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Eco-innovation in manufacturing: Drivers and complementarity

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Outline

- Complementarity as a dimension and augmenting factor of eco-innovation
- Research hypotheses on (a) Drivers of EI and (b) complementarity
- Application: 556 manufacturing fims in Emilia-Romagna (Italy), dataset from direct survey
- Tests on EI drivers
- Tests on complementarity

Preliminary

- Available definitions (e.g. MEI): ‘eco’ attributes of single processes, products and methods that are new to the adopting agent, to be evaluated on technical and ecological grounds
- BUT: Substantial *economic and behavioural dimension*: limited specificity of EI
- Reconciling techno-ecological measures with the behavioural-economic dimension
- What can we gain from the complementarity perspective?

Preliminary: Kinds of complementarity

- Technical jointness: impure public goods
- EMS as EI clustering: organisational innovation with technological implications
- Strategic EI: firms tend to pursue *together* intended eco-innovations that
  - can be *disjoint* on technical grounds, and
  - are not necessarily part of holistic eco-management/responsibility systems
- ***Firm and its strategy the unit of reference: 'eco-innovators' and eco-innovative business models: Why and how?***

Preliminary: Literature

- Complementarity little addressed so far in eco-innovation applied literature (Mazzanti and Zoboli 2009): beyond firm size and sector
- Complementarity: interdependency and coordination for resource, such as knowledge, factor endowments and policy
- Firm specific attributes (Teece 1996): asset specificity regarding firm inputs and/or innovations, which may generate idiosyncratic (non-replicable) organisational frameworks, leading to higher performance
- Complementarity as a non-transferable and non-modular intangible asset (Langlois, 2002)
- Embeddedness: Systems of SMEs and Industrial Districts: networking as internal to firm's socio-technical system, which impacts its behaviour (Smith et al., 2005): "*the relevant variable is not firm size, but degree of integration and the strength of links*" (Nooteboom, 1999, p.143).

Approach and research hypotheses

- **First step:** is to assess the role of main drivers of eco-innovation adoption) (policy related costs; environmental R&D; EMS schemes; networking activity, otherswith innovation, when taken separately.
- **Second step:** to verify whether the effect of such drivers is characterised by some degree of complementarity or if such drivers are substitutes the one another

First level: drivers

- Reduced form of 'Knowledge production function' (Griliches, 1979):

- $INN_{i,t} = \beta_0 + \beta_{1,t}$(structural firm features) + $\beta_{2,t}$*(environmental R&D)* + $\beta_{3,t}$*(eco-auditing)* + $\beta_{4,t}$*(policy related costs)* + $\beta_{5,t}$*(innovation networking)* + $\beta_{6,t}$*(environmental policy proxies)* + $\beta_{7,t}$*(techno-organisational innovation)* + $\beta_{8,t}$*(industrial relations)* + e_i

- Dependant variable INN is an index of the adoption of the different eco-innovations by firm i

The set of research hypotheses	
Drivers of Innovation adoptions	
H1. Policy induced costs	Policy related costs may induce more innovation
H2. EMS/eco-auditing	Eco auditing may be positively correlated to eco innovations, though insignificant links are not to be excluded
H3. Environmental R&D	R&D should drive stronger innovation adoptions
H4. Networking	Networking may positively correlate with innovation, jointly or separately from R&D effects
H5. Industrial relations	Industrial relations may either spur eco innovations or brake it, depending on the "quality" and content of firm-unions relationships
H6. Other innovation practices	Positive correlation may expected, though eco innovations could crowd out other dynamics in the short run

Second step: complementarity

- Hypothesis [*Hc1*]: complementarity in innovation adoption: correlation between adoption in specific areas, e.g. emission, energy, waste, material. *Expectation: more innovative firms jointly adopt different eco-innovations*
- Hypothesis [*Hc2*]: complementarity bwtween innovation drivers, e.g. between voluntary auditing schemes and policy-driven costs and firm strategy on R&D.
  - (H1) and (H2) consistent with Smith et al (2005), Geels (2004), Geels and Schot (2007)

Complementarity assessment	
Hc1. Innovation adoption (output level)	**Joint adoptions of different eco innovations is expected**
Hc2. Innovation drivers (input level)	**Complementarity is likely to characterise medium small firms innovative behaviour, but is to be tested case by case**

Second step: complementarity

Three methodologies to test complementarity:

- 1. Correlation between two or more variables, controlling for other factors (bivariate or multivariate probit model) (Galia, Legros, 2004b; Laursen, Mahnke, 2001)
- 2. Reduced form approach (Arora, 1996): two factors and their correlation through interaction terms (Athey and Stern, 1998)
- 3. "Productivity approach": estimation of an objective function, i.e. production function or an innovation function (Laursen and Foss, 2003; Brynjolfsson, Hitt, Yang, 2002)
  - 3.1. testing the significance of interaction variables
  - 3.2. within a discrete framework: complementarity holds if (11) + (00) ≥ (01) + (10), where (11) is the state of the world witnessing the presence of both factors (innovation drivers) (Milgrom and Roberts 1995, Amir 2005, Monhen and Roller 2005)
  - *Or: In presence of two factors, complementarity holds if and only if (11) - (10) ≥ (01) - (00), that is the "incremental value" of a strategy that moves from one factor to two factors is higher than the value of a strategy which adds one driver starting from the state (00)*

Descriptive: Dataset

- Interviews to 556 manufacturing firms in Emilia Romagna (Northern Italy), 2009
- Sample: 13,7% of total m. firms (>20 employees)
- NACE sectors DA to DN
- Specialization: 223 firms in sector DK-DL-DM (machinery and equipments and transport)
- Dataset on eco-innovation: Section 5 of a survey on: structural features, performance, productivity, employment, investments, general innovation, internationalisation, response to crisis, etc.

- Questions on eco-innovation:
  - adoption (yes/no) of eco-innovations in 2006-2008,
  - aims or pursued benefits of eco-innovation adoption (CO2 abatement, pollution abatement, energy/material saving)
  - adoption of EMS systems (EMAS, ISO, others),
  - investments of own economic resources in eco-innovation (R&D, specific equipments, clean technologies),
  - motivation of eco-innovation (legislation compliance, market demand, expected policy developments, expected change in demand)
  - adoption of eco-innovations during the crisis.

Descriptive: Eco-innovation (adoption)

- Share firms adopting eco-innovations: 20% of total number (weight of machinery/equipments/transport)
- Firm size: good predictor of adoption rate: Firms over 100 employees adoption rates double than firms between 20 and 99 employees (similar to Mazzanti e Zoboli 2009; Johnstone, 2007)
  - Applies also to adoption rates for EMS and ISO_{14001}, and environmental R&D investments.
- Sectors: higher than the average (28%-32%) in sectors DD-DE-DN, DF-DG-DH, DI, DJ.
  - EMS led by sector DI ('district-level environmental certification' in ceramic tiles industry)
- Environmental R&D led by sectors DF-DG-DH, DI and DJ

Descriptive: Eco-innovation (adoption)

- **Aims, i.e. abatement of CO_2, of pollutants (PM, NMVOC, SOx, NOx), efficiency for materials and energy:**
  - Firm-size matters, with the exception of air pollutants
  - CO2-aimed innovations: only firms in DI e DJ above 20%
  - Energy/material saving: 15% of total firms, 26% of larger firms

- **Motivations:**
  - Mostly response to environmental legislation/regulation or market factors
  - Half of innovating firms try to *anticipate* future legislations, e.g. EU '20-20-20 strategy', and to fit with *expected* demand developments ('CSR oriented strategy',)
  - 'CSR oriented strategy'correlated with firm size in sectors DD-DE-DN

Results step 1: Drivers of EI

Empirical determinants of environmental innovations: Probit models

	ENVIR. INNOV.		CO_2		EMISSIONS		EMS		ISO14001	
	Coeff.	*t-values*	*Coeff.*	*t-values*	*Coeff.*	*t-values*	*Coeff.*	*t values*	*Coeff.*	*t-values*
• R&D	0.205	0.42	0.414	1.18	0.018	0.46	-0.002	-0.48	-0.03	-0.77
• Share of sales on the domestic market	-0.000001**	-3.02	-0.000005**	-4.08	-0.000006**	-4.18	-0.00002	-0.73	-0.00005**	-2.21
• Cooperation with universities	0.276**	2.52	0.178**	2.52	0.240**	2.97	0.010*	1.79	0.217**	3.08
• Cooperation with suppliers	0.266**	4.01	0.159**	3.63	0.198**	3.80	-0.002	-0.46	0.185**	4.27
• Foreign ownership	0.110**	1.92	0.072*	1.76	0.052	1.10	-0.002	-0.77	0.085**	2.06
• District effect	0.023	0.65	0.033	1.29	0.031	1.18	0.007**	2.21	0.007	0.30
• 20-49 empl.	Ref.	Ref.	Ref.	Ref.	Ref.	Ref.	Ref.	Ref.	Ref.	Ref.
• 50-99 empl.	-0.008	-0.19	-0.0002	-0.01	-0.037	-1.01	-0.005	-1.29	0.044	1.19
• 100-249 empl.	0.120**	2.10	0.067	1.53	0.108**	2.23	0.006	1.12	0.184**	3.63
• 250 empl.	0.071	1.08	0.032	0.65	0.048	0.89	0.017*	1.76	0.110*	1.90
• Industry dummies	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Pseudo-R^2	0.120		0.133		0.145		0.184		0.181	
N. Obs.	520		520		520		520		520	

** significant at the 5%; * significant at the 10%

- *ESTIMATION METHOD: we use dprobit. dprobit fits maximum-likelihood probit models and is an alternative to probit. Rather than reporting the coefficients, dprobit reports the marginal effect, that is, the change in the probability for an infinitesimal change in each independent, continuous variable and, by default, reports the discrete change in the probability for dummy variables;*

Results step 1: Drivers of EI

- **Share of sales on the domestic market** : almost always negative and statistically signficant: EI more in internationalised firms

- **Foreign ownership**: dummy =1 if foreing onwership (incoming FDI). More eco-innovative firms are controlled or participated by foreign firms
  - Hypothesis to be tested: are they EI-active before or after foreign control/acquisition?

- **Cooperation with universities**: dummy =1
- **Cooperation with suppliers**: dummy =1
- Both variables have positive sign and are generally statistically signficant, suggesting a role of innovative cooperation

Results step 1: Drivers of EI

- **Environmental R&D**: never statistically significant
- **District effect**: dummy =1 if firm is located in the provinces of MO, RE, BO, where specific Industrial Districts are located: Signficant only in the caso fo EMS adoption
- **Size Dummies**: always significant the estimate for the dummy = 100 - 249 employees: Medium firms seem to be the most EI active
- **Sector Dummy**: the sector is generally relevant

Results step 2: Complementarity

2.1. Correlation between eco-innovations (adoption)

- Strong correlation between different of eco-innovations, i.e. energy efficiency, materials, CO2, pollutants, EMS/ISO, R&D
  - Generally above 0,70, peak 0,80 between CO_2 and air emissions ('technical jointness')
  - Stronger in sectors DI, DJ
- Low correlation (0,23) between EMS and $ISO_{14001:}$ substitutes the one another?
- Environmental R&D strongly correlated with adoption, in particular materials and energy EI

Correlations between eco-innovations adoption (firm level)

	Material/energy	CO_2	*Pollutants*	Summary index Proc/prod innovation (env.)	*EMS*	*ISO*	Index organisational innovation	Environmental R&D
Material/energy	1							
CO_2	0.787	1						
Pollutants	0.737	0.795	1					
Summary index Proc/prod innovation (env.)	0.916	0.930	0.917	1				
EMS	0.322	0.342	0.302	0.349	1			
ISO	0.687	0.628	0.709	0.734	0.233	1		
Index organisational innovation	0.715	0.657	0.704	0.753	0.584	0.860	1	
Environmental R&D	0.792	0.684	0.734	0.802	0.240	0.663	0.681	1

Results step 2: Complementarity

2.2. Complementarity in driving eco-innovation adoption

- *If and how the usual drivers of an innovation function (general R&D, innovation cooperation, etc.) can influence EI*
- *If and how the 'CSR oriented strategy' can favour a higher rate of EI adoption*

- Strong complementarity between overall '**resources invested in innovation'** and **'technological cooperation'** in influencing the **index of overall eco-innovation**: The innovation index is higher when both drivers are above the average
  - However, innovative cooperation weights more that internal R&D: If both are intensively present together the index of eco-innovation is 0.22 (the average is 0.16), but when cooperation is very high alone the index is 0.27

Technological cooperation, economic resource for innovation, and eco-innovation

Variable: Average of prod/prod eco-innovation index	Economic resources for innovation		
Technological cooperation	0	1	Total
0	0.064	0.088	0.073
1	0.273	0.224	0.241
Total	0.114	0.159	0.134

Results step 2: Complementarity

- Dependent variable: Innovation process/product
- Strong and expected complementarity between resources invested in R&D and all other inputs
- Table: cooperation for innovation joined to other factors
- A significant complementarity emerges with organizational innovation.

Complementarity between economic resources for innovation and other drivers

Index of environmental process/product innovation					
	CSR strategy	Demand driven innovation	Policy driven innovation	Organisational innovation (env)	Environmental R&D
Economic resources for innovation	Yes	Yes	NO	Yes	Yes
Cooperation for innovation	Yes	Yes	Yes	Yes	Yes

Results step 2: Complementarity

- Complementarity between (a) the adoption of 'CSR strategies' together with resources invested in R&D and (b) cooperation for innovations
- Only for radical innovations (product) CSR strategies joined with high R&D intensity and networking/cooperation bring to higher innovation adoption

Radical innovations and complementarity between CSR, cooperation for innovation, and economic resources for innovation

Average index for radical product innovation	Economic resources for innovation		
CSR	0	1	Total
0	0.056	0.145	*0.095*
0.5	0.035	0.167	*0.097*
1	0.063	0.270	*0.180*
Total	*0.055*	*0.157*	*0.101*
Average index for radical product innovation	Innovation cooperation		
CSR	0	1	
0	0.068	0.154	*0.095*
0.5	0.069	0.111	*0.097*
1	0.045	0.237	*0.180*
Total	*0.068*	*0.159*	*0.101*
Average index for radical process innovation	Innovation cooperation		
CSR	0	1	
0	0.048	0.106	*0.066*
0.5	0.069	0.125	*0.106*
1	0.106	0.173	*0.153*
Total	*0.051*	*0.117*	*0.075*
Average index for radical process innovation	Economic resources for innovation		
CSR	0	1	
0	0.049	0.089	*0.066*
0.5	0.070	0.147	*0.106*
1	0.104	0.190	*0.153*
Total	*0.053*	*0.101*	*0.075*

A note on EI and firm performance during the crisis

- The performance during the crisis of eco-innovating firms in 2006-2008 is better that those not eco-innovating
- Having invested in environment did not weaken the firms in front of the crisis: it might have made it more economically resilient to shocks

Economic performance of firms adopting and not adopting eco-innovations in 2006-2008

Variable: **Economic performance indexes**	**Overall performance 2009 Q1**	**Performance during crisis**	**Overall performance 2006-2008**	**Productivity 2006-2008**	**Employment 2006-2008**	**Profits 2006-2008**
Firms adopting at least one eco-innovation (process/product, EMS, ISO)	0,400	0,609	0,659	0,614	0,586	0,550
Firms not adopting eco-innovations	0,406	0,568	0,614	0,575	0,567	0,526

Conclusion

- Eco-innovation: embedded in firms' characteristics and business vision, influenced by embeddedness in (local) production environment
- SMEs highlight the relational dimension of eco-innovation: cooperation with other actors of the local production system or the reference production chain
- Dichotomous firm models
  - Firms below and above 100 employees have very different rates of adoption of all kinds of EI
  - Completeness of eco-innovation strategy increasing with size
  - Degree of internationalisation able to explain higher eco-innovation attitudes, even for small firms (another element of embeddedness)

Conclusion

➔ On complementarity

- Couples of eco-innovations and firm features (states 00; 10; 01; 11) tested for augmenting or reducing the performance of an indicator

- **In general, complementarity hypotheses (Hc1 and Hc2) hold, but ...**
- (Hc1): High correlation at the firm level between adoption of different kinds of eco-innovations
- (Hc1): Simultaneous couples of factors (11) has positive effects on eco-innovation: States (11) are always better than states (00)
- However, (11) not always better than (10; 01); complementarity does not always hold according to test (11) + (00) ≥ (01) + (10)
- In some cases, (00) is superior to (10), e.g. 'no CSR' and 'no cooperation' is superior to 'CSR' alone or (10)

- *Intuitively: one input generally better than none, and there are cases in which none input is better than one, but two joint inputs are generally better than one, with exceptions ……*

Conclusion

Implications:

- ***Eco-innovating firms,*** instead of single eco-innovations, can be a meaningful unit of analysis of eco-innovation
- SMEs in local system of production show the demarcation line between non eco-innovation (or no innovation at all) and different stages of an eco-innovation strategy.
- Firms either do not adopt EIs or adopt them in combinations increasingly dense and self-consistent
- Even in the more simple firms settings, eco-innovation is not disjoint from other features of the firm