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Firm Size and Sustainable Innovation: A Theoretical and Empirical Analysis

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Abstract: This paper explores the relationship between firm size and sustainable innovation in large international firms. To this end, we develop a labor demand framework. The contribution to the literature is to explore external knowledge in determining the employment impact of sustainable innovation. Our investigation is based on firms in three economic areas: Europe, Japan, and the United States. In this way, we will appreciate the extent to which the technological spillovers are important from a geographical perspective. The findings provide evidence of the significance of spillover effects on a firm's size; however, these effects depend on the spillover stock type.

Keywords: firm size; sustainable innovation; knowledge diffusion process

JEL Classification: O33; J20

1. Introduction

The analysis concerning the impact of sustainable innovation on a firm's size in terms of employment is subject to present economic debate [1–3]. Indeed, technological progress represents a quest to reduce labor costs, which is a key sustainable goal in a world of finite natural resources.

There exist many definitions of sustainable innovation in the literature. The idea used in this analysis is in line with the concept introduced by Pezzey [4]: Innovation is sustainable in the sense that the innovation process, contributing to sustainable development, assures that the consumption of the current generation is less than or equal to the maximum consumption of future generations, on the basis of the production opportunities available at present.

Thus, the investigation concerning the impact of sustainable innovations on firms' size is important with regard to increasing production opportunities. The main contribution of our analysis is that we explore the role of external knowledge in the context of sustainable innovation. Indeed, the literature lacks a comprehensive explanation of how the firms adapt their strategies after the innovations, as discussed in Cozzolino et al. [5]. Our analysis attempts to provide this by paying attention to the knowledge diffusion process.

In particular, there are studies that provide evidence of the importance of robotics on firms' size quality, as discussed in Brynjolfsson and McAfee [6,7]. We demonstrate that a reduction of the number of employees to achieve the same production level can result after sustainable innovation (destruction effect), and an increase in the number of employees produced by the new competitive context could derive from sustainable innovation (compensation effect). The effect of sustainable innovation on firm size depends also on the product or process innovation, the elasticity of the market demand of the product with respect to its price, the market power, and wage negotiation. Since theoretical and empirical work in the literature has focused on the internal firm size impact of innovation, this paper deals with the important role of international, national, inter-industry, and intra-industry spillovers in affecting firms' sizes in Europe, Japan, and the USA [8–12].

This paper is organized as follows. Section 2 provides a review of the literature concerning the employment effect of sustainable innovation. Section 3 describes the theory. Section 4 explains the methodological approach and the data. Section 5 provides the findings of the investigation. Finally, Section 6 reports and discusses policy implications.

2. Literature Review

Empirical studies exist based on the different results of sustainable innovation on firms' sizes in terms of employment [13–15].

Bogliacino et al. [16] consider the impact of innovation in developed countries. Blanchflower and Burgess [17] demonstrate the positive effect of innovation on labor. Brouwer et al. [18] and Zimmerman [19] report a negative effect. There are studies based on German data [19,20], Spanish data [21], and US data [22,23]. Other works outline positive effects of innovation in other developed economies [24–30]. In Ciriaci et al. [31] the job creation process is persistent in innovative firms. There are also empirical studies concerning developing countries [32].

Recent studies investigate the sustainability-oriented innovation process for firms' sizes [33–35]. Indeed, the development of new products or services—which contribute to economic, environmental, and social sustainability—is considered a key element of achieving sustainability. In particular, foreign direct investments help firms in the realization of their sustainable innovation strategies. Thus, this finding demonstrates that the role of the cooperation patterns between the firms is extremely important for full achievement of sustainability. Moreover, it is important to examine all channels of knowledge through absorptive capacity and cooperation, according to size and age. In this economic perspective, our paper tries to shed light on the role of the knowledge diffusion process of sustainable innovations on firms' sizes.

3. Theoretical Framework

In this section, we follow the approach in Garcia et al. [36], where a firm competes in the differentiated product market and minimizes costs. The choice of this approach is opportune for sustainability context, because the resources are finite and firms must obtain the production at the lowest cost as possible. In this way, the firms, through the sustainable innovation process, allow the use of resources by future generations [4].

We define the accumulated knowledge capital as k , and w and c are the vector inputs prices and the marginal cost, respectively. Thus, we get $c = c(w, k)$ and we denote with y the production, l the firms' sizes in terms of employment, p the output price, μ the mark-up, d^e a measure of the market dynamics, and finally, with p_R, k_R the rival output prices and firms' accumulated knowledge capital, which represent the knowledge spillovers:

$$y = y(d^e, P, P_R, k, k_R) \quad (1)$$

$$P = (1 + \mu)c(w, k) \quad (2)$$

$$l = c_L(w, k)y \quad (3)$$

$$P_R = (1 + \mu_R)c_R(w_R, k_R) \quad (4)$$

$$k_R = g(k) \quad (5)$$

where w_R, c_R, μ_R denote the inputs prices, marginal cost, and mark-up, respectively. For the other firms, c_L measures the derivative of the marginal cost with respect to employment. Once simple computations are made, Equation (4) becomes:

$$l = c_L(w, k)y[d^e, (1 + \mu)c(w, k), (1 + \mu_R)c_R(w_R, g(k)), k, g(k)] \quad (6)$$

From this equation, we can see that the short run impact of innovation on firms' sizes is:

$$\frac{\partial l}{\partial k} = \frac{\partial c_L}{\partial k} y + c_L \left\{ \frac{\partial y}{\partial k} + \frac{\partial y}{\partial p} \frac{\partial p}{\partial k} + \frac{\partial y}{\partial p_R} \frac{\partial p_R}{\partial k_R} \frac{\partial k_R}{\partial k} + \frac{\partial y}{\partial k_R} \frac{\partial k_R}{\partial k} \right\} \quad (7)$$

The first term is the displacement effect, while the second is the compensation effect.

If we consider that wages are w and decided by unions, and denote with z and z_R other potential changes we can get:

$$w = w(z, k) \quad (8)$$

$$w_R = w_R(z_R, k_R) \quad (9)$$

$$\mu = \mu(z, k) \quad (10)$$

$$\mu_R = \mu_R(z_R, k_R) \quad (11)$$

Hence, Equation (6) can be written as:

$$l = c_L(w(z, k), k) D[d^e, (1 + \mu(z, k)) c(w(z, k), k), (1 + \mu_R(z_R, g(k))) c_R(w_R(z_R, g(k)), g(k)), k, g(k)] \quad (12)$$

$$\begin{aligned} \frac{\partial l}{\partial k} = & \left[\frac{\partial c_L}{\partial k} + \frac{\partial c_L}{\partial w} \frac{\partial w}{\partial k} \right] y + c_L \left\{ \frac{\partial y}{\partial k} + \frac{\partial y}{\partial p} \left[\frac{\partial \mu}{\partial k} c + (1 + \mu) \left[\frac{\partial c}{\partial w} \frac{\partial w}{\partial k} + \frac{\partial c}{\partial k} \right] \right] + \frac{\partial y}{\partial p_R} \left[c_R \left\{ \frac{\partial \mu_R}{\partial k_R} \frac{\partial k_R}{\partial k} \right\} + (1 + \mu_R) \left\{ \frac{\partial c_R}{\partial w_R} \frac{\partial w_R}{\partial k_R} \frac{\partial k_R}{\partial k} + \frac{\partial c_R}{\partial k_R} \frac{\partial k_R}{\partial k} \right\} \right] + \frac{\partial y}{\partial k_R} \frac{\partial k_R}{\partial k} \right\} \end{aligned} \quad (13)$$

Equations (6), (7) and (13) allow us to identify the role of the knowledge diffusion process on firms' sizes, through the impact of external sustainable innovations (knowledge spillovers).

In the subsequent paragraph, we analyze the impact of R&D spillovers on firms' sizes in terms of employment.

4. Data

In our dataset, the information comes from all R&D investment scoreboards [37]. We combine the most recent scoreboard to avoid multiple counting of the same observations.

We select sales (y), the firms' sizes (l), the capital expenditures (c), R&D activity (k), and profit (op). The Industrial Classification Benchmark (ICB) measures industrial fields. The data regarding patents are selected from the OECD, REGPAT database [38] (See Maraut, Dernis, Webb, Spiezia and Guellec [39] for the methodology used for the construction of REGPAT database and please contact Helene.DERNIS@oecd.org to download it). We implement the same matching procedure as that described in Aldieri and Vinci [10]. At the final stage, we use an unbalanced panel of 879 firms from 2002 to 2010.

To compute the spillovers components (k_R in theoretical model), we follow Jaffe [40]'s technological index: The sum of R&D weighted on the correlation index between the distribution vectors of patents relative to domestic firms represents the "national spillovers" (ns); the sum of R&D weighted on the correlation index between the distribution vectors of patents relative to firms located in different countries is defined as "international spillovers" (is); the weighted sum of R&D relative to firms operating in the same technological sector is identified as "intra-industry stock of spillovers" (intra-s); and the weighted sum of R&D relative to firms in other technological fields is associated with "inter-industry stock of spillovers" (inter-s).

Because there are no available data on wages, we introduce operating profit and capital expenditures as proxies, as discussed in Bogliacino [41].

Table 1 shows the statistical features of our variables.

Table 1. Summary statistics.

Variables	Mean	Std. Dev.	Skewness	Kurtosis
All samples: 4045 observations.				
Employees (l)	37,012	62,600	3.443	17.437
Sales (y)	8.02	1.676	−0.244	3.190
Capital expenditures (c)	7.03	1.862	−0.083	2.889
Operating profit (op)	4.96	1.945	−0.011	2.908
R&D (k)	6.56	1.486	0.275	3.255
National Spillovers (ns)	11.65	0.772	−2.313	10.28
International Spillovers (is)	12.44	0.514	−1.563	8.537
Intra-industry Spillovers (intra-s)	11.86	1.146	−0.533	2.128
Inter-industry Spillovers (inter-s)	11.87	0.777	−0.089	2.327
Europe: 1467 observations				
Employees (l)	44,766	73,855	3.106	14.360
Sales (y)	8.09	1.793	−0.363	3.203
Capital expenditures (c)	7.13	2.048	−0.230	2.948
Operating profit (op)	4.77	1.791	−0.225	3.283
R&D (k)	6.44	1.762	0.073	2.814
National Spillovers (ns)	11.80	0.523	−2.056	9.989
International Spillovers (is)	12.19	0.575	−1.789	8.745
Intra-industry Spillovers (intra-s)	11.54	1.202	−0.253	1.897
Inter-industry Spillovers (inter-s)	11.87	0.777	−0.089	2.327
Japan: 1030 observations				
Employees (l)	31,735	51,163	3.523	17.881
Sales (y)	8.14	1.293	0.055	2.476
Capital expenditures (c)	7.25	1.462	0.195	2.811
Operating profit (op)	5.00	2.030	0.056	2.599
R&D (k)	6.46	1.218	0.835	3.239
National Spillovers (ns)	11.32	0.428	−0.402	2.509
International Spillovers (is)	12.80	0.325	−1.221	5.889
Intra-industry Spillovers (intra-s)	11.87	1.125	−0.382	1.941
Inter-industry Spillovers (inter-s)	12.15	0.675	−0.118	1.751
USA: 1548 observations				
Employees (l)	33,349	55,853	3.317	16.348
Sales (y)	7.87	1.777	−0.118	3.023
Capital expenditures (c)	6.75	1.814	0.100	2.681
Operating profit (op)	5.10	2.022	0.022	2.792
R&D (k)	6.81	1.357	0.543	2.948
National Spillovers (ns)	12.05	0.368	−1.474	7.590
International Spillovers (is)	12.40	0.380	−1.125	5.502
Intra-industry Spillovers (intra-s)	12.17	0.997	−0.954	3.024
Inter-industry Spillovers (inter-s)	11.72	0.747	0.335	2.386

We estimate the following equation:

$$l = (y, c, op, k, ns, is, intra-s, inter-s) \quad (14)$$

5. Methodology and Empirical Results

The number of employees is a discrete variable, and there are some large values that contribute substantially to the overdispersion. This feature makes it difficult to specify a model with a conditional mean and variance that captures the main characteristics of the data. For this reason, we estimate Equation (14) using Poisson and Negative Binomial models. In Table 2, we run the fixed-effect-Poisson (FE-POISS) estimates based on national versus international spillovers for all samples, while in Table 3 we show the fixed-effect Negative Binomial (FE-NBREG) for all samples. Akaike's information criterion

(AIC) and Bayesian information criterion (BIC) procedures are used, see Table 4, to choose the best model. Because of the lower AIC and BIC, the FE-NBREG model is preferred. In this way, we can take into account the overdispersion in the data in a more opportune way. In particular, we include time and industry dummies in the estimation methods to control the impact of shocks and sector heterogeneity for the firms.

Table 2. Firm size estimates (all samples)—Fixed Effect Poisson (FE-POISS).

Sample: 838 Firms X 9 Years—FE-POISS: Ns/Is Spillovers			Sample: 838 Firms X 9 Years FE-POISS: Intra-s/Inter-s Spillovers		
	Est.	s.e. ^a		Est.	s.e. ^a
Sales (y)	0.52 ***	(0.001)	Sales (y)	0.45 ***	(0.001)
Capital expenditures (c)	0.03 ***	(0.001)	Capital expenditures (c)	0.01 ***	(0.001)
Operating profit (op)	−0.03 ***	(0.001)	Operating profit (op)	−0.03 ***	(0.001)
R&D (k)	0.06 ***	(0.001)	R&D (k)	0.04 ***	(0.001)
National Spillovers (ns)	0.06 ***	(0.001)	Intra-industry Spillovers (intra-s)	0.12 ***	(0.002)
International Spillovers (is)	0.15 ***	(0.003)	Inter-industry Spillovers (inter-s)	0.16 ***	(0.003)

^a: *** Significance at the 1%. Time and Industry dummies included.

Table 3. Firm size results (all samples)—Fixed Effect Negative Binomial (FE-NBREG).

Sample: 838 Firms X 9 Years—FE-NBREG: Ns/Is Spillovers			Sample: 838 Firms X 9 Years FE-NBREG: Intra-s/Inter-s Spillovers		
	Est.	s.e. ^a		Est.	s.e. ^a
Sales (y)	0.36 ***	(0.016)	Sales (y)	0.39 ***	(0.015)
Capital expenditures (c)	0.04 ***	(0.007)	Capital expenditures (c)	0.02 ***	(0.007)
Operating profit (op)	−0.03 ***	(0.004)	Operating profit (op)	−0.03 ***	(0.004)
R&D (k)	0.12 ***	(0.010)	R&D (k)	0.11 ***	(0.009)
National Spillovers (ns)	0.03	(0.026)	Intra-industry Spillovers (intra-s)	0.05 ***	(0.018)
International Spillovers (is)	−0.22 ***	(0.042)	Inter-industry Spillovers (inter-s)	−0.39 ***	(0.004)

^a: *** Significance at the 1%. Time and Industry dummies included.

Table 4. Comparison based on information criteria.

	FE-POISS	FE-NBREG
Nat/Int-Spillovers		
AIC	1,662,009	45,755
BIC	1,662,100	45,858
Intra/Inter-Spillovers		
AIC	1,342,567	45,304
BIC	1,342,659	45,407

Hence, the other estimates are relative to the FE-NBREG model. In particular, Table 5 presents the findings by geographical perspective, and Table 6 shows the results using an intra/inter-industry perspective. We can observe that the output represents the most relevant determinant of firms' sizes with a significant positive effect, as expected. The effect of operating profit is negative; this leads to higher wages, and to lower firm sizes, as suggested in the empirical literature [41].

From the empirical findings, we observe that the compensation effect can be higher than the destruction one: Indeed, R&D activity produces a positive impact on firms' sizes. As far as the knowledge spillovers are concerned, international components have a negative effect on firms' sizes for American firms and a positive effect for European ones, while national spillover components produce a positive impact on firms' sizes in Japan. These findings could be explained by the higher absorptive capacity of American firms to improved productivity and finally, to the decrease in firms' sizes. The reverse idea could be applied to Japan and Europe which have lower absorptive capacities.

Table 5. Firm size estimates by geographical area—FE-NBREG.

	Europe: 316 Firms		Japan: 232 Firms		USA: 290 Firms	
	Est.	s.e. ^a	Est.	s.e. ^a	Est.	s.e. ^a
Sales (y)	0.45 ***	(0.020)	0.26 ***	(0.053)	0.37 ***	(0.029)
Capital expenditures (c)	0.01	(0.010)	0.02	(0.022)	0.03 **	(0.013)
Operating profit (op)	−0.03 ***	(0.006)	−0.02 *	(0.012)	−0.03 ***	(0.006)
R&D (k)	0.10 ***	(0.009)	0.13 ***	(0.041)	0.27 ***	(0.023)
National Spillovers (ns)	−0.01	(0.028)	0.21 *	(0.117)	0.04	(0.049)
International Spillovers (is)	0.11 **	(0.057)	−0.07	(0.146)	−0.56 ***	(0.064)

^a: ***, **, * Coefficient significant at the 1%, 5%, 10%. Time and industry dummies included.

Table 6. Firm size results due to intra-s/inter-s spillovers—FE-NBREG.

	Europe: 316 Firms		Japan: 232 Firms		USA: 290 US Firms	
	Est.	s.e. ^a	Est.	s.e. ^a	Est.	s.e. ^a
Sales (y)	0.44 ***	(0.020)	0.23 ***	(0.055)	0.37 ***	(0.029)
Capital expenditures (c)	0.01	(0.010)	0.02	(0.023)	0.02	(0.013)
Operating profit (op)	−0.03 ***	(0.006)	−0.01	(0.011)	−0.02 ***	(0.005)
R&D (k)	0.09 ***	(0.009)	0.12 ***	(0.042)	0.24 ***	(0.023)
Intra-industry Spillovers (intra-s)	0.14 ***	(0.023)	−0.03	(0.107)	−0.04	(0.032)
Inter-industry Spillovers (inter-s)	−0.10	(0.062)	−0.18	(0.187)	−0.59 ***	(0.063)

^a: *** Significance at the 1%. Time and Industry dummies included.

Moreover, in the same vein, inter-industry externalities have a negative effect on firms' sizes for American firms, and intra-industry spillovers have a positive impact in Europe.

The results demonstrate the key role that competitive firms have with regard to the potential to help the economies to sustain firms' sizes in terms of employment in crucial periods of time, such as during a worldwide economic crisis. The novelty of this analysis for policymakers' industrial strategy is to outline not only the relevant impact of their own innovation [31], but also the existence of a complex structure for the transmission of external innovation through knowledge spillovers. We cannot distinguish between process and product innovation because of the lack of available data. Thus, future research could examine, in depth, this important aspect of firms' industrial organization.

6. Conclusions and Policy Implications

The paper explores the interaction between R&D activity, spillovers, and firms' sizes in terms of employment. The analysis is based on 879 firms from 2002 to 2010 in Europe, Japan, and the USA. The findings outline the significant role of spillover effects on firms' sizes.

This paper confirms both the impact of the internal effects of innovation on firms' sizes, and the external effects due to technological spillovers. For this reason, industrial policy that favors these industrial mechanisms should be supported.

Indeed, adequate policy responses could become important instruments to sustain the effects of innovation on firms' sizes. Firstly, skill levels are closely related to inequality because technological change increases the demand for skilled employment, so it seems essential to invest in education [42].

Secondly, fiscal measures should encourage investments in R&D to obtain the competencies relevant for full competitiveness in the long-run, as discussed in Peneder [43].

Finally, policymakers are likely to face some challenges due to the development of labor markets and the increasing flexible work structure, as requested by the markets.

These industrial strategies towards innovation are important in terms of sustainability, because on the one hand, firms can minimize the costs in such a way that the production is as efficient as possible, and on the other hand, the sustainable innovation allows them to achieve more production opportunities for future generations.

However, the research should be further analyzed. Indeed, we cannot distinguish between process and product innovation impact on firms' sizes. Thus, we could not analyze the extent to which our results are robust with respect to previous technological taxonomy. Moreover, with a wider scope, we could analyze what happens after crises.

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