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Modelling the virtuous circle of innovation.
A test on in Italian firms

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Abstract

The 'virtuous circle' between innovative inputs, outputs and economic performance is investigated in this article with a three-equation model highlighting feedback loops and simultaneous relations. An empirical test is carried out considering innovative expenditure, innovative turnover and economic results in a sample of Italian manufacturing firms, comparing occasional and serial innovators. We use data for the period 1998-2007 from a rich panel of Italian firms over 20 employees drawn from ISTAT, the National Institute of Statistics, including data from three waves of Community Innovation Surveys. The model we use extends the one developed at the industry level by Bogliacino and Pianta (2013a, 2013b), confirming previous findings. For the core of Italian persistent innovators, results show the complex links at play in different phases of the innovation process, and the feedbacks between economic success and the ability to sustain innovation expenditure.

Keywords: Innovation, economic performance, three equation model, Italian firms

JEL Classification: L6, L8, O31, O33, O52.

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1. Introduction[2]

The relationship between innovation and performance in firms is investigated in this article moving beyond approaches that consider unidirectional causal links and building on evolutionary insights that emphasise the importance of cumulative processes and lags, the presence of feedback loops and complex, simultaneous interactions (Schumpeter, 1955; Dosi and Nelson, 2010).

We develop an empirical model on innovation inputs, outputs and performance that accounts for the 'circular' nature of this process. Firms carry out innovative expenditure, facing the cost of improving their products and processes; a qualitative change in output – with innovation-related sales – is the result of such new accumulation of knowledge; larger sales – and Schumpeterian profits – result from such innovation-related output, which in turn can sustain firms' innovative expenditures. Such a 'virtuous circle' is at the root of economic dynamics and sustains the mutual interactions between innovation and performance.

While a large literature has addressed the innovation-performance relationship – usually with a one-way approach from the former to the latter – and several structural models have been developed, few studies have approached this issue in an integrated way, modelling the existence of 'virtuous circles' and testing them with an empirical investigation.

We start from the model of Bogliacino and Pianta (2013a) - developed at the industry level - where industries' R&D efforts lead to successful innovations, new product sales lead to high Schumpeterian profits, which in turn provide resources for funding R&D efforts. The model - based on three simultaneous equations – has been tested on manufacturing and services industries of major European countries, showing that such cumulative effects and feedback loops can indeed account for the industry dynamics of the last two decades (see also Bogliacino and Pianta 2013b and Guarascio, Pianta and Bogliacino 2015).

In this article we want to bring the same approach to the firm level, exploring whether the same 'virtuous circle' of technology-driven growth can be identified in the enterprises where knowledge is accumulated, innovations are introduced and market success is obtained. The empirical test of the model we propose for firm-level analysis is carried out considering innovative expenditure, innovative turnover and economic results in a sample of Italian manufacturing firms, comparing occasional and persistent product innovators. We use data for the period 1998-2007 from a rich panel of 1001 Italian firms over 20 employees drawn from ISTAT, the National Institute of Statistics, including data from three waves of Community Innovation Surveys. We consider differences between non-innovators, occasional innovators and the group of 151 firms that are 'serial innovators', i.e. those firms that introduced a product innovation in the three CIS waves 1998-2000, 2002-2004, 2004-2006.

Results show that findings at the firm level for persistent innovators replicate those

[2] Versions of this work have been presented at workshops at IMT Lucca, Università Cattolica sede di Piacenza, Sapienza University of Rome, University of Trento and ISTAT. We thank participants for the discussion, and in particular Davide Castellani, Giovanni Dosi, Alessandro Zeli; we thank ISTAT for data access. A special acknowledgement to an anonymous referee for his comments which helped us improving considerably this version of the paper.

obtained for industries by Bogliacino and Pianta (2013a, 2013b) and give strong support to the statement that this set of companies shape the overall performance. Innovative efforts are cumulative and supported by high turnover; new product success results from innovative expenditure and demand pull effects; overall firms' turnover is fuelled by innovative sales alongside other factors of competitiveness. Cumulative processes and feedbacks indeed shape the 'virtuous circle' of innovation in firms.

This article proceeds as follows. Section 2 presents a review of the literature, paying special attention to contributions based on Italian data. Section 3 introduces the dataset and section 4 provides a preliminary test on different groups of firms. Section 5 presents the model and the results; section 6 draws the conclusions. Further information and additional robustness checks are included in the Appendix.

2. Innovation and performance in firms

2.1 The existing literature

Most of the literature analyzing the microeconomic relationships at the root of innovation-driven-growth has focused on unidirectional links. Some studies have estimated the impact of R&D and innovation output (usually patents) on firms' economic performance (Bottazzi and Peri, 2007; Crafts and Mills, 2005; Lanjouw and Schankerman, 2004; Bloom and Van Reenen, 2002). Others have explored the role of profits in driving innovation at firm level (Teece, 1986, Geroski et al. 1993, Cefis and Ciccarelli, 2005) or at industry level (Klepper, 1997); some others have studied the role of profits in overcoming the financing constraints for R&D (Hall, 2002; Cantwell, 2002; O'Sullivan, 2005; Coad and Rao, 2010; Bogliacino and Gómez, 2014; Cincera and Ravet, 2010). However, few studies have addressed the "black box" of the innovation process in an integrated way, accounting for the complexity of inter-relations.

The model of Crépon et al. (1998) (the so-called CDM model) has proposed to investigate the contribution of innovation to productivity by means of a three step model, in which R&D is driven by size, demand pull and technology push factors; a knowledge production function relates the amount of resources firms decide to invest in R&D to an innovation output; the latter impinges upon firm performance (usually productivity) through a standard Cobb-Douglas function. Designed to work with survey data and equipped to consider different types of innovation output, this model provides a sequential structure to describe the process behind the innovation activity of firms. An example of application is in Mairesse and Mohnen (2002); an extensive review of the application of this model to innovation surveys is in Mairesse and Mohnen (2010); a similar approach but tailored on a different data source is in Parisi et al. (2006). Using a large unbalanced panel data of Italian manufacturing firms in the 1995-2006 period, Hall et al. (2012) have extended the CDM model to include ICT expenditure as a determinant of the innovation output; they attempt to identify a set of channels through which ICT and R&D investments affect innovation among firms as well as the (indirect) effect on firm productivity. Hall et al. (2009) use a similar CDM framework to estimate the dynamics of Italian SMEs, where R&D, which is more extensively done by large firms, can underestimate their real innovative efforts.

Although the CDM model represents an improvement in understanding the complexity of innovation, it shares several weaknesses of neoclassical views on the operation of firms – seen as homogeneous units - and innovation, including an undifferentiated view of technology, with no distinction between different strategies, such as those mainly directed to new products or new processes. Moreover, the sequential process described in the model neglects simultaneity and feedback effects among variables, and disregards the cumulative processes of innovation in firms.

Evolutionary studies provide a more convincing framework for investigating innovation processes in firms (Dosi and Nelson, 2010; Dosi, 2012). They have shown that growth is characterized by persistent firm heterogeneity, and by cumulative processes that are specific to firms sharing specific characteristics in their knowledge base and business strategies (Dosi et al., 2010). Several studies in this perspective have investigated the dynamics of innovation, growth and productivity of Italian firms. Building on longitudinal micro-evidence on Italian manufacturing firms, Dosi (2007) explored the rich statistical structure of industrial evolution. By examining the basic features of distributions of firms - in terms of their size, growth and profitability - Dosi highlighted the underlying inter-firm heterogeneity that persist over time as an empirical validation of evolutionary theories. The idiosyncratic components of firms - principally their innovation efforts - drive the process of change in such distributions. However, the process of market selection appears to play a minor role in affecting the patterns of growth of firms as differential efficiencies are not turned into higher growth of more successful firms.

A large dataset on Italian manufacturing microdata produced by ISTAT – the same one we use in our investigation in this article – has allowed novel insights into the dynamics of firms and innovations. Bottazzi et al. (2010), using such data for 1989 to 2004, showed that "the survival of the fittest" is barely observable: more profitable firms do not grow systematically more than less profitable ones. Using the same dataset, Dosi et al. (2012) confirmed the intra-sectoral heterogeneity of firms in terms of labour productivity and growth rates; however, they observe that the distribution of labour productivity has not significantly changed over time and no relevant change in patterns seem to be associated to the introduction of the euro. For Italy, they identified a "neo-dualism" where a small group of dynamic firms coexists with a large group of laggard, less innovative firms.

The same ISTAT panel has been used by Oropallo and Rossetti (2011) for the period 2001-2008, finding a strong effect of productivity on export, but a lack – at the same time - of the "learning by exporting" effect on firms. Milana et al. (2013) using DEA techniques for the period 1998-2004 analysed the stagnation of productivity in many industries, finding higher efficiency gains and stronger performances of larger firms compared to SMEs. Nardecchia et al. (2011) confirmed the low productivity of Italian firms, while Velucchi et al. (2011) documented the increasing heterogeneity of productivity performances in the 1998-2007 period.

Several studies – using a variety of approaches - have looked at the factors that can support or hinder the competitiveness of Italian firms. Pellegrino et al. (2012) showed that Italian young innovative companies (indicated as the solution to Europe's low R&D in Cincera and Veugelers, 2010) lack a significant R&D activity and rely more on external sources of innovation. Bugamelli et al. (2011) identified the roots of Italy's productivity stagnation in the persistent smaller size (compared with European and OECD averages) and in the obsolete organizational and managerial routines. The role of employment protection in limiting firms' competitiveness – comparing behaviours of firms above and below the threshold for the enforcement of workers' rights - seems to play a largely negligible role (Boeri and Jimeno, 2005). The more complex pattern of vertical disintegration of production in Global Value Chains has been explored by Agostino et al. (2011) finding that key suppliers have an export premium in their productivity performances. An export premium is documented also in De Nardis and Pappalardo (2011) and, for innovation, by Pla-Barber and Alegre (2007) in Science Based French companies. Finally, using propensity score matching on a large and detailed dataset of German companies, Becker and Egger (2013) document a large export premium of product innovators.

Castellani and Zanfei (2007) document a large heterogeneity in Italian firms in terms of economic and innovative performance, even after controlling for location, sector, age and size. They also show that for manufacturing multinational, exporters are not more productive if compared with those companies that have only non-manufacturing activities abroad.

Innovation and profits have been studied by Bartoloni (2012), using data from three waves of the Italian CIS and administrative sources for the period 1996-2003, finding an important influence of innovation on profitability, as well as a strong innovation persistence. The same persistence has been found by Antonelli et al. (2012). Finally, the micro level study by Castiglione and Infante (2013) pointed out the positive impact of the use of ICTs on total factor productivity of Italian firms, affecting the composition of firms' investments, firm organisation and learning by doing.

2.2 The novelty of this approach

This article brings two novelties to this literature. First, conceptualising the innovation process as a 'virtuous circle' rather than as linear, unidirectional relationships allows to account for the complexity of the ways technological change is introduced in firms and is turned into better performances. The feedback loops that are documented highlight a key characteristic of the innovation process and confirm the relevance of evolutionary approaches.

Second, to the best of our knowledge this is the first article that assesses at the firm level the very same relationships that have been documented at the industry level. In Bogliacino and Pianta (2013a) it is shown that some fundamental divergent dynamics is present, in which sectors where R&D is carried out tend to innovate more and get higher profits, that in turn feed further research effort and innovation success. These feedback loops are an accurate representation of the mechanisms through which technology contributes to the structural change taking place in European economies. Moving this approach at the firm level allows to explore the micro-dynamics resulting in such outcomes. The aim of this exercise is not to propose, in a mainstream fashion, that the aggregate effect is some sort of linear aggregation of micro behaviours, as in the 'representative firm' approach. Conversely, our aim is to investigate the heterogeneous dynamics at the firm level that may account at the same time for the turbulence of micro behaviours and for the emergent patterns of industrial dynamics that are identified, In particular, we find that the more dynamic firms – those who are able to regularly introduce new products – are characterised by the same feedback loops between innovation inputs, outputs and performance documented at the industry level. They emerge as the 'engine' of the same divergent dynamics that shapes at the same time the evolution of firms and of industries.

Moreover, the use in our empirical test of the large Istat panel that is representative of Italian firms over 20 employees assures the robustness of our results. Rather than relying on non-representative panels that are more exposed to the risks of selection bias, we use a dataset that assures the correspondence between the dynamics of firms and that of industries.

3. Data

The data used in the empirical investigation of this article comes from the panel developed by ISTAT (the Italian Institute of Statistics, see Nardecchia et al., 2010; Biffignandi et al. 2009) with yearly data on firms over 20 employees for the period 1998-2007, collecting economic and balance sheet data. The panel design is based on the matching of survey microdata with administrative sources in order to ensure integration of not respondents and continuity over time.[3] Such data have been integrated with information drawn from three additional sources on the innovation and trade activity of firms (Community Innovation Surveys, R&D surveys and trade data).

The ISTAT panel includes 70,000 units in 1998 and more than 82,000 units in 2007, basically covering the population of firms over 20 employees (Biffignandi, Nascia and Zeli, 2009).[4] All variables are originally measured at current prices in euro and transformed in year 2000 prices. Output volumes have been deflated using indexes of producer prices at industry level. Capital values have been deflated by means of the price index for investment goods, whereas the variables related to employment such as labour cost have been deflated by means of wage and salary indexes for each NACE category.

From the ISTAT panel we have extracted a database that includes the firms that: a) belong to manufacturing industry and b) have answered to three waves of the Community Innovation Survey (CIS): CIS 3 (1998-2000), CIS 4 (2002-2004) and CIS 5 (2004-2006).[5]

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[3] The implementation of the panel has included four relevant sources: the Istat Business Register of Italian firms (ASIA), the Italian Structural Business Statistics survey (SCI), focusing on economic data of firms with more than 100 employees, the Italian Survey on Small and Medium Sized Enterprises (PMI) focusing on the firms with 20-100 employees and the database on balance sheets of incorporated firms collected by the Central Balance-Sheet Data Office of Italy.

In order to include business transformations like mergers and acquisitions (M&A) the panel follows a backward perspective. The panel has established all links between firms in the 1998 survey with 2007 survey respondents, including business transformations; it however does not include new firms entering the market after 1998. The features of the panel are compatible with the requirements of information that is complete, consistent and comparable over time (Kessler and Greenberg, 1981).

[4] A well-known weakness of this panel is the lack of consideration of entry and exit of firms, an issue of particular relevance when innovation is investigated. As we cover a short time period – six years – and focus on the existence of a virtuous circle in the industrial system as a whole, this bias may be of limited impact.

[5] For this article, the original ISTAT panel has been extended to include CIS 2006 data for all firms.

In this way, the final dataset we obtain is a large sample of Italian firms with a systematic coverage of Italy's innovative activity in the manufacturing sector.
The number of firms which satisfy such conditions is 1001; the dataset includes 362 enterprises that did not introduce innovations or carried out process innovations only; 488 firms that are 'occasional product innovators', introducing new products in one or two CIS surveys out of the three considered; 151 firms that are 'serial product innovators' introducing product innovations in all the three CIS surveys considered. It has to be stressed that our distinction between the three groups is based on a strong selection. Italian firms introduce more frequently process or organizational innovations, compared to new products; moreover, bringing novel goods to the market is a demanding and discontinuous process by its very nature, as firms have limited resources and have to combine the development of new products with their market exploitation. Therefore 'occasional product innovators' may share some of the positive innovation-performance relationships discussed above, but we decided to focus on the most dynamic 'core' of persistent innovators in products as they are the firms where technological activities are systematically carried out and are continually turned into new goods; in other words, 'serial innovators' are the firms that most relevant in shaping economic change. Our study considers the following variables:

1. **Total turnover** (***Turn***) is the more general indicator for the economic performance of firms; it documents firm growth and market success, and is generally closely associated to profitability; the variable we use is *Total turnover per hour worked*. Hours worked are generally considered as the best indicator of labour input in firms.[6]
2. **Innovative turnover** (***InnTurn***, drawn from CIS) is the part of turnover due to new or significantly improved products, both for the firm than for the reference market. The variable we use is *innovative turnover per hour worked*, a proxy of the economic impact that innovations have.[7]
3. **Innovative expenditure** (***InnExpend***, drawn from CIS and R&D survey data) is defined as the sum of in house and external R&D, acquisition of machinery, equipment and software and acquisition of external technologies. As a measure of innovation inputs the variable we use is *innovative expenditure per hour worked*.
4. **Labour productivity** (***π***), defined as *value added per hour worked*, is used as an overall indicator of efficiency reflecting factors such as capital, organizational models and market power.
5. **Wage levels** (***w***), defined as *total wages per hour worked*, provide information on the skill level of employees but, at the same time, represent a cost and an incentive for the introduction of labour saving process innovations.
6. **Exports** (***Exports***), defined as *export per hours worked,* are considered in order to account for demand pull effects on innovation.

Innovation and economic variables are referred to three periods (2000, 2004 and 2006). The

[6] We use hours worked has a measure of scale, because we think that number of employees may be biased by the high share of precarious and part time jobs.
[7] This measure is different from the standard CIS measure of innovative turnover, which is expressed as share on total turnover.

first year (2000) is the base for the lagged variables affecting the second period (2004). The empirical test of the model will be based on the two periods, 2004 and 2006.

Some descriptive evidence is provided by Table 1, showing the average values of the main variables in 2004 and 2006 for the three groups of firms that never introduced new products, that were occasional or serial product innovators. Firms that have persistently introduced new products account for 15% of the whole sample; close to one half are occasional innovators. Average values are stable across the two periods. As expected, serial innovators show higher innovative expenditures, a greater innovative turnover (more than twice compared to occasional innovators) and higher exports (15% higher than in other groups of firms). Non innovators show much lower values in innovation expenditure, and lower productivity levels compared to the other two groups.

Conversely, total turnover per hour appears to be higher in occasional innovators and non innovators; these values contrast with data on value added per hour, and suggest that in such firms outsourcing of production (that inflates turnover over value added) can be relevant. In fact, non innovators are concentrated in traditional industries - from food to textile - where firm size is smaller and outsourcing of production is widespread (see Tables A1, A2 in the Appendix).

Over time, the importance of being innovative emerges more clearly and distances in performance tend to increase. Between 2004 and 2006 productivity has grown by 3% in serial innovators and has declined by 7 and 8% in occasional innovators and in non-innovating firms. Innovative turnover per hour worked has increased by 5% in serial innovators and has drastically declined in occasional innovators. Export show very high growth also for occasional innovators and non-innovators, 'pulling' the growth of total sales; such benefits, however, are hardly visible in terms of productivity, wages and innovative activities.

Table 1. Innovation and performance in a panel of Italian manufacturing firms. Economic variables are expressed in euros per hour worked in constant 2000 prices**.**

	2004			2006		
	No product innovation	**Occasional product innovators**	**Serial product innovators**	**No product innovation**	**Occasional product innovators**	**Serial product innovators**
Turnover per hour worked	183	224	163	198	232	175
Innovative turnover per hour worked	-	19	41	-	14	43
Innovative expenditure per hour worked	1	4	7	1	5	6
Wages per hour worked	15	16	16	15	16	16
Exports per hour worked	56	57	75	65	62	77

Value added per hour worked	38	43	40	35	40	41
Number of firms	362	488	151	362	488	151

Source: Selection from ISTAT Panel of Italian Firms.

When we look at the firm size distribution of firms (Table A1 in the Appendix), the importance of size in innovative performances clearly emerges; firms under 249 employees account for 73% of non-innovators and for 45% only of serial innovators; firms above 1,000 workers account for 3% of non-innovators and for 14% only of serial innovators. Considering the distribution of the three groups across industries (Table A2 in the Appendix), we find that serial innovators are concentrated in sectors that the Pavitt taxonomy defines as 'science based', with some firms belonging to scale intensive and traditional sectors (Bogliacino and Pianta, 2015).

4. Innovation and performance in Italian firms

In order to explore the innovation-performance link in Italian firms, a preliminary analysis has to include all the three types of firms considered, comparing the different relationships that emerge in each of them. A first investigation has to focus on the determinants of overall economic performance, proxied by total turnover per hour. The equation we use is the following:

$$Turn_{it} = \alpha_0 + \alpha_1 InnTurn_{it} + \alpha_2 \pi_{it} + \alpha_3 w_{it} + \varepsilon_{it} \quad (1)$$

The key variables we consider in order to explain total turnover include:
1) innovative performance, captured through innovative turnover, which documents the market success of innovation and growth through technological competitiveness;
2) overall efficiency, resulting from investment, organisation, etc., captured through hourly productivity;
3) workers' skills, competences and efforts, reflected in wages - in an efficiency wage perspective - and proxied by hourly wages (Shapiro and Stiglitz, 1984). At the same time, however, wages could have a negative effect on turnover when firms rely on lower labour costs for their strategies of price competitiveness.
We also include in the regression the number of hours worked as a proxy of firm size and industry dummies to account for key dimensions of heterogeneity. [8]
It is well known that at the micro level demand is not a constraint to the growth of firms, as a company can grow at the expense of competitors through business stealing. This is one of

[8] In preparing the panel for the econometric investigation, a few firms with extreme data in some variables have been excluded. Thus, the number of observations has been reduced to 981 for each of the three periods considered (148 serial innovators, 478 occasional innovators, 355 non innovators).

the main difference with the industry level analysis à la Bogliacino and Pianta (2013a), where the expansion of sectoral demand is a necessary condition for allowing the positive link between innovation and performance to emerge.

At the firm level, however, we may find different strategies in terms of innovative efforts, mechanisms of productivity growth, extent of outsourcing, quality of labour employed; our assumption is therefore that such relationships can be different across the three groups of firms described in Table 1 above.

For non-innovators, the variable on innovative turnover is always zero and the engines of turnover performance lie in other factors. Therefore, we first estimate a selection equation on the innovation status (a dummy equal to one if the firm is either occasional or serial innovator, and equal to zero if the firm is a non innovator). Then we run the regression of equation (1) excluding non-innovators from the analysis; for occasional and serial innovators we expect that different relationships may emerge and therefore we estimate separate coefficients.

In the probit regression of the selection equation we use as a key instruments the size class of employees, together with industry dummies; results are shown in Table A3 in the Appendix. From such equation we compute the inverse Mills ratio in order to include such new variable among the determinants of total turnover in equation (1); in this way we control for the sample selection bias due to the exclusion of non innovators. The lack of significance of the inverse Mills ratios implies that we cannot reject in this case the hypothesis of lack of sample selection bias. Results are shown in Table 2 below.

Table 2. The determinants of total turnover per hour worked.

Dependent Variable: Total turnover per hour	
Innovative turnover per hour worked (Serial)	0.32 (0.11)***
Innovative turnover per hour worked (Occasional)	0.07 (0.05)
Value added per hour worked (Serial)	1.25 (0.32)***
Value added per hour worked (Occasional)	4.08 (0.19)***
Wages per hour worked (Serial)	8.16 (1.25)***
Wages per hour worked (Occasional)	3.37 (0.88)***
Worked Hours (Serial)	0.00 (0.00)
Worked Hours (Occasional)	0.01 (0.00)***
Sectoral dummies	Yes
Inverse Mills ratio	-25.94 (34.44)
Constant	-69.36 (16.04)***
R^2	0.48
Chi^2	794.64***

No. Obs.	1252

Source: Selection from ISTAT Panel of Italian Firms (serial and occasional innovators).
*, **, *** stand for significance at 10, 5 and 1 percent. Dependent variable is the total turnover per hour. The inverse Mills ratio is calculated from a selection equation where the identification variable is the class of employees (other controls includes hours worked and the Pavitt dummies, with suppliers dominated as omitted category). Results of the selection equation are reported in Appendix, Table A3.

The structure of the coefficients obtained clearly shows a fundamental difference in the determinants of turnover between occasional and serial innovators. Persistent innovators are characterized by a strong and significant role of innovative turnover – which is not significant for occasional innovators. Wages play a positive role in both groups, but the coefficient for serial innovators is more than twice the one for occasional innovators; as expected, this result reflects the higher skills and competence of workers employed by serial innovators. Conversely, occasional innovators show a much higher coefficient for hourly productivity levels that accounts for overall efficiency, possibly rooted in the introduction of new processes, organisational factors, and a greater reliance on outsourced production. Finally, there is a significant scale effect captured by total hours worked in the case of occasional innovators, possibly showing the presence of firms benefitting from a higher degree of market concentration.
From these findings we can conclude that occasional and serial innovators are rather different types of firms, with different sources of growth and innovative dynamics. Innovative turnover appears to play a role for serial innovators only, while for occasional innovators the link between innovation input and output is weaker.[9]
Starting from this evidence, in the rest of the article we focus on serial innovators in order to investigate in depth the innovation-performance relationships using the simultaneous three equation model we propose.

5. The three equation model

5.1. The model

The model we propose here is an extension of the one developed in Bogliacino and Pianta (2013a) where a simultaneous three equation model is estimated - at the industry level - linking innovation inputs, innovation outputs and economic performance, considering the presence of cumulative processes and feedback loops. The model has been tested on 38 manufacturing and service sectors of eight European countries and two time periods. Extensions of the model have been provided by Bogliacino and Pianta (2013b) and Guarascio et al. (2015, 2016). The interest of replicating a similar model at the firm level is in the identification of patterns of coherence at different level of aggregation and in the

[9]The same distinction between the determinants of serial and occasional innovators has been tested using a regression with an endogenous switching model. Results do not change qualitatively but in this case they are not robust because our main identification restriction (the variable class of employee) is not significant. Results are available from the authors upon request.

possibility to identify the role of different groups of firms in shaping aggregate patterns. If the same relationships are found at the industry and at the firm level, we can argue that the most dynamic firms - hence the focus on serial innovators - collectively drive the process of structural change detected at the industry level, through similar same cumulative processes, lags and feedback loops, lending support to an evolutionary view of the mechanisms of change in our economies.

The model we propose for investigating the 'virtuous circle' of innovation in firms is the following:

$$\begin{aligned} Turn_{it} &= \alpha_0 + \alpha_1 InnTurn_{it} + \alpha_2 \pi_{it} + \alpha_3 w_{it} + \varepsilon_{it}^1 \\ InnTurn_{it} &= \gamma_0 + \gamma_1 InnExpend_{it-1} + \gamma_2 Export_{it} + \varepsilon_{it}^2 \\ InnExpend_{it} &= \beta_0 + \beta_1 InnExpend_{it-1} + \beta_2 Turn_{it} + \beta_3 w_{it-1} + \varepsilon_{it}^3 \end{aligned} \qquad (2)$$

where i and t are the index for firms and time respectively; *Turn* is the total turnover per hour worked, *InnTurn* the innovative turnover per hour; *InnExpend* is the innovative expenditure per hour; π is labour productivity per hour, w is labour compensation per hour.[10]

The first equation – already described above – identifies the determinants of total turnover, including innovative turnover, productivity and wages.

The second equation explains the innovative performance of firms, proxied by innovative turnover. Independent variables include lagged innovative expenditure, accounting for total innovation inputs; export intensity, a variable that includes the demand pull effect of exports on innovation success and the importance of larger markets for exploiting innovative capabilities and dynamic increasing returns (Kaldor, 1981, 1972).

The third equation considers the determinants of innovative expenditure, a measure of the overall innovative efforts. They are a function of:

1) Lagged innovative expenditure, that reflect the cumulative nature of technological change in firms, capturing technology push effects and the path dependence nature of innovation (Mowery and Nelson, 1979);

2) Total turnover that reflects, indirectly, the demand pull effect on technological efforts (Piva and Vivarelli, 2007; Kleinknecht and Verspagen, 1990; Schmookler, 1966);

3) Wages, which are associated (possibly with a lag) to higher innovation through two effects: on the one hand, higher wages are related to higher skills of workers, reflecting knowledge that is complementary to innovative efforts in firms; on the other hand, higher wages may induce greater effort for labour saving innovation through a Ricardo-Sylos Labini effect (Ricardo 1919; Sylos Labini, 1984).[11]

[10] The variables considered in the model are the ones presented in the data section; we remind here that all variables are normalized through the number of hours worked in order to account for different size of firms.

[11] We have also controlled for the role of firms' market power using a version of the Herfindal index, calculated on the basis of firms' turnover in relation to the turnover of the

In addition, in all three equations we consider a proxy for firm size the number of hours worked - and we control for industry dummies. The error term is in standard components form, i.e. including both time invariant and time variant part.
The system in (2) can be consistently estimated by OLS if the regressors satisfy strict exogeneity (Wooldridge, 2002). By strict exogeneity we mean that the expected value of the error term conditioned on both lags and leads of the regressors should be zero. In other words, the introduction of a panel structure requires (for OLS to be unbiased) not only the standard exogeneity requirement but also that there are no feedback effect.
The identification assumption is very unlikely to be satisfied for two reasons: 1) the regressors may be correlated with the time invariant component of the error (violating exogeneity); 2) since we have cross equations restrictions with a lag structure, feedback effects are very likely.
As shown by Wooldridge (2002) and Arellano and Bond (1991), once we transform the data through First Differencing, we eliminate two sources of problems: on the one hand we eliminate the time invariant part of the error component term; on the other hand we eliminate the feedback effect and we can identify the effects of the regressors if they are predetermined. As a result, we first differentiate the data and then we run two stages least squares. We estimate the system jointly to increase efficiency of the estimates. The number of observation is reduced since we use only variation from one wave to the other. In order to increase the number of instruments, we include also the second lag of all the variables in level and the industry dummies. Using the variable in levels as instrument for the change is the standard practice in GMM estimation, thus our methodology is very robust.
Results are reported in Table 3; additional tests have been carried out considering a Within Group estimation and simple First Differences, finding the same results.
Finally, we control for the sample selection bias due to the exclusion of occasional and non innovating firms, using again a selection equation on the innovation status of firms (the dependent variable is a dummy equal to one if the firm has introduced a product innovation in all three innovation surveys). The results of this regression are shown in the Appendix in Table A4; again, firms class size emerges as a key discriminating variable between persistent innovators and other firms. From this equation we compute the inverse Mills ratio in order to include such new variable in all three equations.

5.2. Results

The innovative 'virtuous circle' clearly appears in the results reported in Table 3. In the first equation, turnover is driven by innovative sales, productivity and wages, as discussed above. A high innovative turnover directly affects total sales, supporting firm growth and market shares. Productivity and wages also support sales growth through greater efficiency and complementarities with workers' skills.
In the second equation, innovative turnover is affected by lagged innovative expenditure as well as by exports. The close link between innovation inputs and outcomes is confirmed; exports show a crucial 'pull' effect on innovative sales.
Finally, in the third equation innovative expenditures are mainly the result of total turnover,

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relevant industry; the variable never emerges with a significant effect, and in any case is controlled for by fixed effect and first differencing.

which reflect the possibility to overcome cash constraints in the financing of innovative efforts. Wages do not appear to play a significant role. The cumulative nature of innovative efforts does not emerge from these results; the coefficient for the lagged innovative expenditure turns negative and significant, due to an econometric problem - fixed effects cannot estimate consistently the autoregressive term and asymptotically the coefficient is biased downwards; since we do not have enough information time-wise, we cannot apply GMM and identify correctly the autoregressive term.[12]

Table 3. The three equation model for serial innovators.

Dependent Variable	(Delta) Total turnover per hour	(Delta) Innovative turnover per hour	(Delta) Innovative expenditure per hour
(Delta) Total turnover per hour worked			0.07 (0.02)***
(Delta) Innovative turnover per hour worked	0.64 (0.16)***		
(Delta) Innovative expenditure per hour worked (first lag)		1.18 (0.45)***	-0.28 (0.08)***
(Delta) Wages per hour worked	4.28 (1.54)***		
(Delta) Wages per hour worked (first lag)			0.07 (0.26)
(Delta) Value added per hour worked	0.87 (0.24)***		
(Delta) Exports per hour worked		0.35 (0.12)***	
(Delta) Worked Hours	0.00 (0.01)	-0.00 (0.01)	0.00 (0.00)
Inverse Mills ratio	4.00 (1.92)**	-3.85 (2.22)*	0.21 (0.36)
R2	0.29	0.10	0.13
F-stat	18.91***	4.17***	4.56***
No. Obs.	148	148	148

Source: Selection from ISTAT Panel of Italian Firms (serial innovators only).
Added Instruments: industry dummies, second lag of all variables in levels.
*, **, *** stands for significance at 10, 5 and 1 percent.
First Difference estimation with two stages least squares. The inverse Mills ratio is calculated from a selection equation where the identification variables are the class of employees, the innovative turnover, the value added per hour, and the export per hour (other controls includes hours worked and the Pavitt dummies, with suppliers dominated as omitted category). Results of the selection equation are reported in Appendix, Table A4.

[12] In a preliminary test, we carried out a SURE estimation where all the above relationships are confirmed; in addition, we also find the cumulative effects of lagged innovative expenditure on current ones and the positive role of wages in driving innovative effort. The results based on fixed effects and first differences, however, do not confirm such findings.

Since this is a linear model, we can express the magnitude of the effect in percentage of one standard deviation of the dependent variable, once allowing the independent variable to vary by one standard deviation. In the turnover variable, the stronger effect is that of innovative turnover - a change of one standard deviation increases sales per worked hour by 18% of its standard deviation. Hourly wages and productivity follow in the ranking of the magnitude of the impact, with increases in sales around 8% of the standard deviation. In the second equation innovative turnover is affected by exports - a change of one standard deviation increases innovative sales per worked hour by 38% of its standard deviation – and by innovative expenditure with a 21% impact. Finally, in the third equation, innovative expenditure per hour are mainly affected by total turnover – a change of one standard deviation in sales per hour worked leads to an increase in innovative expenditure by twice a standard deviation.

6. Conclusions

This article has investigated the existence of a circular relationship and feedback loops between innovative input, output and firm performance. While these relationships have usually been investigated with a one-way approach, we have developed an integrated perspective, accounting for the complexity of links and their feedback loops, leading to a better understanding of the 'virtuous circle' of innovation.

The simultaneous model we have proposed is characterized by the following relationships. Firms carry out innovative expenditure – including R&D, technology adoption, acquisition of new machinery and other activities - on the basis of total turnover – which represents a key source of funds for innovation, reducing financial constraints. Second, innovative efforts lead to new products whose sales are also driven by exports through the role of 'demand pull'. Third, innovative sales lead to higher turnover – and improved overall performance, including profits. This 'virtuous circle' of innovation is portrayed in an original way by our model, improving on previous literature that has investigated some of these links in isolation or in a sequential way. Our model extends at the firm level the model and empirical investigation carried out by Bogliacino and Pianta (2013a, 2013b) on manufacturing and service industries for the main European countries; an extension to the innovation-competitiveness link has been carried out by Guarascio et al. (2015, 2016).

The empirical test on data for Italian manufacturing firms that have been persistent product innovators in the 2000-2006 period has shown that this 'virtuous circle' of innovation is indeed shaping the microeconomic dynamics of innovation. While the expectations of our model are confirmed, three results deserve specific consideration.

First, the circular and simultaneous relationship between innovative efforts, innovative sales and turnover success is a strong characteristic of firms that are persistent innovators. When we consider occasional innovators – i.e. firms who did not report the introduction of new products in all three CIS surveys from 2000 to 2006 – we find that innovative sales do not operate as a driver of total turnover; firms' growth appears to be rooted in other factors, including new processes, organisational change, outsourcing of production and overall efficiency improvements that are captured by productivity growth.

Second, the role of wages – that has been largely neglected in previous innovation studies – emerges with an important influence on total turnover of firms. In firms that have been regularly introducing new products – as the ones in our panel - wages cannot be considered mainly as a cost, but reflect workers' skills and competences that are necessary for the introduction of innovation and for the very growth of firms. For such firms, in fact, higher sales are driven by a technological competitiveness based on new knowledge and new products, rather than by lower costs and wages that may sustain a short-sighted strategy of cost competitiveness (Pianta, 2001). This association is strong for serial innovators and much weaker for occasional innovators, as shown in Table 2, confirming that a greater technological effort requires higher skills and workers' competences.

Third, the role of demand – again an aspect that is often neglected in the innovation literature – also emerges from our findings. As pointed out in section 2, at the firm level demand constraints are less relevant, as enterprises can grow through business stealing. Although success in innovation and exports can be driven by the same characteristics of a 'well performing' firm, our results highlight the specific role that export demand plays – with its 'pull' effect - in driving market success of new products; the role of exports in the innovative 'virtuous circle' has been further investigated at the industry level by Guarascio et al. (2015, 2016). On the empirical front, we should point out that in Italy in the period considered, exports were the only dynamic component of demand in a generally stagnating economy.

A few general lessons on the analysis of firms and industries emerge from our work. The focus on serial innovators has meant that we can explore the specific characteristics of firms that regularly carry out innovative efforts and introduce new products. Most of the innovation literature – including evolutionary perspectives - has studied the innovation process in the generality of firms, identifying the characteristics of innovative enterprises as opposed to the rest of firms. Due to the high heterogeneity of firms, ownership structures, competences and strategies, these studies have generally found weak relationships between innovation and business growth. Conversely, in our sample we focus on persistent innovators that share a systematic involvement in innovation related activities and represent the more dynamic component of manufacturing industries. Thus, in this sample we can identify the emergence of specific relationships between innovation input, output and performance.

Some lessons from this evidence may have policy implications. In Italy's case, the presence of the 'virtuous circle' we identified, means that persistent innovators in Italy pursue a strategy of technological competitiveness relying on accumulation of knowledge, development of new products and use of internal resources for R&D efforts that require high workers competences and are associated to high wages. The opposite search for cost competitiveness and labour cost reductions appears to be incompatible with the 'virtuous circle' of innovation.

Such a 'virtuous circle' requires that all its elements work effectively - knowledge and capabilities are developed; new products have market success; firms grow and profits are used to sustain innovative efforts. Failure in one of these connections means a much poorer impact of innovation or a 'virtuous circle' that may involve a rather small number of firms. These factors highlight the systemic nature of these dynamics and the importance of the national innovation system as a key policy framework for building successful relationships between innovation input, output and performance in firms.

Finally, we find that the same simultaneous and recursive model can successfully explain the innovation-performance relationships both at the industry and at the firm level. Recent literature has generally focused on micro studies, arguing for the need of micro-foundations in our understanding of economic relationships. Evolutionary approaches too have emphasised the need for micro investigations in order to account for the heterogeneity of behaviours. On the other hand, studies on sectoral technological regimes and systems of innovation have shown that industries differ in terms of innovation dynamics and growth trajectories; within an industry, firms' heterogeneity is therefore bounded by the presence of commonalities. Finally, structural change approaches have shown the importance of combining technological and demand dynamics for understanding growth and decline of industries and economies.

Such diverse concerns have rarely been addressed in a unified framework, where firms' heterogeneity could be combined with more aggregate economic and innovation dynamics. Our findings show that the 'virtuous circle' between innovation and performance is a fundamental characteristic of the dynamics of both firms and industries – in manufacturing as well as in service sectors. We could thus argue that the findings of this article provide a sort of micro-foundation to the industry-level analysis pointed out above. Conversely, the coherence with industry level findings shows that firms do not evolve along random patterns, driven by idiosyncratic characteristics, but along the trajectories charted by broader patterns of technological and structural change (Dosi, 1982, 2007).

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Appendix

In Table A1 and A2 we show some descriptive statistics on the composition of our panel considering the totality of 1001 firms.

Table A1. Firms by class of employees (average 2000, 2004, 2006) (percentages)

	Total	Non innovator	Occasional	Serial
20-49	7	9	7	5
50-249	52	64	46	40
250-499	21	17	23	25
500-999	12	7	14	17
>=1000	8	3	11	14
Totale	**100**	**100**	**100**	**100**

Table A2. Firms by sector of economic activity (percentages)

	Total	Non innovator	Occasional	Serial
Manufacture of food products and beverages	10	13	9	5
Manufacture of textiles	6	7	7	3
Manufacture of wearing apparel; dressing and dyeing of fur	3	6	2	0
Tanning and dressing of leather; manufacture of luggage, handbags, saddlery, harness and footwear	2	3	1	1
Manufacture of wood and of products of wood and cork, except furniture; manufacture of articles of straw and plaiting materials	3	4	2	1
Manufacture of pulp, paper and paper products	4	5	4	0
Publishing, printing and reproduction of recorded media	2	3	2	1
Manufacture of coke, refined petroleum products and nuclear fuel	2	4	1	1
Manufacture of chemicals and chemical products	10	5	13	13
Manufacture of rubber and plastic products	3	3	4	1
Manufacture of other non-metallic mineral products	6	6	6	5
Manufacture of basic metals	7	13	5	2
Manufacture of fabricated metal products, except machinery and equipment	8	9	8	7
Manufacture of machinery and equipment n.e.c.	11	4	11	28
Manufacture of office machinery and computers	0	0	1	0
Manufacture of electrical machinery and apparatus n.e.c.	4	2	5	9
Manufacture of radio, television and communication equipment and apparatus	3	1	3	4
Manufacture of medical, precision and optical instruments, watches and clocks	3	1	3	8
Manufacture of motor vehicles, trailers and semi-trailers	6	5	8	6
Manufacture of other transport equipment	2	2	2	4
Manufacture of furniture; manufacturing n.e.c.	3	3	4	1
Recycling	0	0	0	0
Total	**100**	**100**	**100**	**100**

In Table A3 we report the selection equation on the entire panel of firms for identifying the determinants of serial or occasional innovators. We use as instruments the size class of employees and industry dummies; firm size appears as a key determinant of the probability to introduce product innovations. Sectoral heterogeneity, caught by industry dummies, seems to be relevant.

Table A3. Selection equation: dummy for serial or occasional innovator

Dependent Variable: Serial or occasional innovator innovator =1	
Class of employees	0.26 (0.04)***
Sectoral dummies	Yes
Constant	-0.47 (0.10)***
R^2	0.10
Wald Chi^2	208.68***
No. Obs.	1962

In Table A4 we report the selection equation on the entire panel of firms for identifying the determinants of serial innovators. We use a set of instruments including the size class of employees, productivity, export, worked hours and industry dummies. Again, among the key determinants of the probability to introduce a product innovation in all the three CIS, we find a relevant role for the size of firm. Sectoral heterogeneity, caught up by industry dummies, seems to be relevant.

Table A4. Selection equation: dummy for serial innovator

Dependent Variable: Serial innovator =1	
Class of employees	0.12 (0.04)***
Hourly productivity	0.00 (0.00)
Worked Hours	0.00 (0.00)
Export per hour	0.00 (0.00)
Sectoral dummies	Yes
Constant	-0.85 (0.14)***
R^2	0.13
Wald Chi^2	208.68***
No. Obs.	1962

Source: Selection from ISTAT Panel of Italian Firms.*, **, *** stand for significance at 10, 5 and 1 percent.