pianta@sns.it

1 Università di Siena, Siena, Italy

2 Università di Camerino, Camerino, Italy

3 Scuola Normale Superiore, Palazzo Strozzi, Piazza Strozzi 1, 50123 Florence, Italy

new interest recently emerging in firm-level empirical works finding a positive relationship between innovative efforts and subsequent investment in fixed assets (Barbieri et al. 2019; Carboni and Medda 2019; Spescha and Woerter 2021). Little investigation has addressed the link between innovation activities, investments and profits at the industry level and the presence of different accumulation regimes based on the nature and strength of such a relationship.

This article aims at filling this gap in the literature, by developing a model of the relationships between profit growth, types of innovation introduced and capital accumulation across industries. Building on evolutionary and structural change approaches, we adopt the distinction proposed by Pianta (2001) between technological and cost competitiveness in order to highlight the existence of different sources of profits and drivers of accumulation across industries. Capital investments in our framework have a twofold function. On the one hand, they are a major source of embodied technological change spreading productive tools and technologically advanced machines and equipment across the economy (Kaldor 1967); on the other hand, especially in technologically advanced industries, investments allow the expansion of the production capacity in innovative goods and services, sustaining technological competitiveness and growth.

In evolutionary and Marxian views of growth, profits are the primary source of a cycle of expansion, financing expenditure in innovative activities and fixed investment (Schumpeter 1995; Duménil and Lévy 2021). In our model, product innovations and capital accumulation are two key drivers of profits, which in turn shape—together with other factors—the dynamics of new investments and innovative efforts. Due to the conflictual nature of income distribution between capital and labour, an additional source of profits—included in our model—is the reduction of relative wages through lower union protection and greater labour market flexibility.

We first test the model estimating three stand-alone equations, searching for the determinants respectively of profits, product innovation and capital investments. We then integrate the three equations in a simultaneous model, exploring the linkages between our variables, but also their dynamic interrelations and the presence of lags, feedbacks and reinforcement mechanisms—that can be described as a virtuous circle—between, profits, product innovation and investment.

The rest of the paper proceeds as follows. Section 2 describes the conceptual framework and the background literature. The data used in the empirical analysis is described in Sect. 3 while the following section is dedicated to the description of the econometric model and strategy. Section 5 presents the results of the econometric estimates and Sect. 6 concludes the work highlighting the main findings and some implications stemming from this contribution.

2 The conceptual Framework

2.1 The Sources of Profits: Technology, Investment and the Capital-Labour Conflict

The dynamics of capitalism is based on the accumulation of profits through the use of labour in production and their reinvestment into an expanded capital stock. Investments are driven by profitability—the net returns over the capital invested—which is the ultimate criterion for determining the success or failure of an investment decision. The diversity of profit rates in the different sectors of the economy is a key driver of the evolution of the economy, as capital leaves activities with high competition and lower profits and goes into new activities promising higher returns. This process of structural change is affected by a plurality of factors including industry-specific conditions related to the dynamics of demand and the level of saturation of markets, the conditions of uncertainty, risk and bounded rationality characterizing the different competitive contexts and technological regimes, as well as the institutional settings of national economies and the policies affecting distribution, profits and capital assets. Structural change approaches pointed out that "free-market competition inevitably drives capital funds out of low-profit sectors and into high-profit sectors" (Pasinetti 1981, p. 175), generating turbulence and disequilibrium processes. This is associated with short-term business cycles and with the longer-term "long waves" of accumulation (Freeman and Louçã 2001; Pianta 2020) that characterise the evolution of capitalism.

A first key issue is the relationship between investment and profits, which runs both ways. Investments lead to higher profits through a variety of mechanisms. The use of more advanced machines increases productivity and expands output. A greater quantity of capital leads to a substitution of labour with capital, reducing production costs and wage expenditures. Investments in plants and equipment allow exploiting scale economies by expanding output with diminishing unit costs. Large-scale investments are associated with the emergence of oligopolistic industrial structures and the acquisition of market power leading to greater profits. The link between profits and capital accumulation is at the core of the approaches of classical economists, Marx and the post-Keynesian school (Kalecki 1991). Conversely, profits are a fundamental source for financing investments. In a Schumpeterian 'mark II' innovation model, past profits of large companies finance R&D expenditures and innovative investments in order to sustain new accumulation trajectories (Schumpeter 1975). Duménil and Lévy (2021) point out that the strong association between retained profits and capital accumulation is a central factor in explaining long-run economic dynamics.

A second key driver of profits is technological change. In a Schumpeterian perspective, innovation leads to market power and temporary monopoly profits. We build here on the work by Bogliacino and Pianta (2013) showing that industry profits are driven by the introduction of innovative products, which are the result of R&D efforts performed by industries; in turn, past profits stimulate innovative activities, with a virtuous circle of technological accumulation, that may also extend to export performances (Guarascio and Pianta 2017). Further evidence on innovation and profits has emerged from firm-level studies (Cefis and Ciccarelli 2005); the case of the monopoly profits of digital platforms and large ICT corporations has been investigated by Rikap (2021).

Finally, given the rate of labour productivity growth, profits may also increase at the expense of wages. This dynamics reflects the conflict between capital and labour (Shaikh 2016), mirroring the conflicting nature of distribution at the roots of the growing functional income inequality. Coveri and Pianta (2022) develop and test empirically a model in which profit growth is driven by the capital-labour conflict, the expansion of value-added per hour worked, different technological strategies and the offshoring of production. On the one side, introducing product innovations, boosting sales and gaining market power, increase profits, without exerting downward pressure on wages. On the other side, an additional way to sustain profit growth is through process innovation, labour saving technologies and the use of non-standard employment with lower wages (Reljic et al. 2021a).

The contributions summarised in this section provide a robust theoretical background to our model and empirical analysis, suggesting that the dynamics of profits is fuelled by several interconnected drivers, the most important being the quantitative and qualitative growth of the capital stock, the competitive strategies of firms and the technological characteristics of industries, the level of market power as well as the result of the balance of power between capital and labour determining the distributive outcomes (Coveri and Pianta 2022; Duménil and Lévy 1993; Kotz and Basu 2019; Louçã, 2021).

2.2 Investment and Innovation

Despite the growing relevance of intangible assets and knowledge in the production process (Orhangazi 2019; Rikap 2021), investments in fixed capital are still a core source of innovation and technology throughout the economy (Evangelista 1999). Building on the conceptual distinction between embodied and disembodied knowledge, it is helpful to shed light on the multiform ways in which investments are linked to technological change. Embodied knowledge denotes technical, productive assets and devices, which are involved in the sphere of production. In this view, embodied technological change consists of the accumulation of new technologically advanced machines and equipment and innovative intermediate inputs to upgrade the production process. Conversely, disembodied knowledge refers to the stock of codified or tacit knowledge available for use in the production process. From the disembodied perspective, technological change is related to the efforts to develop new technological knowledge throughout activities such as R&D, education, patents, applied research, learning by doing and organisational change.

Classical economists, as well as contributions in the Post-Keynesian tradition, have stressed the embodied nature of technological change, recognizing the central role of capital investments as a source of technology diffusion across the economy. They connect capital accumulation to technological development, the latter having a capital-deepening and labour-saving effect. Evolutionary scholars tend to privilege a disembodied perspective of technological change (Evangelista 2018, 2022). In this perspective, efforts undertaken by firms to generate new technical knowledge are the primary source of technological development.

Building on the evolutionary perspectives, Pavitt's taxonomy (Pavitt 1984; Bogliacino and Pianta 2010) considers the role of capital investments in the process of technological change by looking at the heterogeneity of innovation patterns of firms and industries. Firms in low-technology sectors innovate and upgrade their production processes mainly through the acquisition of machinery and intermediate inputs from high-tech producers. Conversely, firms in high-tech sectors rely more on within-industry innovative efforts aiming at generating new disembodied knowledge and introducing product innovations. In this framework investments and the development and introduction of product innovations might be thought as alternative innovation patterns and firms' strategies. The existence of a cross-industry substitutive nexus between these two different technological activities will be tested in Sect. 5.

Evangelista (1999, p. 181) showed that high-tech sectors perform innovation by relying more on the generation of disembodied knowledge, R&D expenditures, and product innovation, which seem to substitute for expenditure in capital investments. Conversely, low-tech sectors perform more fixed investments and process innovation with lower R&D efforts, suggesting a straight connection between capital accumulation and innovative activities in these industries. However, some technology-oriented industries largely complement product innovations and disembodied knowledge with fixed capital investments. This is the case of sectors such as aerospace, office machinery, and telecommunication, in which the capital-intensity of the production is very high.

The relationship between innovation activities and capital investment have been recently examined also at a firm level. Carboni and Medda (2019), by using a panel of European firms, found a positive link between R&D expenditures and investment in capital in firms with a higher export propensity. Spescha and Woerter (2021), instead, by focusing on a Swiss sample of firms, found that R&D expenditures and the introduction of product innovations cause a subsequent rise of capital investments. The reverse link running from capital investments to innovative activities has on the contrary remained an under-investigated empirical topic. Pianta and Reljic (2022) consider the connection between investment and productivity growth in a "virtuous circle" perspective at the industry level. In their model, indeed, fixed capital increases generate productivity gains, which in turn are able to increase wages and good-quality jobs, sustaining the introduction of innovative products and supporting technological competitiveness strategies.

2.3 Innovation Activities and Their Determinants

In the XX century, the dynamics of capitalism has been characterised by the contribution of science and technology in shaping new areas of economic activity. Schumpeter (building on Marx's insights) has pointed out that innovation lies at the very heart of the process of *creative destruction* that works both at the firm and industry level, fuelling the competition between firms and the process of structural change. Along with acknowledging the continuous transformative character of industrial structures the evolutionary perspective emphasizes at the same time the cumulative and path-dependency nature of technological change (Dosi 1988, 2023). Retained profits, R&D activities and the accumulation of technological capabilities boost virtuous innovation-based dynamics of industrial growth. Previous profits are fundamental to overcoming financial constraints and supporting innovative activities. High R&D expenditures are the core inputs to generate new products and new processes, allowing to enlarge sales and improve productivity (Bogliacino and Pianta 2013; Pianta and Reljic 2022).

The heterogeneity of innovation activities—with different technologies, products and strategic behaviours—has been emphasised by evolutionary approaches. The sector-specific nature of innovation activities has also been pointed out by the studies on "technological regimes" (Breschi et al. 2000; Nelson and Winter 1982; Malerba and Orsenigo 1990, 1995; Malerba 2004) and the ways in which innovation patterns are linked to different production and market structures (Evangelista 1999; Marsili 2001).

We follow such stream of literature, distinguishing between two possible industry-specific growth and innovation strategies, with contrasting outcomes in terms of distributional gains among wages and profits, demand dynamics, and employment patterns (Crespi and Pianta 2008a, b; Pianta 2020); the first one is based on the *cost competitiveness* strategy driven by process-oriented technological progress, mainly aimed to reduce labour cost and optimize the production process. Investments in this setting have the fundamental role of expanding embodied technologies in the economy, particularly among sectors that buy advanced machinery from other industries. The second relies on a *technological competitiveness* strategy, in which industries and firms innovate mainly through the introduction of new products and the creation or expansion of new markets. Investments across these industries can be complementary to R&D and the introduction of product innovation, allowing the expansion of productive capacity needed to match the growing demand for innovative commodities. We expect that this distinction can help us to identify the different relationships between profit growth, innovation and investments.

2.4 Profits, Investment, Innovation: An Integrated Approach

The complex nature of the relationships between profits, innovation and investment emerging from the previous section requires a conceptual and methodological framework able to grasp in a systematic way the dynamic and self-reinforcing linkages across these three major sources of economic development. We adopt here the "virtuous circle" perspective, building on the seminal work of Myrdal (1957) on the cumulative causation patterns fuelling economic development. Rather than being isolated from the others, variables affecting economic development are interlinked; changes in one variable cause cumulative effects on the others, which in turn affect the first one and the development of the entire system, mirroring how economic development proceeds in a complex circular way. Kaldor (1967) has applied the same approach to highlight the circular relationship between supply and demand forces.

A large empirical literature has effectively adopted the "virtuous circle" perspective to study the link between technological change and economic development. Bogliacino and Pianta (2013) and Bogliacino et al. (2018) found a positive association between R&D efforts, profit dynamics and the introduction of product innovations. Guarascio et al. (2015) analysed the relationship between R&D expenditures, profits and internationalization strategies of firms and industries; Guarascio and Pianta (2017) consider the role of export dynamics in fostering product innovation and profit growth. More recently, Bogliacino et al. (2018) analysed the complex dynamic relationships between technology, offshoring and wages, also looking at the different impacts on workers' skill categories of the offshoring strategy. Carboni and Medda (2019) have analysed the link between internalization dynamics, R&D expenditures, and investment decisions, finding a positive relationship among the variables. Spescha and Woerter (2021) have observed a positive effect of R&D expenditures on capital stock investments for a sample of Swiss companies but have not found empirical evidence of an inverse linkage. Furthermore, Pianta and Reljic (2022) have modelled the" virtuous circle" of *good jobs-high innovation,* considering the interdependencies between labour quality, wage dynamics, innovative efforts, and productivity increases.

In this contribution we apply the "virtuous circle" approach to the dynamic relationships between profits, innovation and investments, considering their interdependences and taking into account lags and feedback loops. In the model we develop, past profits stimulate new investments in fixed capital or efforts aimed at the introduction of product innovations, and both contribute to profits. These two growth strategies are expected to have different determinants and outcomes, which may differ across sectors. In high-tech sectors, product innovation is expected to be supported mainly by R&D efforts and by high-skilled workers, with the latter augmenting the knowledge stock of firms and fuelling a technology-oriented competition. Conversely, investments are expected to play a key role in sectors characterized by the compression of labour costs and the introduction of process and labour-saving innovations.

3 Data

The empirical analysis uses the Sectoral Innovation Database (SID) (Pianta et al. 2021) that merges different industry-level data sources for the time span 1994–2017, covering six major European countries—France (FR), Germany (DE), Italy (IT), the Netherlands (NL), Spain (ES) and the United Kingdom (UK).[1] The dataset covers 18 manufacturing and 23 service sectors and corresponds to the two-digit NACE Rev.2 classification. The list of variables used in the analysis along with their sources is provided in Table 1; they cover economic, innovation and labour market indicators. The dataset has a longitudinal structure covering five sub-periods within the 1994–2017 time span, accounting for the different phases of the business cycle (see the Appendix—Table 6 and 7—for the list of industries and the periods covered by the analysis).

[1] Variables related to innovation activities are drawn from different consecutive waves of the Community Innovation Survey (CIS) from CIS 2 (1994–1996), to CIS 10 (2014–2016). Economic variables are drawn from the OECD's Structural Analysis Database (STAN) and the World Input–Output Tables (WIOT). Data on employment and wages are provided by the EU Labour Force Survey (EU LFS) of Eurostat. Concerning the classification of industries, data before 2008 have been converted into the NACE Rev. 2 using the conversion matrix elaborated by Perani and Cirillo (2015). Each monetary variable is expressed in constant prices (using 2000 as the base year), converted to euros, and adjusted for the purchasing power parity index guaranteeing full comparability of data over time and across countries. Profits (Gross operating surplus) refer to real economic activities (i.e. they do not include financial profits and speculative gains obtained through financial rents). In each of the five periods, the economic and labour market variables are lagged with respect to the innovation variables. The variables capturing the dynamics of demand (ΔVA and ΔEXP) are also introduced in the econometric model with a t-1 time lag with respect to the variables they are expected to have an impact on. We used lags of different length in the econometric estimations and for the different variables. This was constrained by the data-set used containing innovation and economic variables referring to not perfectly overlapping pluriannual periods (see Table 7 in the Appendix).

Table 1 List of variables

Label	Description	Source
R&D	In-house research and development expenditures per employee	CIS
INPRD	Share of firms that significantly improved their goods and services in the observed period	CIS
INPCS	Share of firms introducing a new or significantly improved production or delivery method in the observed period	CIS
EDU	Share of employees holding at least a bachelor's degree (ISCED 6–ISCED 8) over the total number of employees	OECD-STAN
$\Delta\pi$	Gross operating surplus per employee—compound annual growth rate	OECD-STAN
ΔINV	Gross fixed capital formation per employee—compound annual growth rate	OECD-STAN
ΔLPROD	Value-added per hour worked—compound annual growth rate	OECD-STAN
ΔVA	Industry value added—compound annual growth rate	OECD-STAN
ΔEXP	Exports—compound annual growth rate	WIOT
ΔW	Labour compensation per working hour—compound annual growth rate	OECD-STAN
UNSTABLE	Share of workers having a non-standard type of contract over the total number of employees	OECD-STAN
FIRM SIZE	Total number of employees over total number of firms in the sector	CIS

4 The Model and Econometric Strategy

In this section we empirically explore the determinants of profits, product innovation and capital investments as well as the presence of a dynamic cumulative relationship between these three variables. Accordingly, our econometric strategy consists of (a) estimating three single equations having as dependent variables the growth of profits, the relevance of product innovation and the dynamics of investment; (b) estimating the three equations nested in a simultaneous model.

4.1 The Profit Equation

Our profit equation is based on the work of Bogliacino and Pianta (2013), Bogliacino et al. (2018), Coveri and Pianta (2022), Guarascio and Pianta (2017), Pianta and Tancioni (2008) in which the growth of profits is driven by innovation, productivity and the conflicting nature of the capital-labour relationship. Higher profits are driven by the rise of labour productivity (value added per employee), that can be obtained by augmenting value-added and by reducing the work hours per unit of product. This can be pursued, on the one hand, through a technological competitiveness strategy, based on the introduction of new products in greater demand. On the other hand, a cost competitiveness strategy increases profits through investments in labour-saving technologies, reducing jobs and the wage bill as well as expanding the use of low-wage non-standard labour. Profits can also be positively associated with the average firm size of industries with such variable reflecting the relevance of barriers to entry and the level of market power. The profit equation is the following:

$$\Delta\pi_{i,j,t} = \alpha_0 + \alpha_1 INPROD_{i,j,t} + \alpha_2 \Delta LPROD_{i,j,t} + \alpha_3 \Delta INV_{i,j,t} + \alpha_4 \Delta W_{i,j,t-1} + \alpha_5 \Delta UNSTABLE_{i,j,t} + \alpha_5 FIRMSIZE_{i,j,t} + \mu_i + \tau_i + \delta_{i,t} + \varepsilon_{i,j,t} \quad (1)$$

In Eq. (1), the rate of growth of the profit per employee ($\Delta\pi$) at industry level, is related to the share of firms introducing product innovations (*INPRD*), to the rate of change of labour productivity ($\Delta LPROD$), to the rate of growth of gross fixed capital formation (ΔINV) and to the rate of growth of workers with a non-standard employment contract ($\Delta UNSTABLE$). The growth rate of hourly wages (ΔW_{t-1}) is expected to be negatively associated with the growth of profits, reflecting the distributive conflict between labour and capital while a positive association is expected with the average firm size of the sector (*FIRMSIZE*). The product innovation variable has a time lag of 2 years with respect to economic variables, accounting for the time needed for innovation to affect the economic process (see Table 7 in the Appendix); i, j, t indicate respectively industry, country and period. μ_i captures industry effects, including a series of dummy variables for the Revised Pavitt classes (see Table 6 in the Appendix) allowing to control for the existence of different industry-specific technological trajectories. δ_i accounts for country fixed-effects, capturing differences in the national institutional setting and the peculiarities of each national system of innovation. τ_i are time dummies allowing to control for the different phases of the business cycle. $\varepsilon_{i,j,t}$ is the error term.

4.2 The Product Innovation Equation

Innovation in products in each industry is expected to be driven by the internal expenditure in R&D and the availability of highly educated human resources. Both supply-side and demand-side processes are relevant here. In industries with growing demand, there is space for introducing profitable new products, but also for the survival of less innovative businesses with lower incentives to undertake technological efforts. On the other hand, industries with higher profits and populated by large firms can more easily finance innovative efforts, releasing financial constraints. Our product equation is the following:

$$INPRD_{i,j,t} = \beta_0 + \beta_1 R\&D + \beta_2 \Delta\pi_{i,j,t-1} + \beta_3 EDU_{i,j,t-1} + \beta_4 \Delta VA_{i,j,t-1} + \beta_5 FIRMSIZE_{i,j,t} + \mu_i + \tau_i + \delta_{i,t} + \varepsilon_{i,j,t} \quad (2)$$

In Eq. (2) product innovation (the share of firms in each industry introducing a product innovation ($INPRD$)) is driven by the level of R&D expenditures per employee ($R\&D$), by the presence of a large number of tertiary educated employees ($EDU_{i,j,t-1}$) and by the rate of growth of lagged profits per employee ($\Delta\pi_{t-1}$). We control for the potential effect of demand conditions on product innovation including the rate of change of value added (lagged) ($\Delta VA_{,t-1}$) and the average firm size (*FIRMSIZE*). As in the previous equation, industry, country and time dummies are included.

4.3 The Investment Equation

The drivers of investment include the profits used to finance them and the strategies of cost competitiveness leading to labour-saving process innovations, that may be particularly relevant in the industries with higher wage costs. Investments may be higher in industries where a search for technological competitiveness based on product innovation is less relevant. Finally, we expect the demand factors to positively affect investments: we use export growth instead of value-added growth as a proxy of a demand pull factor as the latter variable is highly correlated with the dynamics of profits. Our investment equation is the following:

$$\begin{aligned}\Delta INV_{i,j,t} = \gamma_0 + \gamma_1 \Delta\pi_{i,j,t-1} + \gamma_2 INPRD_{i,j,t} \\ + \gamma_3 INPCS_{i,j,t} + \gamma_4 \Delta EXP_{i,j,t-1} + \gamma_5 \Delta W_{i,j,t} \\ + \gamma_6 FIRMSIZE_{i,j,t} + \mu_i + \tau_i + \delta_{i,t} + \varepsilon_{i,j,t}\end{aligned} \quad (3)$$

Equation (3) estimates the rate of growth of gross fixed capital formation per employee (*ΔINV)* which is driven by the rate of change of lagged profits per employee ($\Delta\pi_{t-1}$), by the product and process innovation propensity of industries (*INPRD* and *INPCS*), by the lagged rate of growth of exports (ΔEXP_{t-1}) the rate of growth of wages per work-hour (ΔW) and firm size (*FIRMSIZE*). The profit growth variable refers to a previous period with respect to investments while innovation variables have a 2-year lag (the longitudinal structure of the data set is shown in Table 7 in the Appendix). The details of the equation are the same as discussed in (1). Considering the high heterogeneity across manufacturing and services industries in the use of gross fixed capital, including the one associated with digital technologies (Cainelli et al. 2004; Reljic et al. 2021b), we also include a manufacturing dummy θ_i.

4.4 The "Virtuous Circle" Model

The final econometric step consists of estimating Eqs. (1), (2) and (3) through a simultaneous three stage model (3SLS), under the hypothesis that profits per employee (Eq. 1) are driven by productivity gains which can, in turn, be realized through technological and cost competitiveness strategies, captured respectively by the propensity of industries to introduce product innovations (Eq. 2) and investment (Eq. 3). 3SLS allows to explore the simultaneous relationships and feedback loops among variables and control for most of the potential sources of endogeneity which may affect these relationships (Guarascio and Pianta 2017).

4.5 The Econometric Strategy

Regarding the single equations, we adopt the following identification strategy. First, we estimate each equation using a weighted least squares estimator (WLS). According to Wooldridge (2010), the use of this method should be preferred when the observation units largely differ in their absolute size; industry-data is clearly the case. We use the number of employees of each industry as weights since it is not subject to monetary fluctuations. Second, we estimate each single equation considering different specifications and using various control variables. Firm size is one of such variables capturing a basic structural dimension of industries and market structure conditions. In all specifications we also insert time, country and Pavitt dummies. Time dummies capture the different phases of the business cycle and the time-effects that may bias the estimations and enlarge the error term. Country dummies capture national specificities, including differences in labour markets and national systems of innovation. Pavitt dummies account for the heterogeneity of the technological regimes of industries. In the investment equation, additionally, we account for the different use of gross fixed capital between manufacturing and service industries.

We use Huber and White robust standard errors, in order to soften the heteroscedasticity problem and provide a more precise measure of the variance and covariance matrix as suggested in Wooldridge (2010), which should make more accurate our tests and statistical significance. This method is particularly useful to grasp heterogeneity within the sample, which is the case of industry data.

The time structure and the use of lags (see Table 7 in the Appendix) for most of the regressors may help in softening the simultaneity-related endogeneity bias of our estimations. This specification follows the work of Van Reenen (1996) highlighting the economic and econometric advantages associated with the use of lagged regressors in analyzing causal relationships between innovation and economic performances. This econometric strategy has been successfully used by several studies examining the dynamic linkages between technological and economic variables at the industry level (Guarascio and Pianta 2017; Pianta and Reljic 2022; Reljic et al. 2021b). In this work, innovation variables in both Eqs. (1) and (3) are implicity lagged given the structure of our dataset and refer to previous periods. The specification of Eq. (2)—in which all economic variables are lagged of one period—follows the same rationale. The use of time lags should help alleviate the potential autoregressive behaviour of the variables.

The simultaneity of the relationships investigated is estimated using a 3SLS model able to (at least partly) deal with the endogeneity issues. The 3SLS estimates a system of equations in which some variables are endogenous to the system and to disturbances correlated with them. Because some of the explanatory variables are the dependent variables of other equations in the system, we expect to have a positive cross-correlation of the error terms. The estimator uses instrumental variables to consistently estimate endogenous variables and the generalized least squares (GLS) method to account for the cross-correlation structure of error terms across the equations. The estimation procedure is performed by three steps. In the first step, it regresses each endogenous variable on all other exogenous explanatory variables, providing instruments resulting from the predicted values for each endogenous variable. The second step provides a

Table 2 The profit equation results

	(1) Δ π	(2) Δ π	(3) Δ π	(4) Δ π
INPRD (product innovation)	0.0560**	0.0590**	0.0670**	0.071***
	(0.026)	(0.025)	(0.026)	(0.027)
ΔINV (investment per emp.)	0.138**	0.149**	0.143**	0.143**
	(0.061)	(0.061)	(0.066)	(0.066)
ΔLPROD (labour productivity)	1.187***	1.224***	1.289***	1.304***
	(0.14)	(0.141)	(0.147)	(0.15)
ΔW (hourly wage—lagged)		−0.299**	−0.377***	−0.383***
		(0.134)	(0.143)	(0.147)
ΔUNSTABLE (unstable workers)			0.032	0.035
			(0.024)	(0.025)
FIRM SIZE				−0.067
				(1.036)
Constant	−5.705***	−5.077***	−5.529***	−5.901***
	(1.704)	(1.683)	(1.735)	(1.847)
Observations	914	914	775	757
R-squared	0.280	0.285	0.323	0.325
Pavitt dummies	Yes	Yes	Yes	Yes
Time dummies	Yes	Yes	Yes	Yes
Country dummies	Yes	Yes	Yes	Yes

Robust standard errors are in parentheses
***p <0 .01, **p <0 .05, *p <0 .1

consistent estimate for the covariance matrix of the cross-equation disturbances using two-stage least squares regression residuals. In the third step, it estimates equation-s—through the GLS method—using the fitted values from the first stage in place of the right-hand-side endogenous dependent variables and the covariance matrix estimate resulting from the second stage. Therefore, it allows to explicitly consider simultaneity across variables.

5 Results

5.1 Profits

Results of the profit equation estimates are provided in Table 2. They are largely consistent with our research hypotheses. Along with the positive role of labour productivity, the growth of profits is found to be associated with two innovation patterns: the first one based on the pursuit of a technological competitiveness strategy, proxied by the share of product innovation introduced by industries; the second one driven by the pursuit of a cost competitiveness strategy, as revealed by the positive effect of investment in fixed capital (see columns 1). When the increase of wages is added among the regressors (column 2) a negative relationship is found between such variable and the growth of profits, confirming the conflicting nature of the functional distribution of income between capital and labour. The relevance of non-standard workers has no significant relationship with profits (column 3), as the labour market effect is likely captured by the wage growth variable. Controlling for average firm size does not alter our results (column 4). Overall, the results of this first set of estimates confirm that profits can benefit from different competitive strategies and growth trajectories. On the one side, product innovations foster profit accumulation; on the other side, also labour and cost-saving strategies emerge as a viable conduct to increase profits.

5.2 Product Innovation

The results of the estimates of the product innovation equation are shown in Table 3. Product innovation is driven by the internal R&D effort, in line with a large literature. A larger share of highly educated employees is positively associated with the introduction of product innovations, confirming the important role played by human competencies as a key intangible asset supporting technological competitiveness strategies. Profits have a strong and significant impact on the introduction of innovative products. Somewhat surprisingly, value-added growth has a negative and significant effect on the product innovation propensity of industries. This result could be explained along three possible interpretative lines. First, it might suggest that markets characterized by a stagnant demand push firms to react by introducing new products. Second, in industries with higher demand, the competitive pressure is softened and there may be more room for survival also for low innovative firms. Third, this result might also reflect the poor structural economic performance of a large section of the European hi-tech industries and markets (characterized by weak internal demand and low competitiveness and an associated poor dynamic of value added).[2]

We also control for average firm size (column 3), used as a proxy of market structure, finding a positive impact on the introduction of new products. A larger firm size reflects greater capabilities in innovative efforts and is typical of industries with higher barriers to entry linked to the nature of technological activities, especially in high-tech sectors.

[2] In addition, it should also be taken into account the relatively long-time span of our lag structure, which might capture only to a limited extent the existence of the demand-pull effect.

Table 3 The product innovation equation results

	(1) INPRD	(2) INPRD	(3) INPRD
R&D (R&D exp. per emp.)	2.627***	1.782***	1.761***
	(0.276)	(0.22)	(0.226)
Δπ (profits per employee—lagged)	0.309***	0.109*	0.110*
	(0.084)	(0.065)	(0.064)
ΔVA (value added—lagged)	−0.555***	−0.443***	−0.457***
	(0.204)	(0.165)	(0.163)
EDU (high educated workers—lagged)		0.131***	0.102**
		(0.045)	(0.045)
FIRM SIZE			3.405**
			(1.344)
Constant	32.258***	27.43***	27.616***
	(2.407)	(2.161)	(2.156)
Observations	703	702	696
R-squared	0.538	0.717	0.722
Pavitt dummies	Yes	Yes	Yes
Time dummies	Yes	Yes	Yes
Country dummies	No	Yes	Yes

Robust standard errors are in parentheses
***$p < 0.01$, **$p < 0.05$, *$p < 0.1$

5.3 Investment

Table 4 shows the results of the investment equation. Profits emerge as a crucial driver of capital formation. The growth rate of lagged profits (per employee) is positive and significant across the two specifications. Product innovation is (as expected) negatively associated with capital accumulation confirming the existence of two distinct competitive strategies, one based on the introduction of product innovations and the other one consisting of the acquisition of new machinery and equipment.

The process innovation variable does not emerge as significantly associated with the investment dynamics; this is likely due to the fact that the investment per employee variable that we use captures the relevance of (labour-saving) process innovations that are usually incorporated in such investments. The labour-saving nature of investment is also shown by the positive association with the wage variable: industries experiencing a high wage growth tend to invest more in labour-saving technologies.

Both the growth of exports (used as a proxy of the most dynamic component of demand) and firm size are not significantly associated with investment.

The main messages emerging from the results of Table 4 can be synthesised as follows: (i) lagged profits are a fundamental financial source to boost investments with a capital deepening orientation; (ii) investment growth is higher in the industries in which

Table 4 The investment equation results

	(1) Δ INV	(2) Δ INV
$\Delta\pi$ (profit per emp.—lagged)	0.094**	0.094**
	(0.04)	(0.04)
INPCS (process innovation)	0.018	0.011
	(0.048)	(0.054)
INPRD (product innovation)	−0.069*	−0.070*
	(0.038)	(0.038)
ΔEXP (exports—lagged)	−0.026	−0.025
	(0.037)	(0.037)
ΔW (hourly wages)	0.739***	0.727***
	(0.273)	(0.271)
FIRM SIZE		0.646
		(1.227)
Constant	2.827**	2.856**
	(1.389)	(1.396)
Observations	591	590
R-squared	0.188	0.189
Pavitt dummies	Yes	Yes
Manufacturing dummies	Yes	Yes
Time dummies	Yes	Yes
Country dummies	Yes	Yes

Robust standard errors are in parentheses
***p <0 .01, **p <0 .05, *p <0.1

labour compensation grows more, indicating the labour-substituting nature of capital accumulation in sectors following cost competitiveness strategies; (iii) a clear trade-off between product innovation and capital investments emerges, confirming once again the existence of two alternative competitive strategies, what we call technological and cost competitiveness.

5.4 The "Virtuous Circle" Results

Table 5 presents the results of the estimates of the simultaneous (three stage) equation model, where the key cumulative relationships among variables can be captured. The results show that:

(a) The growth of profits is driven by productivity gains and the introduction of product innovation (Eq. 1), reflecting the strategies of technological competitiveness;
(b) The product innovation performances of industries are supported by the availability of financial resources associated with lagged profits and by the presence

Table 5 The "virtuous circle" 3SLS estimation results

	(1) $\Delta\pi$	(2) INPRD	(3) ΔINV
INPRD (product innovation)	0.110***		−0.762***
	(0.0412)		(0.284)
ΔINV (investment per emp.)	0.125		
	(0.442)		
ΔLPROD (labour productivity)	1.046***		
	(0.212)		
ΔW (hourly wage)	−0.0707		
	(0.216)		
$\Delta\pi$ (profits per emp.—lagged)		7.948**	5.553***
		(3.173)	(1.364)
R&D (R&D exp. per emp.)		−0.665	
		(0.836)	
EDU (highly educated workers—lagged)		0.227***	
		(0.0835)	
INPCS (process innovation)			0.186
			(0.226)
ΔEXP (exports—lagged)			0.0194
			(0.0515)
Constant	−2.249	6.244	9.443*
	(1.828)	(10.80)	(5.420)
Observations	521	521	521
R-squared	0.261	−15.576	−37.987
Pavitt dummies	Yes	Yes	Yes
Time dummies	Yes	Yes	Yes
Country dummies	Yes	Yes	Yes

Robust standard errors are in parentheses
Endogenous variables: $\Delta\pi$, INPRD, ΔINV, $\Delta\pi$(lagged)
Exogenous variables: dependent variables, included Time, Country, and Pavitt dummies
***$p < 0.01$, **$p < 0.05$, *$p < 0.1$

of employees with a high level of qualification (Eq. 2), completing the "virtuous circle" of technological competitiveness;

(c) Lagged profits support both technological and cost competitiveness strategies: they stimulate the introduction of product innovations (Eq. 2) and, at the same time, are an important driver of investment (Eq. 3);

(d) The presence of two distinct competitiveness strategies is confirmed by the negative relationship between investment in fixed capital (reflecting cost concerns) and product innovation (reflecting technological efforts) (Eq. 3).

(e) A "virtuous circle" between profit, innovation and investment clearly emerges in the case of industries pursuing a technological competitiveness strategy while a somewhat weaker cumulative mechanism emerges in the case of industries pursuing cost competitiveness strategies, where labour-saving, capital-deepening investments are the dominant driver of change.

It should be noted the loss of statistical significance of some coefficients of the 3SLS estimates, as compared to the single-equation estimates, namely those associated with the dynamics of wages in Eq. (1) and R&D in Eq. (2). This reflects the complexity of (and the difficulty of grasping) the looping and cumulative dynamic interactions among the key variables included in the model. This is the reason why we have also strategically constrained the number of explanatory variables included in the 3SLS estimates to maximize the statistical robustness and economic interpretability of our results.[3]

Overall, the 3SLS model proposed in this contribution has proved to be a consistent and robust analytical framework for exploring the cumulative and looping relationships between profits, product innovation, and investment as well as testing and qualifying the presence of virtuous circles fuelling and shaping the dynamics of industries and the process of structural change.

6 Conclusions

Technological change and investments are key elements of the process of accumulation in capitalism.

Industries are affected in different ways by such processes, as structural change guides the expansion of new activities and the contraction of old ones. Technological activities provide the knowledge and the new products that are needed, while investments build the new production capacity required for the evolution of firms and industries. Both investment and innovation are driven by the profit motive; as pointed out by Classical economists and Schumpeter, capital flows towards new industries, searching for the monopolistic profits of innovators and for the gains offered to early imitators. This process increases competition and eventually brings profits in line with those of the rest of the economy.

Capital does not act alone in this process. Labour plays a key role in technology, production and distribution. First, the development of knowledge relies on human competencies and the presence of highly educated workers is crucial for industries' ability to innovate. Second, in production activities capital and labour can be organised in different ways, and where wages are a relevant component of production costs, the profit logic leads to investments relying on new processes, that are usually capital-deepening and labour-saving. Third, there is the capital-labour conflict over income distribution; profits can grow at the expense of wages when the balance of power and

[3] In Table 8 in the appendix we present the results of our 3SLS model when all regressors used in the single equations are included. The wage variable in Eq. (3) comes out significant and with the expected sign although it takes away the statistical significance of the product innovation regressor. The ΔVA (lagged) variable in Eq. (2) is confirmed to be negatively correlated with product innovation. FIRM SIZE is never significant largely confirming the results of single equations.

institutional factors—the fragmentation of labour with non-standard employment, the weakening of trade unions—allow for a larger capital share.

In this article we have disentangled such concepts, identifying some of the key relationships between innovation, investments and profits—and the role of labour and wages—focusing on links that are relevant at the industry level.

In this work, we have introduced four novelties in the literature on these issues.

First, we move beyond a linear vision of the relationships examined, tackling the complexity of the linkages between profits, innovation and investments, building a" virtuous circle" model that explicitly accounts for simultaneous links, reciprocal interactions, cumulative effects, feedback loops and lags. We build on the tradition of models of circular and cumulative causation (Myrdal 1957) and operationalise them at the industry level to explore the dynamics of growth and structural change in advanced economies. Our previous works have used such models for investigating the innovation-performance links (Bogliacino and Pianta 2013; Guarascio and Pianta 2017), the labour-innovation-productivity nexus (Pianta and Reljic 2022) and the profit-wage dynamics (Coveri and Pianta 2022). With this article, we integrate the role of investments—alongside innovation—in the profit dynamics, showing that they support a trajectory of growth that is distinct from the one based on product innovations.

Second, we combine a dynamic and structural perspective carrying out a longitudinal cross-sector and country analysis over six time periods characterised by different phases of business cycles. The dynamic dimension is crucial here in order to account for the processes of technological and structural change. Moreover, developing a dynamic investigation through a "virtuous circle" approach allows us to explore both drivers and effects of such processes. In fact, profits are at the same time a result of the success of the "virtuous circle" and a precondition for good performances in innovation and investment. Similarly, innovation is the outcome of the presence of knowledge, educated workers and financial resources and, at the same time, is a factor leading to higher performances and profits. Finally, investments are largely financed by past profits and contribute to higher performances and further capital accumulation.

Third, we explore the diversity of drivers and trajectories in the evolution of industries and economies. In the Economics of innovation discipline, technological change has often been considered as an undifferentiated process, with R&D efforts leading to advancements in the technological frontier, with better outputs (such as patents) or outcomes (such as productivity). We build on our previous work by distinguishing the orientation of technological efforts either towards new products—with the potential to expand markets and employment—or towards new processes—focusing on greater efficiency and labour replacement. These two different innovation patterns are at the root of distinct strategies, aiming either at technological competitiveness—where new products play a crucial role—or at cost competitiveness—where investments incorporating labour-saving process innovations are dominant. Our findings clearly document the coexistence of these two strategies in European industries, with higher-tech sectors characterised by the former, and lower-tech ones relying more on the latter strategy. While such alternative paths have different effects on industry structures, employment and wages, profits are driven by both strategies. In fact, in this article we have highlighted the heterogeneity of the patterns of technological and structural change and how this is reflected on different types of accumulation processes and sources of profits.

Fourth, all the above relationships are set in the wider context of demand dynamics and of labour characteristics. The innovation-investment-profit links mainly operate on the supply side, but we show that they are also affected by the conditions of demand at industry level, shaping patterns of investments in greater production capacity and structural change. At the same time, labour is also found to play a key role. We show that the development of new products and the pursuing of technological competitiveness strategies relies on the capabilities of highly skilled workers; in industries with higher wages, labour-saving investments grow faster; profits can increase also at the expense of wages, but exacerbating the distributive conflict between capital and labour. These four issues have rarely been fully considered in investigations of technological and structural change. The approach and the findings of this article allow us to shed new light on the dynamics of such processes and to locate the trajectories of innovation, investments and profits in the broader processes of economic change.

The evidence presented in this contribution has relevant and straightforward policy implications. Investment and innovation are confirmed to be at the core of the dynamic performances of industries and deserve to be both adequately supported by industrial and technology policies. However, the evidence presented clearly suggests that the economic and social returns of technology and industrial policies crucially depend on what kind of firms, industries, innovation strategies and consequently type of investment are supported. Virtuous circles of investment, innovation and growth are more likely to be activated and—more important—present an endogenous long-term self-sustained dynamics, in industries, product segments and technological regimes based on the accumulation of intangible knowledge-based assets. Policies supporting investment aiming at merely expanding production capacities or passively adopting new vintages of capital are likely to produce limited (in time and scale) technological and economic effects, being unable to activate real processes of upgrading in the dynamic capabilities of firms, industries and economic systems at large. This seems to be a very relevant message and indication considering the recent rediscovery of industrial policy as an important domain of public intervention (at a national and EU level) and the need to speed up the digital and green transition of our economies and societies, a challenging policy target requiring more selective and mission-oriented policies.

Appendix

Table 6 List of industries considered in the analysis

Sectors		Nace Rev. 2 codes
SCIENCE BASED		
	Manufacture of chemicals and chemical products	C20
	Manufacture of basic pharmaceutical products and pharmaceutical preparations	C21
	Manufacture of computer, electronic and optical products	C26
	Telecommunications	J61
	Computer programming, consultancy and related activities; information service activities	J62–J63
	Scientific research and development	M72
SPECIALISED SUPPLIERS		
	Manufacture of electrical equipment	C27
	Manufacture of machinery and equipment n.e.c	C28
	Manufacture of other transport equipment	C30
	Repair and installation of machinery and equipment	C33
	Real estate activities	L68
	Legal and accounting activities; activities of head offices; management consultancy activities	M69–M70
	Architectural and engineering activities; technical testing and analysis	M71
	Advertising and market research	M73
	Other professional, scientific and technical activities; veterinary activities	M74–M75
SCALE AND INFORMATION INTENSIVE		
	Manufacture of paper and paper products	C17
	Printing and reproduction of recorded media	C18
	Manufacture of rubber and plastic products	C22
	Manufacture of other non–metallic mineral products	C23
	Manufacture of basic metals	C24
	Manufacture of motor vehicles, trailers and semi–trailers	C29
	Publishing activities	J58
	Motion picture, video and television programme production, sound recording and music publishing activities	J59–J60
	Financial service activities, except insurance and pension funding	K64
	Insurance, reinsurance and pension funding, except compulsory social security	K65
	Activities auxiliary to financial services and insurance activties	K66

Table 6 (continued)

Sectors		Nace Rev. 2 codes
SUPPLIER DOMINATED		
	Manufacture of food products, beverages and tobacco products	C10–C12
	Manufacture of textiles, wearing apparel and leather products	C13–C15
	Manufacture of wood and of products of wood and cork, except furniture	C16
	Manufacture of fabricated metal products, except machinery and equipment	C25
	Manufacture of furniture; other manufacturing	C31–C32
	Wholesale and retail trade and repair of motor vehicles and motorcycles	G45
	Wholesale trade, except of motor vehicles and motorcycles	G46
	Retail trade, except of motor vehicles and motorcycles	G47
	Land transport and transport via pipelines	H49
	Water transport	H50
	Air transport	H51
	Warehousing and support activities for transportation	H52
	Postal and courier activities	H53
	Accommodation and food service activities	I55–I56
	Administrative and support service activities	N

The industry groups are those of the revised Pavitt taxonomy proposed by Bogliacino and Pianta (2010)

Table 7 The time structure of the dataset

	First period		Second period		Third period		Fourth period		Fifth period		Sixth period	
	CIS2		*CIS3*		*CIS4*		*CIS7*		*CIS9*		*CIS10*	
R&D	1994–96		1998–2000		2002–04		2008–10		2012–14		2014–16	
INPRD	1994–96		1998–2000		2002–04		2008–10		2012–14		2014–16	
INPCS	1994–96		1998–2000		2002–04		2008–10		2012–14		2014–16	
HK		1996–2000		2000–03		2003–08		2008–12		2012–15		2015–17
Δ π		1996–2000		2000–03		2003–08		2008–12		2012–15		x
ΔINV		1996–2000		2000–03		2003–08		2008–12		2012–15		x
ΔLPROD		1996–2000		2000–03		2003–08		2008–12		2012–15		x
ΔVA		1996–2000		2000–03		2003–08		2008–12		2012–15		x
ΔEXP		1996–2000		2000–03		2003–08		2008–12		2012–15		x
ΔW		1996–2000		2000–03		2003–08		2008–12		2012–15		x
UNSTABLE		1996–2000		2000–03		2003–08		2009–12		2012–15		2015–17
FIRM SIZE		1996–2000		2000–03		2003–08		2008–12		2012–15		x

Table 8 The "virtuous circle" 3SLS estimation results, all variables

	(1) Δπ	(2) INPRD	(3) ΔINV
INPRD (product innovation)	0.105**		−0.0615
	(0.0476)		(0.115)
INPCS (process innovation)			0.196*
			(0.108)
ΔINV (investment per emp.)	0.839***		
	(0.314)		
ΔLPROD (labour productivity)	0.913***		
	(0.159)		
ΔW (hourly wage)	−0.371*		0.521***
	(0.205)		(0.166)
R&D (R&D exp. per emp.)		1.471***	
		(0.421)	
EDU (high educated workers—lagged)		0.0401	
		(0.0886)	
Δπ (profits per emp.—lagged)		2.718***	−0.513***
		(0.748)	(0.165)
ΔVA (value added—lagged)		−1.887***	
		(0.517)	
FIRM SIZE	−1.578	0.955	−0.307
	(1.692)	(4.767)	(1.655)
ΔEXP (exports—lagged)			0.00592
			(0.0438)
Constant	−3.244*	23.44***	1.815
	(1.937)	(4.250)	(2.273)
Observations	514	514	514
R-squared	−0.161	−1.053	−0.286
Pavitt dummies	Yes	Yes	Yes
Time dummies	Yes	Yes	Yes
Country dummies	Yes	Yes	Yes

Robust standard errors are in parentheses

***$p < 0.01$, **$p < 0.05$, *$p < 0.1$

Endogenous variables: Δπ, INPRD, ΔINV, Δπ(lagged)

Exogenous variables: explanatory variables, included Time, Country, and Pavitt dummies

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