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Environmental efficiency and labour productivity: trade-off or joint dynamics?

Empirical evidence using NAMEA panel data

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Abstract

This paper provides new empirical evidence on the relationship between environmental efficiency and labour productivity using NAMEA data. We test an adapted EKC hypothesis to verify the relationship between 'environmental efficiency' (namely sector emission on value added) and labour productivity (value added on employees). We exploit NAMEA data on Italy for 29 sector branches and 9 categories of air emissions for the period 1991-2001. We employ data on capital stock and trade openness to test the robustness of our results.

On the basis of the theoretical and empirical analyses focusing on innovation, firm performances and environmental externalities, we would expect a positive correlation between environmental efficiency and labour productivity (i.e. a negative correlation between the emissions intensity of production and labour productivity), which departs from the conventional mainstream view. The hypothesis tested is a critical one within the longstanding debate on the potential trade-off or complementarity between environmental preservation and economic performance, which is strictly associated with the role of technological innovation.

We find that for most air emission categories there is a positive relationship between labour productivity and environmental efficiency. Labour productivity dynamics, then, seem to be complementary to a decreasing emissions intensity in the production process. Taking a disaggregate sector perspective, we show that the macro-aggregate evidence is driven by sector dynamics in a non-homogenous way across pollutants. Services tend always to show a 'complementary' relationship, while industry seems to be associated with inverted U-shape dynamics for greenhouse gases and nitrogen oxides. This is in line with our expectations. In any case, EKC shapes appear to drive such productivity links towards complementarity.

The extent to which this evidence derives from endogenous market forces, industrial and structural change, and policy effects provides scope for further research.

Jel: C23, Q38, Q56

Keywords: Decoupling, NAMEA, air emissions, labour productivity, sector value added, Environmental Efficiency

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1. Introduction

In this paper we test the hypothesis of an 'adapted' 'Environmental Kuznets Curve' (EKC) in which the correlation between labour productivity (value added per employee) and environmental efficiency (here emissions, per unit of value added) is the link being analysed. The dynamic relationship between the abovementioned 'efficiencies' is a core, if not the primary, element behind the observed macro EKC trend. The role of technological (eco-) innovation as a latent factor in this relationship has been highlighted in empirical and theoretical contributions (Karvonen, 2001).

Here we specify an empirical model for an examination of an original NAMEA (National Accounting Matrix with Environmental Accounts) sector-level time-series panel dataset. Emissions per sectoral added value is used as a proxy for environmental efficiency/productivity (environmental intensity of value added generated). The underlying assumption is that the core direction of economic change is towards higher mechanisation (capital/labour ratios) (Pasinetti, 1981) and higher labour productivity, testing whether environmental efficiency is positively or negatively related to labour productivity dynamics (Femia and Panfili, 2005).

Empirical analyses of joint economic and environmental productivity at sector level are quite rare due to the paucity of (panel) environmental data. This constitutes a value added of our paper. We argue that firm based studies (Mazzanti and Zoboli, 2008a,b) and sector-based analyses provide highly complementary evidence, given that the former focus on specific issues and allow greater detail, whereas the outcomes of the latter are more generalisable.

The paper is structured as follows. Section 2 provides a theoretical framework for the empirical analysis and describes the dataset. Section 3 presents the panel-based regression results. Section 4 discusses the factors that support the emerging stylised fact of a joint economic and environmental productivity, offers some interpretations and discusses some open issues. We expect to find robust statistical evidence of the 'double productivity/efficiency hypothesis', i.e. an inverse relationship between emissions intensity and labour productivity, although an articulated set of differences across different pollutants and between industry and services may emerge.

2. Environmental efficiency and labour productivity: theoretical and empirical issues

2. 1 Building stylised facts with NAMEA variables

The Italian NAMEA dataset provides sector-level data on value added (VA), full-time equivalent employees (N), and emissions for 10 air pollutants (E)[2] for several sector branches (table 1b). Using NAMEA variables we can directly define three kinds of efficiency/productivity indicators.

The first indicator is E/VA, the emission intensity of value added, which represents the 'economic efficiency of emissions' at branch level (for each emission category). This indicator is rather usual indicator in analyses of 'decoupling' and EKC. Its meaning in terms of environmental-economic efficiency is discussed elsewhere (Mazzanti et al. 2008). A decrease of this indicator means improved efficiency.

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[2] We do not employ information on lead.

The second indicator is E/N, emission per employee (the average units of the pollutant produced by an employee in the branch) and emission technology. As this indicator is based on quantity not value, it can be taken as an indicator of 'technical emission efficiency', and as reflecting the production technology of the branch[3].

The third indicator directly computable from NAMEA is VA/N, value added per employee (in the branch), which is frequently used 'economic efficiency/productivity' measure.

In order to find a relationship between these three efficiency/productivity indicators we employ the following accounting identity equation:

$$(1) \qquad E/VA * VA = E/N * N$$

By simple algebraic transformations we arrive at the following relationship:

$$(2) \qquad E/VA = E/N * 1/(VA/N)$$

In eq. 2, the 'economic efficiency of emission', E/VA, depends on the interaction between 'technical efficiency of emission' (E/N), and 'economic (labour) productivity' (VA/N). There is a direct relationship between E/VA and E/N, and an inverse relationship between E/VA and VA/N. Any increase in labour productivity (VA/N) for a given technical emission efficiency (E/N) will reduce the emission per unit of VA and increase the 'economic efficiency of emissions'. Similarly, any reduction (increase) in E/N, for a given labour productivity VA/N, will reduce (increase) E/VA, i.e. improve (worsen) the 'economic emission efficiency'.

In terms of changes over time or cross section differences, for an increasing VA/N in eq. 2, E/VA will not change unless E/N and V/AN increase at the same percentage rate. If E/N increases at a faster rate than VA/N (i.e. , if on a technical level, the increase in VA/N requires a more than proportional increase of E/N) then E/VA will eventually increase (worsening efficiency). However, in the case that E/N increases at a lower rate than VA/N (or even improves with an increasing VA/N), an inverse relationship between E/VA and VA/N will prevail, indicating that 'economic productivity' and the 'economic efficiency of emission' are *improving together*.

We can assume that VA and E are *distinct outputs*, respectively economic and environmental, arising from the *same production proces*s, or from the same combination of factor inputs. We could simply refer to two standard production functions for VA and E, with factor inputs K (capital) and N (labour) and 'total factor productivities' A and Z respectively[4]. Assuming constant returns to scale, they can be defined as:

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[3] Given the level of aggregation of NAMEA production branches, E/N can also reflect composition effects.

[4] In eq. 3, we are dealing with the value added production function and total factor productivity (TFP). In this framework, TFP does not refer to 'disembodied' technical change only, as would be the case for gross-output based TFP when assuming Hicks neutrality. In particular, the TFP measure in a value-added framework is a measure of disembodied technical change only when technical change operates exclusively on primary inputs and not on intermediate inputs. Value-added based measures of TFP depend also on the share of value added in gross output, and on the time paths of inputs, outputs, prices and the level of technology. Value-added based TFP then reflects the industry's capacity to translate technical change into income. Furthermore, when labour and capital are not measured so as to take account of their heterogeneity and quality change (e.g. by vintages), the effects of embodied technical change (in capital and intermediate inputs) and of improved human capital (in labour) are not fully reflected in the measured

(3) $VA/N = Af(K/N)$ with $A>0$, $f'>0$, f'' whatever sign.

In eq. 3, VA/N is produced by K/N through a function f, where f’ is unambiguously >0, with or without decreasing marginal returns. A is >0 and Å/A, the time rate of change of A, is>0 if TFP encompasses the positive productivity effects of technical change, whether endogenously or exogenously determined.

(4) $E/N = Zg(K/N)$ with $Z>0$, $g'>0$, g'' whatever sign.

Eq. 4 is an ‘emissions production function’ that models how (in our case) air emissions are produced by the factor input K/N (via energy use associated with the K/N technique). By assuming g’>0, the intensification of capital relative to labour will increase the emissions per employee. The reason is that more capital relative to labour involves more energy use. The TFP represented by Z (exogenously or exogenously determined) will account for all the technical and organisational progress that might change the relationship between quantity of input K/N and quantity of emissions E/N.

We could expect that, in general, □/Z is *negative* to allow for innovation to increase the efficiency of resources use (i.e. technical progress is emission-reducing). However, based on eq. 2, to have a stable E/VA both E/N and VA/N must change at the same percentage rate (their effects must be compensating). This implies that a change (increase) of K/N in eq. 3 and 4, must produce the *same effect* (increase) on both VA/N and E/N, which in turn implies that the *two production functions must be the same*, or f=g, A=Z and Å/A = □/Z. In other words, the technology should enable there always to be a fixed proportion between E and VA. However, this would imply that, if Å/A >0, also □/Z>0, and the technical progress in the emission production function would be emissions-augmenting and not emissions-reducing,.

The latter outcome would obtain if the technology meant that: (a) K/N and energy were strictly complementary inputs in producing VA/N; (b) there was a fixed coefficient of energy use per unit of K, and (c) there was a fixed coefficient of emissions per unit of energy, so that any increase in K relative to N, de facto, implies a fixed proportional increase of E relative to N . It would also imply that any innovation augmenting the productivity of K/N in terms of VA/N would also proportionally increase the ‘productivity’ of K/N in terms of E/N, i.e. it would worsen the emissions per employee effect.

There is no reason to expect such a peculiar technology to prevail because the VA/N and the E/N production functions, and their TFPs can be expected to differ, so that E and VA are not bound to grow in a fixed proportion.

In this case, it is possible that, for an increasing VA/N in eq. 2,, E/VA also *increases*, and there is a trade off between ‘economic productivity’ and ‘economic efficiency of emissions’. This would correspond to a technological setting in which an increase in K/N in eq. 4 increases E/N *more than proportionally* with respect to

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contributions of each factor of production, and TFP would capture the effects of both embodied and disembodied technical change. Finally, labour productivity measures (value added per employee) reflect the combined effects of changes in capital inputs, intermediate inputs and overall productivity; they do exclude any direct effects of technical change, whether embodied or disembodied (OECD, 2001).

the increase in VA/N caused by the same increase in K/N in eq. 3 (or g>f for all K/N values and/or □ /Z is positive and > Å/A). It would mean that any increase in K/N is more 'productive' (worsening) in terms of emissions than in terms of VA.

This would be in line with the following hypotheses on the technology of emissions: (a) the new additional K/N is more energy intensive than existing K/N; (b) the new additional K/N involves inter-fuel substitution in favour of more polluting sources compared to existing K/N; (c) innovation is such that the coefficients of emission per unit of energy in the new K/N are higher than in the old K/N[5].

Such a technology cannot be ruled out ex ante, and would apply to the *ascending* part of an EKC in the variables E/VA and VA/N.

A second possibility is that, for an increasing VA/N in eq. 2, E/VA is *decreasing*. There is no trade-off between 'economic productivity' and 'economic efficiency of emission' and the two *can improve together*. This would be the case where the increase in K/N in eq. 4 increases E/N *less than proportionally* with respect to the increase in VA/N caused by the same increase in K/N in eq. 3, or where E/N even shows a decrease (or g<f for all K/N values and/or □ /Z is *negative* and > Å/A in absolute values). In terms of our simple production function framework, it would mean that any increase in K/N is less 'productive' in terms of emissions E than in terms of VA, and would improve 'economic emission efficiency' while at the same time increasing VA/N.

This would be realistic in the case that: (a) the new additional K/N is less energy intensive than the existing K/N; (b) the new additional K/N involves inter-fuel substitution in favour of less polluting sources compared to existing K/N; (c) innovation is such that the coefficient of emission per unit of energy in is lower in the new K/N than in the old K/N.

This type of technology would prevail in the *descending* part of an EKC in the variables E/VA and VA/N, in which economic improvement and environmental improvement occur together.

All in all, in a time series setting, we can expect a stable E/VA for an increasing VA/N only if a technology with peculiar dynamic substitution properties related to energy/emission and labour (via increasing K/N), and fixed-proportion productivity changes, prevails. In the case of a technology where intensification of K causes emissions to increase more than proportionally compared to VA, we can expect an increasing E/VA for an increasing VA/N, i.e. a trade off between economic productivity end environmental efficiency. This situation, where economic growth can be achieved only at the cost of increased emissions, will correspond to the ascending part of an EKC. Finally, we can expect a decreasing E/VA for an increasing VA/N, i.e. a joint dynamics of 'economic productivity' and 'economic emission efficiency', if intensification of K causes emissions to grow less than proportionally (or to decrease) relative to VA. This joint productivity dynamics corresponds to an 'emission production function' in which intensification of K generally brings gains in terms of emission performance. This seems to be the prevailing condition in current advanced techno-economic systems, and is represented by the descending part of an EKC.

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[5] At the NAMEA branch aggregation level, this situation will prevail if composition effects favour sub-sectors with a more polluting (higher emissions) technology.

Greenhouse gases and air pollutants

As both greenhouse gases (GHGs) and air pollutants are related to energy use, more capital-intensive techniques can increase both types of emissions. However, there may be differences in the 'emission production functions' (eq. 4) for GHGs and for other air pollutants included in NAMEA.

GHG emissions are almost directly related to energy use, and additional K/N (i.e. dynamically substituting K-energy for labour) therefore can be expected to increase GHGs unless there are significant innovations in energy efficiency, interfuel substitution, and 'carbon capture and storage'. Given that, as a result of energy market conditions, energy efficiency and interfuel substitution are likely among the main objectives of firms, and technological inertia can push energy-efficient solutions even in phases of low relative energy prices (see, e.g., Gruebler et al., 1999; Zoboli 1995), even the relationship between increasing K/N and E/N may not be directly proportional and could be (marginally) decreasing even for GHGs.

In the case of air pollutants, provided their emission is more efficient, e.g., as a by-product of innovations in energy efficiency and interfuel substitution (i.e. 'ancillary benefits' of climate change policy), there may be *specific* capital stocks capable of reducing some of them, e.g. end-of -pipe technologies, and the new plant/equipment may be both more K/N intensive and less air emissions intensive, in compliance with the regulation. It should be noted that prior to the Integrated Pollution Prevention Control (IPPC) directive and Europe Union's Emissions Trading Scheme (ETS), GHGs were not regulated directly, whereas air pollutants have been closely regulated since the 1970s in most countries. It is likely that regulation has been the spur for increasing K to reduce pollutants (not only GHGs), which has resulted in increased K/N.

In analysing NAMEA data, we can expect that the relationship between 'economic efficiency of emissions' E/VA and economic productivity VA/N will differ between GHGs and air pollutants even in the descending part of an EKC (i.e. joint economic-environmental efficiency gains) that would prevail for both types of emissions. Similarly, we could expect a trade-off between economic productivity and environmental efficiency (i.e. a direct relationship between E/VA and VA/N) would be more likely for GHGs than air pollutants.

The relationship in a panel setting

We need to consider composition effects in our framework because we use NAMEA as a panel (29 branches, over 1991-2001) to test the relationships for each of nine air emissions categories, at the level the economy as a whole, and distinguishing by industry and services. In our dataset, cross-sector variability is more significant than time variability. However, the latter is important for taking account of the inertia typical in the evolution of energy and emissions systems.

In a panel setting, the relationship between E/VA and VA/N can result not only from the features and the evolution over time, of certain production functions (as eq. 3 and 4 above) in a branch, but also from the variability across different production functions for structurally different branches in the panel. In fact, if we assume that production technologies do not change over time, we still observe a direct or inverse relationship between E/VA and VA/N across groups of manufacturing and service branches, or the economy as a whole. If there is a direct relationship (positive coefficient), i.e. a trade off between economic productivity and emissions efficiency, this would suggest that sectors producing a higher VA/N also produce a higher E/VA, and *viceversa*, and in a statistically regular way. Conversely, if an inverse relationship (negative coefficient) obtains, i.e. economic productivity and emission efficiency go hand in hand, those sectors producing higher VA/N produce lower E/VA, and *viceversa*. It is unlikely that one of these regularities would hold strictly across the whole economy, and even if it did, the evolution of the sector composition of the economy over time, would shift the position and slope (if not the sign) of the relationship.

In addition, within *each* of the sectors in NAMEA, changes in efficiency over time (time variability), as discussed above, can occur. In a panel setting, this may compensate for or reinforce the cross-sector variability of the relationship between E/VA and VA/N. For example, even in the case of a direct relationship between E/VA and VA/N at cross-sector level, the evolution of the same relationship over time across all sectors, could be inverse, i.e. there may be gains in both economic productivity and emissions efficiency, which could compensate for the cross-sector effect in a panel setting.

2.2 The empirical model

We empirically test whether environmental efficiency and labour productivity are independent (no significant links between them), positively related (complementarity between the two), or negatively correlated (substitution or trade-off framework). As illustrated above, the case of 'complementarity' may be opposed to the 'substitution hypothesis' often associated with conventional neoclassic reasoning. It should be noted that, since we specify the ratio of emissions on value added as an index of environmental efficiency, an inverted U-shape would indicate that environmental efficiency is increasing (the ratio decreasing) as labour productivity increases, in association with a negative elasticity between the two productivities.

The basic empirical model of reference is the following reduced form:

(5) $log(Emission/Value\ added) = \beta_{0i}$[6] $+ \beta_1 Log(Value\ added/employees)_{it} + [\beta_2\ Log(Value\ added/employees)^2_{it}] + e_{it}$

We regress the linear forms and then test the inverted U-shape in order to verify whether the link between productivities shows a non linear pattern[7].

Two additional covariates are included in order to modify eq. 5.

First, we test whether the stock of gross capital produces different results with respect to value added. We merged NAMEA data with other ISTAT data on capital stocks in Italy (1995 constant prices) to verify whether the emission-value added relationship is confirmed by exploiting the slightly different heterogeneity across sectors, of capital endowments per employee. Though capital stocks and value added are highly correlated and cannot conceptually coexist in the same specification, capital related heterogeneity may differ, thus providing additional insights. The model is as follows[8]

(6) $log(Emission/value\ added) = \beta_{0i} + \beta_1 Log(capital\ stock/employees)_{it} + [\beta_2\ Log(capital\ stock\ /employees)^2_{it}] + e_{it}$

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[6] The constant term is α_i in the fixed effect (FEM) – least square dummy variables (LSDV) model.

[7] For a 'standard' EKC analysis, specifying all emission indicators in per capita terms see Mazzanti et al. (2008).

[8] The relationship between emissions per value added and capital stock per employee in eq. 6 is equivalent to a reduced form of eq. 2, 3 and 4 above.

A third specification of the models (5) and (6) includes the variable *trade openness*, calculated as the ratio between imports plus exports and value added, all at current prices:

$$(7) \qquad (5) \text{ or } (6) + \beta_4 \, (Trade\ openness)_{it} + e_{it}$$

Trade openness (TO) is used here as a 'control factor' in the results for the baseline specifications. The hypothesis about needs to be adapted in our within-country cross-sector environment with respect to a cross-country framework. Here, a positive (negative) significant link between TO and emissions could mean that increasing openness over time and/or higher openness for some sectors decreases (increases) sector 'environmental productivity'. We refer to Mazzanti, Montini and Zoboli (2008) for an in depth theoretical discussion.

Note that our specifications lack a test for policy effects, which are only indirectly assessed. Over the period observed there was no strong environmental policy commitment in Italy in relation to many of the emissions included in NAMEA; it would have been extremely difficult to attach policy proxies to the various sectors and/or different periods. This represents an avenue for fruitful future research using this or other datasets. Future studies could also test the relevancy of factor, such as sector intensity in R&D, for which no panel data are available at this level of detail.

2.3. Database and econometric issues

The Italian NAMEA is published and regularly updated by the Italian Statistical Agency. The data include 10 air pollutants, and refer to emissions from several production branches, which we recoded to include 29 economic branches (2 in the agricultural sector, 18 in the industrial sector, 9 in the service sector). This paper, for reasons of brevity and effectiveness, focuses only on six types of emissions: two GHGs (CO_2 and CH_4), two regional scale pollutants (NOx, SOx), two local toxic pollutants (NMVOC, PM_{10}). Full estimates are available upon request.

Data on branch-level value added and units of labour are included in the NAMEA database with full branch-by-branch correspondence with emissions data - one of the biggest advantages of NAMEA matrices. In order to test specifications (6) and (7) above, we built a dataset on total capital stocks in Italy, and on Italian international trade, at the same two-digit level of aggregation as in NAMEA. Here, we use the 1990-2001 series for all variables.

Given the panel data framework, we used the Hausman statistic to compare the relative fit of the FEM and random effects models (REM). Note that our FEM/REM estimates often differ very slightly. Conceptually, given that we do not have a sample of units, FEM specifications are preferable. However, as the underlying data source is a sample of establishments, it is relevant to test FEM/REM using the Hausman test.

It should be noted that, although the availability of longer datasets is improving, the most common panel setting is one where T is limited (e.g. 2-4 years) and N is very high, say hundreds or thousands. Autocorrelation and dynamic issues are not a primary factor in this context. The increasing availability of longer panels of data is forcing researcher to cope with typical time series problem such as autocorrelation, dynamic specifications, etc.

Given that, although cross-sectional heterogeneity is dominant, our dataset is sufficiently long, here we test first for autocorrelation (first order) in addition to heteroskedasticity[9], and then analyse whether a dynamic setting with one lag of the E/VA variable might also affect our base estimates. These tests are intended to check the robustness of our baseline estimates; recall, that they appear to offer robust evidence insofar as they exploit a quite rich and unusual time series and cross section variability. Autocorrelated regressions are shown in cases where the test procedures show them to be more relevant

While autocorrelation and heteroskedasticity are data-related issues, the specification of a dynamic model is a conceptual issue. Given the potential influence of past emissions trends in driving current levels, it is appropriate to attempt to regress a dynamic model. In this case we use a corrected LSDV model, named after Kiviet (1995, 1999), that has been evaluated as better performing even than the widely used Arellano-Bond and Blundell-Bond generalised method of moment (GMM) techniques?[10].

Finally, we check whether estimates are influenced by the assumption of homogenous slopes, by running a *random coefficient model.*

For reasons of space, we present estimates for the (baseline) heteroskedasticity-corrected specification, the eventual autocorrelation corrected model, and the dynamic specifications. Other regressions are commented on and results are available upon request.

3. Empirical results

Empirical results are reported in tables 2-4. These can be summarised in terms of typology/scale of environmental externality: global, regional, local. Recall that estimates refer to baseline and auto-correlated specifications and dynamic models, including the role of TO. We provide comments on the random coefficient regressions and the analysis of the role of capital stocks as a ‘driver’ (full estimates are available upon request).

3.1 GHGs

As far as the main GHGs are concerned, we note that, besides the baseline regression, which presents an inverted U shape, auto correlated and dynamic models show the higher robustness of a linear negative relationship for eq. 5. In any case, the negative link, i.e. joint economic-environmental productivity, prevails. Even the random coefficient regression is robust and adds to the evidence on a linear relationship arising from the panel sector investigation.

TO is related to a positive coefficient: the (increasing) TO over the period observed would suggest that the ‘pollution haven’ hypothesis cannot be validated. Emissions increase probably due to higher specialization of the economy in pollution-intensive sectors.

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[9] We eventually corrected for both flaws in FEM or REM depending on which specification was preferred. Conceptually, it is ambiguous to choose between the two on a mere conceptual level: while NAMEA is not a sample of sectors, emission coefficients are drawn from representative establishments, which change over the years.

[10] Judson and Owen (1999) strongly support this model when N is either small (10–20 units) or only moderately large. This is the case in our setting in which we are dealing with a somewhat ’strange’, at least in comparative terms, panel setting: neither T nor N can be judged to be short and limited, but neither are they very long/extensive series of data. We refer the reader to the contributions by Bruno (2004, 2005) on the issue for specific details we do not address for brevity.

CH_4 confirms the evidence. All regressions show a significant negative coefficient. As in the case of CO_2, elasticity is consistently lower than unity and the coefficient is relevant in relation to size. TO is not significant in this case.

3.2 SOx and NOx

The evidence on SOx also supports a negative relationship for eq. 5, although a U shape arises applies to the baseline not the auto correlation (AR(1)) corrected regression. Statistically speaking, the non-linear shape is quite weak and vanishes when AR(1) and dynamic models are implemented. Even random coefficient models present a robust linear form as the preferred specification.

It is interesting that in contrast to the case of CO_2, TO here has a negative sign: 'pollution haven' factors may outweigh the pollution intensity deriving from the economy's industrial specialization. TO is also coherently attached to a negative sign regarding NOx, though in this case, its significance vanishes when moving to AR(1) and dynamic models. Both of these types of models also show statistical 'preference' for a linear negative relationship for NOx. The baseline regression shows an inverted U shape.

3.3 Local pollutants

The focus is on NMVOC and PM_{10}, two major drivers of local toxicity effects on air and water resources. The evidence is quite homogenous. In both situations the linear form is the more robust specification. TO, besides the baseline regression for NMVOC, is not significant, as it may be plausible for local pollutants. Dynamic and random coefficient models confirm the evidence from the LSDV models.

3.4. Capital stocks and environmental efficiency

In terms of the role of sector-level gross capital stocks, the evidence for GHGs evidence differs from the above: CO_2 is associated with a U shape, rather than an inverted U, and methane has a negative linear relationship, which confirms the evidence above. TO is a positive and significant driver for both the GHGs considered. Only SOx shows a U-shape. NOx presents a linear negative shape. This evidence is consistent with the comments on value added, above. TO has a negative coefficient for SOx.

For other local air pollutants, the link confirms the previous results on the absence of a trade-off between environmental efficiency and labour productivity, with TO being not significant.

Overall, then, the relationship between capital stocks and environmental intensity of value added resembles that for value added as a driver. This is not unexpected given the high correlation (0.728 overall) between capital stock and value added, which however may hide some sector based heterogeneity and show different dynamics if we focus on specific and short time periods.

The specifications are quite sensitive to the introduction of TO, which nevertheless does not impact on the sign of the coefficients.

3.5. Industry and services

We also searched for evidence on the drivers of the relationship between the two productivities, for the macro-sectors. Femia and Panfili (2005) using NAMEA data, found service activities to be more efficient from an environmental point of view, though not as much as might have been expected. The reason perhaps is that those sectors involve transformation of matter even if the 'product' may not be directly material. This is one key hypothesis that we can test.

Table 5 summarises the evidence. We rely here on baseline specifications in order to avoid further data losses resulting from dynamic models.

Firstly, CO_2 and also CH_4 (in the non-preferred REM model) show inverted U shapes. In addition, similar to the aggregate analysis, NOx shows an EKC-like trend. This means that there is/was a partial trade-off between the two productivities, which then became a negative relationship that represents a joint dynamics. GHGs and regional externalities are more likely to be associated with trade-offs in terms of economic and environmental productivity (as discussed in Section 2), though we would make the claim that our evidence generally favours a 'complementary' pattern even in those cases. Services present linear negative signs for all GHGs and regional pollutants.

Secondly, local pollutants present negative and linear relationships for both industry and services. This evidence is also in line with expectations.

We can see that while, on the one hand, industry shows a mix of inverted U and negative shapes, services all robustly fit linear negative relationships. It seems that services drive the decoupling of the economy by linking environmental and economic productivities, at least in the context of air emissions performance[11].

These results suggest that composition effects (see Section 2), and in particular the possible structural shift towards services with high value added and low emissions, are relevant to our aggregate level findings, but are not the main explanation of the joint economic-environmental productivity, which emerges across the majority of sectors.

3.6. Summary of results

We can conclude that all emission efficiencies in the Italian NAMEA show a negative relationship with labour productivity, for the period of 1991-2001, which supports the hypothesis of 'complementarity' or joint economic-environmental productivity.

In only one case do we observe a robust inverted U shape (CO_2) for all the specifications, and only for SOx does a U-shaped relationship emerge. It should be noted, nevertheless, that the AR corrected specifications and dynamic models all show the preferred and more robust specification to be a linear form with a negative coefficient, significant at 1%. Signs of a negative 'dynamic relationship' (i.e. positive sign on the coefficient) emerge only for some GHG and NOx, driven by industry. Services show robust linear and negative coefficients across all the cases examined.

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[11] The new series 1990-2005 of NAMEA, available in 2008, will allow for more robust in depth investigation of sector specificity.

The reasons for the predominant complementarity between the two productivities can be found among the market drivers, from input prices to market demand. Policy may also have played a role through emissions (pollutants) regulations, policy support for energy efficiency, firms' strategic behaviour in anticipation of GHG abatement policies (e.g. the EU ETS), and other effects (see discussion below).

The positive relationship between environmental efficiency and labour productivity, as suggested in the EKC literature, could also depend, in part, on a trade elements, i.e. re-location of higher polluting plants and industries in other countries. Our evidence does not support the significant effect of TO, frequently found in the literature, and in two cases out of six we found significant and opposite signs on the coefficient. Regarding CO_2, where the sign on the coefficient is positive, trade specialisation in capital intensive (GHG intensive) sectors might, on balance, more than compensate for 'pollution haven' dynamics, increasing emissions per employee in sectors more open to trade. On the other hand, SOx (and to a lesser extent NOx) shows a negative sign, meaning that in this case 'polluting haven' motivations could have outbalanced specialisation in more polluting sectors. Although the general insignificant role of TO confirms that the variable is somewhat approximate in its capture of the relationship between trade dynamics and environmental efficiency, we show that there are cases where one of the 'internal drivers' prevails. Further research is needed.

4. What factors support 'joint productivity' dynamics? A discussion

4.1 Porter's hypothesis, innovation levers and policies

In this section we discuss the possible factors, and from different theoretical perspectives, supporting the empirical evidence presented above.

We start with 'Porter's hypothesis' (Porter and Van der Linde, 1995; Jaffe et al., 1995). Environmental regulation may influence innovation and market (rent) creation. In the long run, regulation costs, or environmental R&D expenditures, are more than compensated for by the benefits of innovation in terms of higher efficiency and/or higher value added. This conclusion seems to run counter to the conventional wisdom that environmental regulation (like any other regulation, of course) imposes significant direct and indirect costs on firms and industries, with the primary effect of impacting negatively on economic performance, and especially (labour and total factor) productivity (Jaffe et al. 1995). In this case, the picture is one where most pollutants show a strong decrease (in levels) over the recent decades, with total compliance costs rising over time.

The key point from a theoretical and empirical perspective is the extent to which innovation is motivated by pure market strategies and/or policy-related effects.

Following the mainstream reasoning, if the firm is optimising resource allocation in production *over* environmental regulation, any additional abatement cost or innovation cost deriving from policy enforcement will lead, at least in the short run, to an equivalent reduction in productivity, since labour and capital inputs are re-allocated from 'usual' production output to 'environmental output' (pollution reduction).

This emphasis on substitution and trade-offs between the 'two productivities' may stem from the roles in neoclassic reasoning of the assumption of optimal allocation of resources in the *status quo* and of input prices (and green taxes) as innovation levers. In fact, resource prices have been the main driver of change only in specific conditions of strong relative price changes coupled with structural economic transformations, such as prevail after oil shocks; more generally it is technology that affects prices by changing factor combinations and capital intensity. In other approaches, the development of new production processes is viewed as an ongoing process within firms and sectors, independent of, or less reliant on, input prices, except in particular circumstances (Kemp, 1997; Krozer and Nentjes, 2006; Mazzanti and Zoboli, 2006). According to evolutionary theory, interlinked technologies evolve along a dynamic path, generating positive spillovers and effects on productivity. This discussion can be also be positioned with the analysis of **complementarity** in terms of regarding input factors in the production of innovation and higher performance practices (Milgrom and Roberts, 1990, 1995; Mohnen and Roller, 2005; Laursen and Foss, 2003; Mazzanti and Zoboli, 2008b). Complementarity generates increasing returns and non-appropriable innovation rents.

Economies of scale and scope are another linked argument. Labonne and Johnstone (2007) conceptually and empirically analyse the extent to which firms have incentives to adopt end-of-pipe or production process innovation strategies[12]. Complementarity and economies of scale and scope, among other factors, might lead to states where the productivity effect of environmental investments or compliance becomes positive (plausibly in the medium long run).

A more general question is whether it is possible to **separate eco-innovation from other typologies of innovation**. In practice it is often not easy to separate the two (Rennings, 2000). With or without policy aimed at innovations, cost-saving motivations and demand-related product market objectives could work as innovation drivers. All could be complementary in the ultimate aim of enhancing firm productivity, and no sharply defined difference between them may be possible, in that (i) eco-innovations may generate low or high eco-impacts depending on their nature and their integration with other innovations and production processes; (ii) standard innovations may also provide eco-innovations. Much of the current empirical research is aimed at disentangling intended and unintended (e.g. mere cost savings in the more general meaning) eco-effects stemming from innovations: in these approaches, only those innovations linked to intended 'proper' environmental strategies and effects are classified as eco-innovations. A broad definition of eco-innovations encompasses intentional and unintentional actions. This may lead to a framework in which economic and environmental goals are more easily identified as being complementary, and are integrated. Jaffe et al. (1995, 2003) note that firms can engage in some or a great deal of pollution control "Besides end of pipe technologies, firms usually have strong difficulties in accounting for specific capital and current environmental expenditures". As discussed above, it might also be due to the entangled nature of many environmental and 'normal' innovations.

Collins and Harris (2005) discuss the dynamics of productive efficiency of firms according to the effect of pollution expenditures. On the one hand, as claimed by many authors, a polluter that invests in abatement activities is likely to have reduced technical efficiency, as a result of reduced investments in intermediate inputs and capital goods, other things being equal. On the other hand, the impact may be low or even negligible at the margins, given the often limited proportion of resources potential 'diverted' by regulation, and because (i)

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[12] "The choice to invest in either change in production process or end of pipe will be used to evaluate the extent to which production and abatement are undertaken jointly. End of pipe technologies are considered to reflect evidence of the existence of a separable production function, with production the conventional output and abatement of pollution as essentially separate plants within a single facility. Different resources are used for each plant. Production process is considered to reflect a production process in which abatement and production of the conventional output are integrated, allowing for the complementary use of inputs in both abatement and production" (Labonne and Johnstone, 2007, p.3).

abatement technologies, which are environmental innovations, may, to some extent, be not strictly separable from 'other' technologies, as often claimed by mainstream scholars, and (ii) private and public external rents may be correlated.

This reasoning, though mostly framed within the discussion of regulatory tools, defines less clear cut boundaries between what is referred to as optimal (maximising) behaviour in the absence of policy, and the impact of policies. If complementarities happen to exist, the links between private and public elements lead to an endogenous firm strategy aimed at internalising a part of the social costs of following motivations related to cost savings, market based drivers and technological rents. Even at the private profit maximisation level, environmental issues are not excluded *a priori* by firms, but it could be that they are more integrated than expected within business strategies[13]. The nexus between labour productivity and environmental productivity depends strongly on the existing interconnections at the technological level and at the level of the specific externalities addressed[14]. It concerns the manifold 'employment, added value and environmental impact' of environmental and non-environmental technology.

This likely 'jointness' of eco and 'normal' innovations has some connections with the **evolutionary perspective on industrial dynamics**, where the balance between firms' entries and exits is the main driver of development. Along these lines, environmental pressures could constitute an increasing wedge between innovative firms (sectors) and less innovative firms, which could in the end disappear. The former may demonstrate higher performance on all-inclusive innovative grounds, positively integrating and correlating environmental and non-environmental dynamics.

In the heterodox framework, the role of **market demand** creation is relevant, together with the intertwined elements of process and product innovation. Environmentally-oriented new demands are a component of the qualitative (and structural) change in production along economic development (Saviotti and Pyka, 2004; Saviotti, 2005). The role of demand in innovation dynamics has been rather neglected. The environmental costs borne by firms are aimed at increasing efficiency in static terms; nevertheless, in an evolutionary setting, they are associated with a situation in which the presence of potential unmet demand spurs innovative firms. Innovative firms more than non innovative ones, may perceive the 'new (increasing) demands' arising from public and private spheres more strongly. Sector heterogeneity is nonetheless relevant, probably more so than dimensions and performance.

To sum up, the key question revolves around the possibility that firms may adopt some environmental strategies even on an endogenous market-based path. Starting with Porter's framework we discussed elements that might enrich the set of motivations behind a possible joint path of environmental and labour productivity in the medium-long run, even in the absence of direct policy intervention. Evolutionary theories and borderline issues,

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[13] To relate productivity to abatement costs (environmental input) is not equivalent to relating productivity to pollution production (environmental output). In average terms, higher pollution expenditures should be associated with lower pollution levels; at the margin, more efficient and less polluting agents should/could invest fewer resources. A focus on expenditure rather than pollution indicators may be misleading if inefficient firms have both higher pollution costs and lower productivity.

[14] Our evidence is consistent with the so called 'asymmetric case' (Collins and Harris, 2005, p.750), where it is assumed that as efficiency is higher in technical terms, the firm produces more good output and less bad output. The 'symmetric' case instead assumes that higher efficiency produces more good *and* bad outputs.

such as complementarity, could constitute some conceptual pillars that extend the intrinsically static neoclassic reasoning.

4.2 Double externalities, innovation complementarities and impure public goods

Environmental innovations often give rise to a 'dual externality', providing the typical R&D spillovers and also reducing environmental externalities (Jaffe et al., 2003; Rennings, 2000). Therefore, innovation aimed at reducing environmental impact may spur positive innovation spillovers. This is the first element of complementarity that in our framework could explain why environmental efficiency is linked to labour productivity dynamics.

Another motivation is related to the issue of rent generation and appropriability. The production of some 'environmental goods' is associated with rents that are appropriable, at least partially, by firms. They are in fact correctly defined as the private share of an impure public good, which encompasses other entangled pure public features. Many environmental innovations combine an environmental benefit with a benefit for the company or user. For example, there might be differences between water use and CO_2 emissions: in the first case, it is more likely that firms autonomously adopt saving strategies, whether or not a policy exists, whereas in the second case it is less likely given the prevalent public good nature (for the firm) of emissions, which are more difficult to internalise or reuse in production processes. However, innovations in 'carbon capture and storage', which enable CO_2 to be used to increase the efficiency of extraction in oil fields, can increase the 'private' returns from reducing emission externalities.

The gaps between environmentally accounted and standard productivity often emerges in the differences between natural resources and correlated externalities (Bruvoll et al., 2003). Such differences may be in both directions - positive and negative Thus, the innovation potential of policies, and the associated innovative endogenous strategy of firms depend on the features of the environmental goods. Those goods may be characterised by private appropriable rents and by public good elements. This complementarity in production, i.e. a technologically-based positive correlation between the private (fully appropriable) and the public good elements (Cainelli et al., 2007), is potentially linked both to the kind of externalities we are dealing with, e.g. local/global emissions, private or public product/process innovation features (Kotchen, 2005; Rubbelke, 2003; Loschel and Rubbelke, 2005), and to technological factors, e.g. the relationships existing among apparently separate technological dynamics.

Technology and externalities are in any case theoretically interrelated environments; and non-convexities in production could be an important element for the joint production of private and public values, depending on fixed costs and technological constraints (Papandreou, 2000; Boscolo and Vincent, 2003).

The mix and the correlation of the two levels, within an impure public good framework, are crucial for assessing the environmental strategies of firms, and the role of policies. The dual externality may increase the importance of the regulatory framework since the addition of two externalities, one positive and one negative, may lead to suboptimal investments in environmental innovations, which are supposed to be appropriable with difficulty. A correlation between the private and public elements may mitigate this outcome, favouring investments in innovation even in the absence of policy intervention. The core in this reasoning is the private incentive of firms to invest, which depends on the degree of appropriability of innovation rents, which is key.

The impure public good feature (Cornes and Sandler, 1997) has an effect in two directions, which are shown to be interrelated. It also provides new insights and concreteness to the cited 'dual externality' metaphor.

The role of policies remains relevant and emerges as correcting for externalities that are not 'already' tackled endogenously by firms and industries, which are driven by demand, cost, product value added and other market-based motivations, including the private provision of a public good through the idiosyncratic entanglement of public and private features in most environmental issues at the local and global levels.

The 'pessimistic' view of a trade-off between firms' environmental and non-environmental strategies may be mitigated by a framework in which those complementarities, which at heart involve different technological innovations (labour-oriented, environmentally-oriented), might explain, at least in part, why sustained increasing environmental efficiency is compatible with sustained increasing labour productivity in the *ex post* setting.

5. Conclusions

We find that for most NAMEA emissions there is a positive relationship between 'labour productivity' and 'environmental productivity' (emissions efficiency). We show that this macro-aggregate evidence is driven by sector dynamics in a non-homogenous way, across pollutants. If services tend to show always a 'complementary' relationships, industry is to some extent characterised by inverted U-shaped dynamics for GHG and NOx. This evidence fits with our expectations. The prevailing technological dynamics is one in which the intensification of capital in the Italian economy has led, ex post, either to increasing value added per employee and to reducing air emissions per value added, which corresponds to the descending part of an EKC in these two variables, or to an EKC pattern in which a jointly increasing productivity has substituted for a trade-off between value added and environmental efficiency.

This stylised fact on joint economic-environmental productivity for NAMEA emissions across production branches seems to depart from the conventional neoclassical trade-off between 'optimal' allocations in terms of labour productivity, and allocations aimed at reducing emissions. Of course, our results cannot exclude that, *ex ante*, single firms face a trade-off in allocating investments, and the opportunity costs of investing in environmental efficiency. However, these trade-offs are not observable outside of a firm-based information set. The evidence we have provided is on *ex post* joint productivity trends at the level of production branches, but it also calls into question the existence of systematic trade-offs between different kinds of productivity at the level of firm strategies, as well as the separability between optimisation with and without the environment.

We discussed certain factors behind the stylised fact that emerges from our analysis. The key suggestion is that at the roots of the (joint) dynamic between environmental and labour productivity different types of innovation play different roles, with a possible key role of the 'impure public good content' of R&D processes. Major restructuring processes in the economic system, and environmental policies are further credible 'drivers', with the latter possibly provoking 'anticipating' innovation strategies by some firms and sectors, both for air pollutants and GHGs. The dynamics of exogenous energy market forces can be added as an underlying determinant of energy/emission savings through capital intensification. The motivations of a joint productivity dynamics may also depend on the links between different innovations, which make the one conditional on the other and can prevent full separability of production factors and innovative strategies. These mechanisms should be clarified by further empirical research at firm and industry level, to provide a fuller explanation of the joint dynamics we have presented above.

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Table1a. Descriptive statistics

Variable	mean	min	max
VA/N	53.10	10.77 (B, 1992)	286.70 (CA, 1997)
K/N	148.26	22.89 (F, 1992)	852.66 (E, 2001)
Trade Openness	1.07	0 (F, and most services)	8.01 (CA, 2001)
CO_2/VA	685.58	4.30 (CA, 1997)	9081.41 (E, 1997)
CH_4/VA	2.49	0.0019 (J, 2001)	38.17 (A, 1990)
NOx/VA	2.23	0.0347 (CA, 2001)	29.83 (E, 1991)
SOx/VA	2.56	0.00074 (CA, 2000)	61.01 (E, 1990)
NMVOC/VA	2.28	0.01 (M, 2001)	16.1 (DF, 1990)
PM_{10}/VA	0.325	0.0029 (CA, 1997)	2.76 (E, 1990)

N=employees (thousands); VA=added value (Millions of euro liras 1995); Emissions (tons), trade openness (TO=import+export/VA)

Table 1b. Sector branches description

Sector Code	Description
A	Agriculture
B	Fishery
CA	Extraction of energy Minerals
CB	Extraction of non energy Minerals
DA	Food and beverages
DB	textile
DC	Leather textile
DD	Wood
DE	Paper and cardboard
DF	Coke, oil refinery, nuclear disposal
DG	chemical
DH	Plastic and rubber
DI	Non metallurgic minerals
DJ	Metallurgic
DK	Machinery
DL	Electronic and optical machinery
DM	Transport Vehicles production
DN	Other manufacturing industries
E	Energy production (electricity, water, gas)
F	Construction
G	Commerce
H	Hotels and restaurants
I	Transport
J	Finance and insurance
K	Other market services (Real estate, ICT, R&D)
L	Public administration
M	Education
N	Health
O	Other public services

Table 2. Environmental efficiency and labour productivity (Baseline regression)

Dep var Indep var	CO2/VA	CH4/VA	NOx/VA	SOx/VA	NMVOC/VA	PM10/VA
VA/N	0.675*	-0.476***	1.209**	-8.46***	-1.498***	-0.705***
(VA/N)2	-0.162***	/	-0.202***	0.487*	/	/
TO	0.073***	0.070	-0.055***	-0.726***	-0.238***	0.018
FEM/REM	REM	FEM	REM	FEM	FEM	REM
F test (Chi squared prob.)	0.0000	0.0059	0.0000	0.0000	0.0000	0.0000
N	319	319	319	319	319	319

Notes: Coefficients are shown in cells: *10% significance, **5%, ***1%. For each column we present the best fit specification in terms of overall and coefficient significance. Random or fixed effect specifications are presented accordingly to the Hausman test result. The FEM model estimated is a LSDV model; individual fixed effect coefficients are not shown. Fem and REM estimated as expected in this case are often similar in size and significance. T=1991-2001

Table 3. Environmental efficiency and labour productivity (AR regressions)

Dep var Indep var	CO2/VA	CH4/VA	NOx/VA	SOx/VA	NMVOC/VA	PM10/VA
VA/N	-0.671***	-0.690***	-0.673***	-1.002***	-0.724***	-0.691***
(VA/N)2	/	/	/	/	/	/
TO	0.062***	0.033	-0.010	-0.175**	-0.038	0.002
FEM/REM	REM	FEM	REM	FEM	FEM	REM
F test (Chi squared prob.)	0.0000	0.0000	0.0000	0.0030	0.0000	0.0000
N	319	319	319	319	319	319

T=1991-2001

Table 4. Environmental efficiency and labour productivity (LSDV Kiviet corrected dynamic models)

Dep var Indep var	CO2/VA	CH4/VA	NOx/VA	SOx/VA	NMVOC/VA	PM10/VA
Y(t-1)	0.854***	0.975***	0.984***	0.950***	1.064***	0.991***
VA/N	-0.273***	-0.280***	-0.193***	-0.900***	-0.203**	-0.186***
TO	0.036**	0.020	-0.0002	-0.094**	-0.016	0.007
N	290	290	290	290	290	290

Standard errors derive from bootstrapping procedures. Arellano Bond model is chosen to estimate initial values; the accuracy of the estimation is up to an order of (1/NT^2), T=1991-2001

Table 5. Environmental efficiency and labour productivity (Industry and services, AR(1) regressions)

Dep var Indep var	CO2/VA	CH4/VA	NOx/VA	SOx/VA	NMVOC/VA	PM10/VA
Industry (C-F)						
VA/N	1.745**	-0.816***	1.803**	-1.256***	-0.744***	-0.833***
(VA/N)2	-0.264***	/	-0.266***	/	/	/
TO	0.002	0.025	-0.048*	-0.190***	-0.088***	-0.013
FEM/REM	REM	FEM	REM	FEM	REM	FEM
F test (Chi squared prob.)	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
N	198	198	198	198	198	198
Services (G-O)						
VA/N	-1.029***	-1.545***	-1.266***	-1.955***	-1.432**	-1.312***
(VA/N)2	/	/	/	/	/	/
FEM/REM	REM	REM	REM	REM	REM	FEM
F test (Chi squared prob.)	0.0000	0.0090	0.0002	0.0170	0.0407	0.0001
N	109	109	109	109	109	109

T=1991-2001