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Complementarity between environmental efficiency and labour productivity in a cumulative growth process

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The aim of this paper is to analyse the potential complementarity between environmental efficiency and labour productivity in a cumulative growth model, which in this paper is called 'efficiencies complementarity'. Environmental efficiency is defined as the ratio between income and pollutant emissions, and its growth rate may be a proxy of eco-innovations. Eco-innovations are defined as the innovations able to "reduce the environmental impact of an organisation in terms of resource use and environmental loads" (Mazzanti and Zoboli, 2008, pp. 18-19). As in a Post-Keynesian standard approach, the growth rate of labour productivity is the proxy of innovations (e.g. Sylos Labini, 1984).

The centrality of innovation for analysing the sustainability of development is in line with the classical-Keynesian idea of technological progress as a central factor for all main aspects of economic development. By contrast, the neoclassical analysis of environmental issues mainly examines the scarcity and utility of natural resources, in keeping with its general view of the economic system (Schefold, 1985; Roncaglia 2003).

The paper follows the classical-Keynesian view of the relationship between environmental issues and economic growth, according to which the environment is "an element to be kept in mind when considering the possibilities for both economy and society to survive and prosper over time" (Roncaglia, 2003). On the contrary, within to the neoclassical approach

> "the environment is seen as setting limits to the possibilities of growth […], it implies renouncing expansionary dreams, in particular the dream of overcoming word poverty by presently underdeveloped countries

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> catching up to the production and living standards of industrialized countries" (Roncaglia, 2003, p. 653).

Consequently, the paper proposes a theoretical framework to ground political initiatives aimed at coping with both the environmental crisis and the economic crisis by means of an overarching strategy, one different from the mainstream view based on the conflict between the social goals of economic growth and environmental sustainability.

Extant literature mainly focuses on the complementarity of efficiencies on a micro level within firms' strategies. However, the investigation of the role of efficiencies complementarity within a macroeconomic growth process is interesting too, since on one hand labour productivity increases are a fundamental factor in technological progress, competition and economic growth and, on the other hand, environmental efficiency is a crucial element of ecological sustainability. In fact, considering the green identity

$$H = \frac{Y}{\left(Y/H\right)}$$

where *H*, *Y* and $\left(Y/H\right)$ are the levels of pollutant emissions, income and environmental efficiency respectively, the decrease of pollutant emissions should involve the efficient use of resources, and most notably an increase in environmental efficiency. At policy level, the promotion of efficiencies complementarity represents a win-win strategy for both the environment and the socio-economic system. This is in line with "Europe 2020", the EU's strategy to exit the economic crisis based on three mutually reinforcing pillars: smart, sustainable and inclusive growth.[1]

The structure of the paper is the following: first I will analyse the theoretical elements that justify the positive correlation between the two efficiencies; second, through a Structuralist-Keynesian baseline model, I will illustrate how this complementarity is a necessary condition to have cumulative growth that is socially and ecologically sustainable; finally, I will verify this complementarity with a dynamic panel analysis for European countries covering the period 1992-2012.

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[1] For a general theoretical and empirical analysis of the potential virtuous circle among innovation, sustainability and inclusion according to a Structuralist-Keynesian perspective, see Guarini *et al*. (2014).

1. Efficiencies complementarity

According to the economic literature, there may be complementarity between eco-innovations and innovations, namely between environmental efficiency and economic efficiency, where the latter is measured by labour productivity.

Eco-innovations, like (all) innovations, may be classified into three types, according to how they relate to firms' product, process and organisation. There are two kinds of process eco-innovations. The first are the end-of-pipe technologies, which reduce pollution by inserting technical apparatus at the end of a production process (such as filters, dust removal techniques or desulphurisation equipment). The second type are cleaner production technologies, which reduce pollution by transforming the production process (ranging from the optimisation of processes and switching to less-polluting raw materials and fuels, to the replacement of coolants, encapsulation of equipment and strict dosage of chemicals in use: see Oltra, 2008; Hammer and Lofgren, 2010).

The main explanation of efficiencies complementarity is the principle of the 'dual externality' (or 'double externalities') of eco-innovations. They have a twofold effect in terms of externalities: on one hand they reduce pollution, namely they decrease a negative externality; on the other hand they generate, as does any type of innovation, new knowledge that is a public good, namely they produce a positive externality (Johnstone *et al*., 2010). These 'green' spillovers may concern R&D activities and they may refer to firms, regions and countries (Jaffe *et al*., 2003; Rennings, 2000).

Furthermore, complementarity may be derived from dynamic economies of scale. Indeed eco-innovations, like normal innovations, are characterised by learning processes, technological capability and cumulativeness (Horbach, 2008). Moreover, complementarity concerns the 'economies of scope' among cleaner technologies and 'normal technologies' (Johnstone *et al*., 2008). Indeed, the former change the production process by involving the quantity and quality of capital intensity and thereby they may induce an increase in labour productivity.

Eco-innovations can be introduced trough new machinery that fulfil new environmental normative and this may increase both labour productivity and environmental efficiency. Normal organisational innovation may positively influence the eco-innovations, which often need changes made to the management of the productive process

(Horbach *et al*., 2012). Thus, according to Collins and Harris (2005), due to the strict correlation between eco-innovations and normal innovations, it may frequently be difficult to disentangle the effects of environmental expenditures and thereby the specific cause of environmental efficiency gains. Finally, according to Mazzanti *et al*. (2009), the positive interaction between 'clean' technologies and 'normal' technologies may be part of the general joint dynamic among all production factors in the innovation processes as analysed in the evolutionary approach (Milgrom and Roberts 1990, 1995; Mohnen and Roller, 2005).

2. A Structuralist-Keynesian growth model with efficiencies complementarity

According to the Structuralist-Keynesian approach (such as those developed by Cimoli *et al*., 2006; Ocampo, 2005), a cumulative growth process may be drafted by the following system of equations.

$$y = bg \tag{1}$$

$$g = \alpha + \beta y \tag{2}$$

Equations (1) and (2) represent respectively the demand regime describing the macroeconomic dynamic and the productivity regime describing the technological dynamic.[2] Variables *y* and *g* are respectively the growth rate of income and of labour productivity. As discussed in appendix A, equation (1) combines the concept of the trade multiplier, according to which growth is influenced by export growth and the income-elasticity of imports (Harrod, 1933; Kaldor, 1975; Thirlwall, 1979; 2011),[3] with the technological gap multiplier, according to which growth is conditioned by the ratio between the productivity growth rate of the export-oriented sector and that of the technology frontier (Cimoli *et al*., 1986; Cimoli, 1994). Thereby, parameter $b > 0$ represents the international competitiveness of the country and it is defined as $b = \frac{\rho y_0}{\delta g_0}$

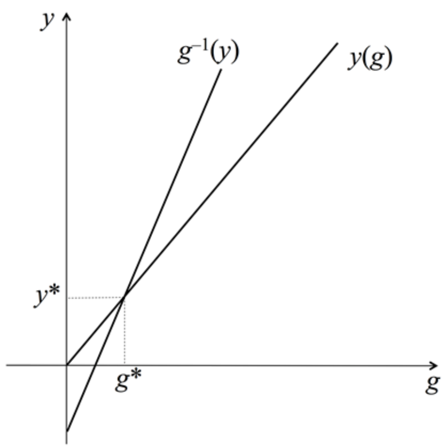
[2] On cumulative growth models, see also Thirlwall (1983).
[3] See the special issue of *PSL Quarterly Review*, vol. 64 n. 259 (2011).

where ρ is the income-elasticity of exports, y_0 is the growth rate of is the foreign income growth rate, g_0 is the foreign productivity growth rate and δ denotes the income elasticity of imports.

Equation (2) represents the Verdoorn-Kaldor law, according to which labour productivity is positively correlated with value added growth. Parameter $\alpha > 0$ stands for exogenous factors that directly and indirectly influence productivity dynamics, such as R&D investments and human capital formation. It stands for innovations not stimulated directly by economic variables. Parameter $0 < \beta < 1$ represents the Kaldor effect, related to increasing returns of production due to static and dynamic economies of scale. The former concern indivisibility and threshold effects in production, the latter the processes of learning by doing, learning by using and networking (Guarini, 2009).

The solutions for stationary equilibrium of the system are as follows: $g^* = \frac{\alpha}{1-\beta b}$, $y^* = b\frac{\alpha}{1-\beta b}$ and $n^* = (b-1)\frac{\alpha}{1-\beta b}$. As in Cimoli *et al.* (2006), the assumption necessary for stability is $0 < (1-\beta b) < 1$. The cumulative growth model is represented by figure 1, where equation (2) is substituted by its inverse $g^{-1}(y)$, that is $y = -\frac{\alpha}{\beta} + \frac{1}{\beta}g$.

Figure 1 – *The cumulative growth process*



Let us integrate this model with the environmental efficiency dynamic. Mazzanti and Zoboli (2009) analyse the efficiencies complementarity in static terms by the following equation:

$$\frac{Y}{H} = \left(\frac{Y}{N}\right)^{\varepsilon} \tag{3}$$

where Y is the level of value added, H is the level of pollutant emissions and N is the level of employment. The condition $\varepsilon > 0$ indicates efficiencies complementarity, while $\varepsilon < 0$ implies efficiencies substitutability. In order to analyse this phenomenon within a growth process, in this paper the efficiencies relationship is represented in dynamic terms since ecological matters are characterised by continuous ecological transformation, which implies structural changes both economic and social (Gilli *et al.*, 2013). The dynamic version of equation (3) is the following:

$$q = \varepsilon g \tag{4}$$

where q is the growth rate of environmental efficiency. Thereby, we analyse the conditions of a growth that is ecologically sustainable (green) and socially sustainable (inclusive) and is called inclusive green growth, according to the World Bank's definition (2012). Starting from the static identity

$$H = Y\frac{H}{Y} = Y\Big/\frac{Y}{H} \tag{5}$$

the dynamic condition for green growth, defined as growth that does not increase pollutant emissions ($h \leq 0$), can be expressed as

$$y - q \leq 0 \tag{6}$$

that is $y \leq q$, from which derives

$$\varepsilon \geq b > 0 \tag{7}$$

Combining the income identity $y \cong n + g$ with equation (1),[4] we obtain $n = (b\text{-}1)g$. If $g > 0$, the condition for inclusive growth, defined as growth that increases employment ($n > 0$), is $b > 1$ and therefore, also considering equation (6), the condition for an inclusive green growth is:

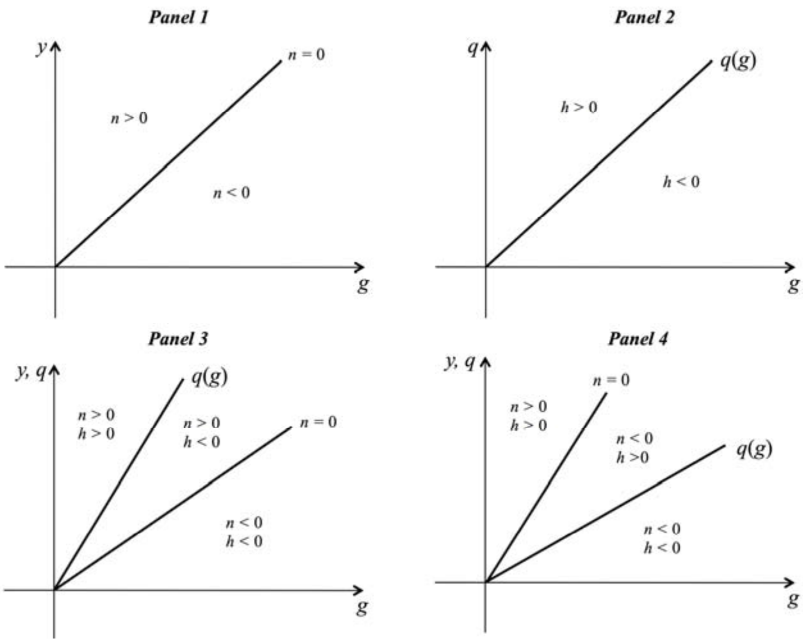
[4] In dynamic terms, the static income identity $Y = (Y/N)N$, where N is employment, becomes $y = n + g + ng$. In empirical studies, ng is usually dropped because it is very small (Corsi and Roncaglia, 2002).

$$\varepsilon \geq b > 1 \tag{8}$$

In fact, this condition allows for growth without increasing emissions and increasing employment.

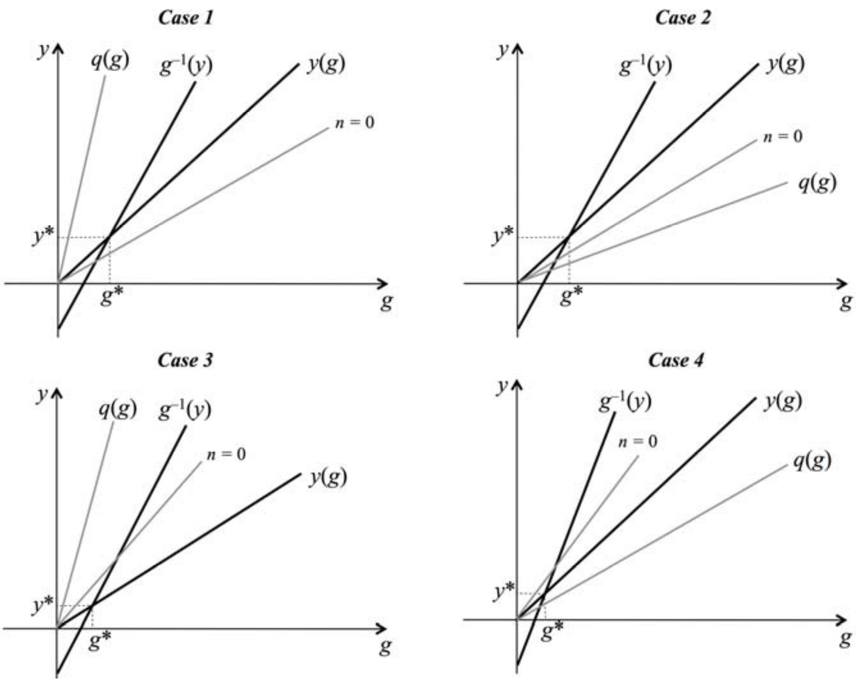
Figure 2 describes the conditions of social and ecological sustainability in the cumulative growth context, namely in terms of income and labour productivity growth rates. In panel 1, the bisector is the locus where $y = g > 0$ that is where employment remains constant, $n = 0$. With respect to this line, combinations of y and g in the left (right) generate increasing (decreasing) employment, $n > 0$ ($n > 0$), that is inclusive (not inclusive) growth. In panel 2, the slope of the function $q(g)$, ε, determines the ecological sustainability of the growth process. In fact, according to (6), the combination of y and g in the right (left) of this line generates decreasing (increasing) pollutant emissions, that is to say a green (not green) growth. Panels 3 and 4 illustrate different types of growth. The case of inclusive green growth is $n > 0$ and $h \leq 0$.

Figure 2 – *The conditions of social and ecological sustainability*



Finally, figure 3 shows four alternative cases of stationary equilibria of cumulative growth: an inclusive and green growth process with $\varepsilon \geq b > 1$ (case 1); an inclusive but not green growth process with $b > 1, \varepsilon < 1$ (case 2); not inclusive but green growth $b < 1, \varepsilon > 1$ (case 3) and neither inclusive or green growth $\varepsilon < b < 1$ (case 4). In the case of efficiencies substitutability $\varepsilon < 0$ all solutions represent a cumulative growth that is ecologically unsustainable. Thus the efficiencies complementarity is a condition necessary, but not sufficient for the social and ecological sustainability of a growth process.

Figure 3 – *Social and ecological sustainability in a cumulative growth process*



3. Empirical analysis of efficiencies complementarity in European countries

In this section, I intend to estimate the efficiencies complementarity expressed by equation (4) for European countries[5] during the period 1992-2012, by using the Eurostat database and considering both the whole economy and the manufacturing sector. The choice of European countries may contribute to evaluate the general framework of the EU's "Europe 2020" growth strategy that is based on the efficiencies complementarity.

The econometric technique adopted is the one-step difference GMM dynamic panel-data methodology (Roodman, 2006). It is useful to take into account both the potential path-dependence of dependent variables and the endogeneity among environmental efficiency and labour productivity that are linked not only by equation (4) but also by the identity $q = g + l$, where l is the growth rate of the ratio between employment and pollutant emissions. The equation estimated is the following:

$$q_{i,t} = \beta_1 q_{i,t-1} + \beta_2 g_{i,t} + \beta_3 GAP_{i,t-1} + \sum_{t=1}^{c} \mu_t \tau_{i,t} + \theta_{i,t} \qquad (9)$$

where q is the growth rate of environmental efficiency and g is the growth rate of labour productivity, GAP is the ratio between the maximum European value of environmental efficiency and the value of the country considered, subscripts i and t represent country and time respectively. Finally, τ_{it} stands for a temporal dummy, from year 1 (1993) to year c (2012) and θ_{it} for the error term. The environmental efficiency is constructed as Y/H, where Y is total value added at constant prices and H is an index of the level of total greenhouse gas emissions.[6] Index H is a proxy of the implemented political strategy because it is one

[5] The European countries considered are: Austria, Belgium, Cyprus, the Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Latvia, Lithuania, Luxemburg, Macedonia, Malta, Netherlands, Norway, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden, Switzerland and the United Kingdom.

[6] Namely, H is total greenhouse gas emissions (excluding aviation, since data are few and biased due to the lack of repartition of the emissions among countries, for the international flies) as thousand tonnes of carbon dioxide ($CO2$) equivalent. Eurostat publishes the indicator H based on data from the European Environment Agency. For further information, see http://epp.eurostat.ec.europa.eu/portal/page/portal/eurostat/home.

of the indicators for the EU Sustainable Development Strategy and also a target of Europe 2020, with particular reference to the Resource Efficiency Initiative. Variable *g* is the growth rate of ratio Y/N, where *N* represents total employment, namely the number of persons employed. Variable *GAP* takes into account the potential catching-up of the considered country in respect to the leading countries in terms of environmental efficiency, and it is inserted in analogy with the representation of technological catching-up in the labour productivity function (such as in Hein and Tarassow, 2010). The introduction of $GAP_{i,t-1}$ does not generate multicollinearity with $q_{i,t-1}$, since these variables are correlated only at 21 per cent (economy) and at 22 per cent (manufacturing sector). The error term θ_{it} consists of both unobserved country-specific effects, $u_i \sim N\left(0, \sigma_u^2\right)$, and observation-specific errors $v_i \sim N\left(0, \sigma_v^2\right)$. The stationarity of variables is verified by unit root tests (see appendix B). In appendix C, equation (9) is verified without considering the *GAP* term.

Table 1 – *The econometric estimations of the efficiencies complementarity*

Total economy

	Coef.	Robust Standard. Error	z	Pr>|z|
q_{it-1}	-0.0733	0.0864	-0.8500	0.3960
g_{it}	0.4471	0.2216	2.0200	0.0440
GAP_{it-1}	0.0118	0.0050	2.3700	0.0180
Observations				397
Test				
AR(1)		*z =-3.22*		*Pr>|z| =0.001*
AR(2)		*z =-1.29*		*Pr>|z| =0.197*
Sargan test		*chi2 =22.11*		*Pr>|chi2| =0.942*
Hansen test		*chi2 =2.18*		*Pr>|chi2| =1.000*
Test for Temporal Dummies		*chi2 =5762.02*		*Pr>|chi2| =0.000*

Manufacturing sector

	Coef.	Robust Standard. Error	z	Pr>|z|
q_{it-1}	-0.0591	0.0411	-1.4400	0.1510
g_{it}	0.9992	0.1648	6.0600	0.0000
GAP_{it-1}	0.0353	0.0196	1.8000	0.0730
Observations				381
Test				
AR(1)		*z =--2.89*		*Pr>|z| =0.004*
AR(2)		*z = -1.12*		*Pr>|z| =0.265*
Sargan test		*chi2 =34.58*		*Pr>|chi2| =0.440*
Hansen test		*chi2 =1.31*		*Pr>|chi2| =1.000*
Test for Temporal Dummies		*chi2 = 550.25*		*Pr>|chi2| =0.000*

Note: Dependent variable: growth rate of environmental efficiency (q_{it})

According to the econometric results (see table 1), the complementarity between environmental efficiency and labour productivity in Europe is verified both for the whole economy and for the manufacturing sector. Particularly, the sectorial estimation supports the approach of the European Commission concerning the promotion of an industrial policy that improves both competitiveness and sustainability together (European Commission, 2010). Moreover it is possible to discern that there is a catching-up process of environmental efficiency.

4. Concluding remarks

The paper has analysed the nature of complementarity between environmental efficiency and labour productivity and the positive role it plays in achieving social and ecological sustainability in a growth process. The paper has also verified this complementarity in Europe through an econometric analysis with a dynamic panel method both for the whole economy and for the manufacturing sector.

The original element of the paper mainly concerns the introduction of this topic into a Structuralist-Keynesian cumulative growth model and the study of ecological sustainability in terms of innovation processes. In this framework, the ‘green’ dynamic fits inside the relationship between the technological dynamic and the macroeconomic dynamic, by making the growth process more complex for the interactions among different dimensions. Thus, this paper may provide a baseline theoretical structure for further necessary analyses to better understand this multidimensional dynamic. The following theoretical and empirical studies may regard for example the specification of the conditions for an inclusive green growth and the identification of the technological, social and economic drivers of environmental efficiency. Thereby, this line of research introduces the ‘human development perspective’ into the Post-Keynesian growth model, according to which the concept of sustainability is related not only to inter-generational equality, but also to intra-generational equality (Anand and Sen, 2000).

This issue also has relevant repercussions in policy terms, since institutions have to promote political initiatives that are able to attain social, economic and environmental goals together. From this perspective, the empirical analysis is useful to confirm the validity of the general framework of the European Commission's Europe 2020 growth strategy, and would seem to indicate that this complementarity is a crucial element to achieve an inclusive, smart and sustainable growth.

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Appendix A

Following Cimoli *et al*. (2006), I start from the equilibrium trade balance between imports, M, and exports, E:

$$M = E \tag{a.1}$$

Equation (a.1) is the standard assumption of the balance of payments constrained growth models (Thirwall, 2011). Let us consider the imports equation:

$$M = Y^{\delta} \tag{a.2}$$

where δ is the income-elasticity of imports and Y represents domestic income and the exports equation. Further, let us assume

$$E = Y_{\circ}^{\rho\varphi} \tag{a.3}$$

In equation (a.3), $Y_{\circ}$ is foreign income, ρ is the income-elasticity of exports and φ is the technological gap multiplier, defined as:

$$\varphi = g/g_{\circ} \tag{a.4}$$

where g and $g_{\circ}$ are respectively the growth rate of domestic labour productivity and of foreign labour productivity. The dynamic versions of equations (a.1), (a.2) and (a.3) are respectively:

$$m = e \tag{a.5}$$

$$m = \delta y \qquad \text{(a.6)}$$

$$e = \rho\varphi y_{\circ} \qquad \text{(a.7)}$$

Combining equations (a.5), (a.6) and (a.7), we obtain $g = \rho\varphi y_{\circ}/\delta$. Defining $b = \rho y_{\circ}/\delta g_{\circ}$ and considering equation (a.4), we obtain $y = b$.

Appendix B

Table B.1 – *Descriptive statistics*

Total economy

Variable		Mean	Std. Dev.	Min	Max	Observations
q_{it}	overall	0.031	0.047	-0.162	0.207	N = 412
	between		0.012	0.013	0.057	n = 26
	within		0.046	-0.184	0.205	T = 15.85
q_{it-1}	overall	0.032	0.048	-0.162	0.229	N = 412
	between		0.012	0.013	0.053	n = 26
	within		0.047	-0.183	0.213	T = 15.85
g_{it}	overall	0.019	0.030	-0.086	0.169	N = 412
	between		0.015	-0.002	0.051	n = 26
	within		0.026	-0.116	0.151	T = 15.85
GAP_{it-1}	overall	4.997	4.153	1.000	23.517	N = 419
	between		4.104	1.000	17.940	n = 26
	within		0.958	0.266	10.573	T = 16.11

Manufacturing sector

Variable		Mean	Std. Dev.	Min	Max	Observations
q_{it}	overall	0.052	0.110	-0.366	0.814	N = 396
	between		0.040	0.017	0.148	n = 26
	within		0.103	-0.421	0.813	T = 15.23
q_{it-1}	overall	0.055	0.114	-0.366	0.814	N = 396
	between		0.042	0.012	0.148	n = 26
	within		0.106	-0.418	0.794	T = 15.23
g_{it}	overall	0.039	0.065	-0.210	0.342	N = 396
	between		0.028	-0.007	0.106	n = 26
	within		0.059	-0.203	0.293	T = 15.23
GAP_{it-1}	overall	5.391	4.940	1.000	39.049	N = 403
	between		4.390	1.000	21.594	n = 26
	within		2.500	-11.181	22.847	T = 15.5

Table B.2 – *Test of autocorrelation*

Total economy

augmented Dickey-Fuller test

	drift		drift and trend	
variable	chi2	Pr>|chi2|	chi2	Pr>|chi2|
q_{it}	287.91	0.00	197.00	0.00
g_{it}	233.62	0.00	186.37	0.00
GAP_{it-1}	127.78	0.00	165.23	0.00

Ho: unit roots; lag =1

Manufacturing sector

augmented Dickey-Fuller test

	drift		drift and trend	
variable	chi2	Pr>|chi2|	chi2	Pr>|chi2|
q_{it}	286.90	0.00	164.65	0.00
g_{it}	362.58	0.00	299.53	0.00
GAP_{it-1}	122.32	0.00	125.67	0.00

Ho: unit roots; lag =1

Note: dependent variable: growth rate of environmental efficiency (q_{it}).

Appendix C

Table C.1 – *The econometric estimations of the efficiencies complementarity without the GAP term*

Total economy

	Coef.	Robust Standard. Error	z	Pr>|z|
q_{it-1}	-0.0748	0.0944	-0.7900	0.4280
g_{it}	0.547637	0.2220482	2.47	0.014
Observations				397
	Test			
AR(1)	*z =-3.37*		*Pr>|z| = 0.001*	
AR(2)	*z =-1.17*		*Pr>|z| =0.243*	
Sargan test	*chi2 =22.09*		*Pr>|chi2| =0.942*	
Hansen test	*chi2 =2.14*		*Pr>|chi2| =1.000*	
Test for Temporal Dummies	*chi2 =7460.23*		*Pr>|chi2| =0.000*	

Manufacturing sector

	Coef.	Robust Standard. Error	z	Pr>|z|
q_{it-1}	0.0195	0.0538	0.3600	0.7180
g_{it}	1.098837	0.2063111	5.33	0
Observations				381
	Test			
AR(1)	*z =--2.31*		*Pr>|z| =0.021*	
AR(2)	*z = -0.73*		*Pr>|z| =0.464*	
Sargan test	*chi2 =31.23*		*Pr>|chi2| =0.604*	
Hansen test	*chi2 =1.73*		*Pr>|chi2| =1.000*	
Test for Temporal Dummies	*chi2 = 195.87*		*Pr>|chi2| =0.000*	