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ICT, innovation, and firm productivity: New evidence from small local firms ☆

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ABSTRACT

This study analyzes new co-innovative sources of labor productivity (i.e., ICT use, human capital and training, and new forms of work organization) in small firms that produce for local markets. The study presents an application of structural equation modeling (SEM) to 2009 survey data for a representative sample of 464 SMEs in the province of Girona (Spain). Results show that wage is the main determinant of labor productivity. Furthermore, in contrast to evidence regarding larger firms, co-innovation does not directly affect small local firms' productivity. The study establishes an indirect relationship between co-innovation and productivity in firms that initiate international expansion. The study also identifies guidelines for public policy to improve productivity in small local firms.

1. Introduction: ICT, innovation, and firm productivity in the scientific literature

The widespread use of information and communication technologies (ICT) is crucial for economic activity (Jorgenson & Vu, 2007) for two reasons. First, ICTs directly increases productivity and boost economic growth (Jorgenson, Ho, & Stiroh, 2008). Second, ICTs generate complementary innovations that improve economies' total factor productivity (TFP) (Ceccobelli, Gitto, & Mancuso, 2012; Jorgenson, Ho, & Samuels, 2011).

Empirical analysis of ICT's effect on firm productivity shows that return rates on digital investment are higher than return rates on physical investment. The reason for this difference is that digital investment and use often occur alongside other endeavors, namely, human capital improvement and changes in organizational structure (Arvanitis, 2005; Bresnahan, Brynjolfsson, & Hitt, 2002; Kunz, Schmitt, & Meyer, 2011). The transformative effect of ICT investment and use on business performance becomes more apparent when firms simultaneously engage in co-innovation processes (Brynjolfsson & Hitt, 2003; Cardona, Kretschmer, & Strobel, 2013; Greenan, L'Horty, & Mairesse, 2002).

ICT investment and use improve general productivity only when firms and workers achieve the necessary technological, educational and training, organizational, business, labor, and cultural competencies. In other words, organizational and business process changes enable firms to benefit from ICT's full potential as a general-purpose technology (Arvanitis & Loukis, 2009; Timmer, Inklaar, O'Mahoney, & Van Ark, 2010).

New evidence shows the existence of co-innovative productivity sources among broad samples of firms in the United States (Atrostic & Nguyen, 2005; Black & Lynch, 2001, 2004; Bresnahan et al., 2002; Brynjolfsson & Hitt, 2003) and the rest of the world (Cardona et al., 2013; Draca, Sadun, & Van Reenen, 2007; Jiménez-Rodríguez, 2012; Matteucci, O'Mahoney, Robinson, & Zwick, 2005; Torrent & Díaz-Chao, 2014). However, scarce evidence is available on co-innovative productivity sources for small and medium enterprises (SMEs) (Audretsch, 2002, 2006; Hall, Lotti, & Mairesse, 2009; Wymenga, Spanikova, Barker, Konings, & Canton, 2012). Evidence is particularly meager in the case of SMEs that produce primarily for local markets (Díaz-Chao et al., 2013; Torrent & Díaz-Chao, 2014). Such SMEs have low degrees of openness and innovation (Drechsler & Natter, 2012).

This study bridges the research gap by examining data from a representative sample of 464 small local firms in the region of Girona (Spain). Structural equation modeling (SEM) exploits these data. SEM is capable of analyzing relationships not only between productivity explanatory factors but also among such factors. Thus, the analysis investigates the structural form explaining firm productivity and provides new findings in co-innovative productivity sources for small local firms.

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Section 2 describes the data and the research design. Section 3 presents the model and the results. Section 4 discusses conclusions and implications for innovation policy.

2. Data and research design

The study uses survey data from a sample of 464 firms operating in Girona (overall margin of error of $\pm 4.6\%$ in the case of maximum indetermination, $p = q = 50$, for a confidence level of 95.5%). The sample universe comprised 66,682 firms operating in Girona in 2009. The study took a random sample to achieve a margin of error of less than $\pm 5\%$.

A 47-question pilot questionnaire gathered data from 30 firm managers with an overall view of their companies' activities. Managers responded to pilot questionnaire items in 1-hour face-to-face interviews. By gathering data on the value chain, the study analyzed productivity sources in Girona-based firms. The fieldwork took place between June and October 2009—a period during which the current financial crisis was affecting innovation (Hausman & Johnston, 2014) and the sector in general. The Girona Observatory on ICTs, the Girona Association of New Technology Firms, and the Chamber of Commerce of Girona supported the research.

In the region of Girona, small local firms account for the majority of economic activity. These firms' structure is similar in most areas in Spain and may well be representative of Spain's SME sector. The sectors where these firms operate make low-intensity use of technology (food, metal and construction, trade, and tourism). The firms have low levels of worker training, unexploited ICT use, and productivity problems (Torrent & Díaz-Chao, 2014). Table 1 shows descriptive statistics illustrating the value generation process in the sample.

3. Direct and indirect sources of small local firms' productivity

3.1. Modeling small local firms' productivity

The research uses structural equation modeling with measurement to test how the presence of co-innovation explains Girona-based firms' productivity. Structural equation systems are formal mathematical models. They consist of a set of linear equations that encompasses various model types (i.e., regression models, simultaneous equation systems, factor analysis, and path analysis). The equation system's variables can be either directly observable measurable variables or latent (theoretical) variables representing unobservable concepts. While latent variables are continuous, observable dependent variables can be continuous, censored, binary, ordered, categorical (ordinals), or combinations of these variable types.

The general SEM model comprises two sub-models: a structural model that relates latent variables to each other and a measurement model that relates each latent variable to the respective variables measuring the model. Scholars generally use the term indicators to refer to these variables measuring the model. In this model, the basic assumption is that a causal structure between latent variables usually exists.

SEM has distinctive features that make SEM a suitable analysis tool in the current study: (1) SEM admits the explicit inclusion of measurement error in the estimation process for as many variables as necessary; (2) SEM admits simultaneous estimation of the parameters of a series of dependence relationships, whereby a variable can act as dependent in some equations and independent in others; (3) SEM can show reciprocal causes and recursive and non-recursive models; and (4) SEM is also suitable for prospective analysis with additional out-of-the-sample data.

Consistent with the most common notation among scholars (Jöreskog & Sörbom, 2004), the following system of linear structural equations formally defines SEM models:

$$\eta = \alpha + B\eta + \Gamma\xi + \zeta \tag{1}$$

where η $(m \times 1)$ and ξ $(n \times 1)$ are random vectors of latent dependent and independent variables; α $(m \times 1)$ is a vector representing the intersections of axes; B $(m \times m)$ is the matrix of coefficients of endogenous latent variables representing the effects of variables η on other variables η; Γ $(m \times n)$ is the matrix of coefficients of exogenous latent variables representing the direct effects of variables ξ on variables ξ; and ζ is a vector $(m \times 1)$, indicating the random perturbations in the equation. According to assumptions in the SEM model, $E(\eta) = 0$, $E(\xi) = 0$, and $E(\zeta) = 0$.

The vectors y $(p \times 1)$ and x $(q \times 1)$ represent the observed (measurable) variables, where p is the number of indicators of η and q is the number of indicators of ξ. The following equations relate x and y to the latent variables:

$$y = \tau_y + \Lambda_y\eta + \varepsilon \tag{2}$$

$$x = \tau_x + \Lambda_x\xi + \delta \tag{3}$$

where ε $(p \times 1)$ and δ $(q \times 1)$ are the vectors of the error terms. In this model, the assumption is that ε does not correlate with η, ξ, or δ and that δ does not correlate with η, ξ, or ε. Λ_y $(p \times m)$ and Λ_x $(q \times n)$ are matrices containing the structural coefficients λ_{ij} that relate the latent and observed (measurable) variables; τ_y $(p \times 1)$ and τ_x $(q \times 1)$ are the vectors of constant intersection terms.

The fundamental hypothesis of structural equation systems is $\Sigma = \Sigma(\theta)$, where Σ is the population covariance matrix and $\Sigma(\theta)$ is the model covariance matrix, written as a function of a parameter vector of θ. Minimizing the following function of adjustment obtains the estimation of parameters:

$$F(\theta) = F\,[S,\ \Sigma(\theta)] \tag{4}$$

After estimating the model's parameters, the next step is to compare the resulting covariance matrix to the data covariance matrix. If the difference between the two matrices is statistically acceptable or zero, the proposed SEM model represents a plausible explanation of the reality.

The application of this analysis method to productivity sources in the sample yields (1) a more complete explanatory model using multiple equations and (2) specific measurement errors for each variable. By doing so, the process will eliminate any potential problems that

Table 1
Descriptive statistics of Girona-based firms.

	Valid %		Valid %
Business sector:		Firm innovation:	
- Manufacturing and construction	26.2	- R&D department in firm	8.8
- Wholesale and retail trade	20.4	- Source of innovation: staff	86.0
- Hotels, restaurants and tourism	21.6	- Innovation in last two years	26.5
- Other market services	31.8	- Product innovation	50.4
Size of firm:		ICT use in value chain:	
- Fewer than 10 employees	95.4	- No ICT use	21.1
- From 11 to 49 employees	4.0	- Low ICT use	33.1
- 50 or more employees	0.6	- Medium ICT use	26.7
		- High ICT use	19.1
Firm ownership:		Average turnover (thousands of €):	
- Family firm	89.7	- 2008	183.5
- Business group	10.3	- 2009	165.0
Worker training:		Destination of sales:	
- Untrained or primary education	32.8	- Girona and rest of Catalonia	94.7
- Secondary education	47.3	- Spain	2.5
- University education	19.9	- European Union	2.5
- Extended education paid by the firm	8.1	- Rest of the world	0.3