Nitrogen surplus displays a spurious Environmental Kuznets Curve in Germany

by Bente Castro Campos and Martin Petrick

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Abstract

We examine the relationship between nitrogen surplus per hectare and the median monthly wage per capita considering the Environmental Kuznets Curve (EKC) theory. The EKC hypothesizes an inverse U-shape relationship between environmental pollution and economic growth. We use a novel panel data set for nitrogen surplus as an environmental pollutant and a measure of the median monthly wage per capita during the period from 1999 to 2018 for 401 counties in Germany. Our estimation results show that nitrogen surplus displays a spurious EKC in Germany. It is spurious because the inverse U-shape relationship produced by parametric and non-parametric panel regression of nitrogen surplus on median wage is rejected by first difference regression and tracing of individual county paths. This implies that in Germany economic growth has not cleaned up the environmental damage from nitrogen surplus. The affected counties remain in a self-reinforcing equilibrium (shown with the individual county paths) that they cannot break out of in the course of the EKC, at least not without political intervention. Scientific effort to better understand the complexity and interlinkages of the underlying behavioural, cultural, social, economic, institutional and innovation dynamics is deemed necessary for positive environmental change.

Keywords: Environmental Kuznets Curve (EKC), nitrogen surplus, Germany

JEL: C33; Q53; Q58

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1. Introduction

The environmental Kuznets curve (EKC) postulates an inverted U-shape relationship between environmental pollution and economic growth. The EKC assumes that environmental pollution increases with rising income linked to economic growth until a certain threshold (turning point) after which environmental pollution decreases with rising income per capita. The Kuznets Curve is named after Kuznets (1955) who originally postulated that income inequality first increases and then decreases with economic development. Grossman and Krueger (1991, 1995) and Panayotou (1993) pioneered research on the EKC; it has since then been the main approach in economics for studying the relationship between environmental pollution and economic growth (Stern 2017).

The EKC is an important indicator for environmental policy and follows a reverse logic to the one put forth in the *Limits to Growth* (Meadows et al. 1972), given that the EKC postulates an inverted U-shape relationship between economic growth and the environment (Grossman and Krueger 1995) and not its limitations. This suggests that after a turning point, environmental improvement towards more sustainability through higher willingness to pay for environmental quality and lower opportunity costs for environmental friendly production through technological innovation, structural change, environmental regulation and education (Pasten and Figueroa 2012), rather than environmental degradation from limited resources is likely to occur.

The academic evidence on the presence of an EKC is mixed. Stern (2004, 2017) provides two literature reviews about EKC studies. He takes a rather critical stance on the theoretical and empirical studies linked to the EKC. The presence of an EKC is often rejected in country comparison studies but becomes more relevant at smaller scales and for specific pollutants (e.g., Song et al. 2008; Pasten and Figueroa 2012; Paudel and Poudel 2013). The pace of environmental improvement crucially depends on a region´s existing position on the EKC (Zhang et al. 2015). Developing countries, thus, often have monotonically increasing curves, while developed countries show a higher evidence of EKCs (Stern et al. 1996; Stern and Common 2001; Pasten and Figueroa 2012). Despite the efforts taken to estimate EKCs at country level, Dasgupta et al. (2002) points out that the underlying mechanisms and possible regional heterogeneity are hardly discussed in empirical investigations, possibly leading to imprecise policy recommendations.

The results of the EKC literature for the specific pollutant of nitrogen show a clear empirical relationship; however, theoretical explanations for this relationship are largely missing (e.g., Dasgupta et al. 2002). At local scale, Paudel and Poudel (2013) find significant coefficients for income and income polynomials for nitrogen, measured as the sum of Kjeldehl and nitrate plus nitrite nitrogen weighted for each county in the US state of Louisiana using data from 1985 to 1998. The authors compared parametric and nonparametric models and find parametric estimation to be suitable for nitrogen. Li et al. (2016) confirm the presence of EKCs for nitrogen, phosphorus and pesticide indicators in China by applying dynamic panel data models for data from 1989 to 2009. Similarly for India, Singh and Narayanan (2015) find a nonlinear relationship between per capita income and per hectare of agrochemical use by means of data for the period from 1990 to 2008 for 25 Indian states. At global scale, Zhang et al. (2015) suggest shapes analogous to the EKC for nitrogen pollution from agriculture in many countries of the 113 countries considered from 1961 to 2011 using parametric estimations.

This article extends the existing literature with a study of the EKC for the environmental pollutant of nitrogen surplus considering 401 counties in Germany for the period from 1999 to 2018. We selected Germany because the second highest groundwater nitrogen pollution levels in the European Union (EU) are found in Germany (European Commission 2018, 7).[4] European policies, especially the changes in the Common Agricultural Policy (CAP), the Nitrate and Water Directives, have affected the turning points of EKCs in Europe through supply side reductions of environmental pollutants (Sutton et al. 2011; Grinsven et al. 2012; Grinsven et al. 2015); however, high nitrogen surplus remains in many regions in Germany even though the Fertilizer Ordinance has been amended in 2017 and 2020 towards stricter measures for fertilizer application (Kirschke et al. 2019; Haeussermann et al. 2020). The European Commission is currently threatening Germany with a daily penalty of 858,000 Euro if local efforts to combat nitrogen contamination of its water bodies are not enhanced considerably (Frankfurter Allgemeine Zeitung 2019; Bundesministerium für Ernährung und Landwirtschaft 2019). Nitrogen pollution comes at a high cost. The European Union spends roughly 70 billion to 320 billion Euro annually for the consequences of nitrogen pollution (Sutton, Oenema, et al. 2011). To the best of our knowledge, there are no previous studies measuring the EKC of nitrogen surplus in Germany. Analysing nitrogen surplus in Germany is, thus, not only of high scientific but also, as just highlighted, of high political importance, not to mention the devastating environmental and health consequences for the affected people. This article will close this research gap.

[4] However, the nitrogen measurement networks of EU countries are not directly comparable triggering a national debate about the issue of comparability at EU level (Bach et al. 2020).

The findings of this article show that nitrogen surplus displays a spurious EKC in Germany. It is spurious because the estimation results considering different model specifications provide no straightforward results. While some of the model specifications using fixed effects and the panel corrected standard error (PCSE) estimator provide evidence for an inverse U-shape relationship between median wage and nitrogen surplus, the first difference estimation and the individual county plots cannot support this finding. Our findings largely suggest that in Germany economic growth has not cleaned up the environmental damage from nitrogen surplus. Furthermore, the tracing of individual county paths indicate that the affected counties remain in a self-reinforcing equilibrium that they cannot break out of in the course of the EKC, at least not without political intervention.

The classical framework for explaining the presence of an EKC, as given by Pasten and Figueroa (2012), uses an expansion path of the intersections between utility and production functions, where pollution, in this article nitrogen surplus, is considered as an additional determinant in both functions. The utility function is determined by the willingness to pay for decreasing the marginal pollution or for increasing the marginal quality of the environment. The production function is determined by the opportunity cost for decreasing the marginal pollution or for increasing the marginal quality of the environment. The global goal is to move countries above the turning point (to decrease pollution with increasing economic growth) with policy interventions affecting either the demand or the supply side determinants or both. This macroeconomic reasoning is very useful for understanding global differences of EKCs but fails to provide microeconomic explanations that are crucial for policy making.

In the specific case of Germany, the regional differences cannot be explained by these macroeconomic differences. The supply and demand curves are not determined at regional level in Germany. Regional markets that would allow an EKC to emerge from demand and supply side mechanisms do not exist. Instead, Germany is a leading exporting country and its regions are highly interconnected economically. Furthermore, the formal laws and regulations to combat environmental pollution are largely the same across Germany. Differences in formal regulations can, thus, hardly explain the regionally different positions on the EKC for nitrogen surplus in Germany. This article will, thus, discuss additional underlying determinants of an EKC for nitrogen surplus to explain potential regional differences.

The methodology to measure the EKC, in particular the incorrect econometric specification and missing statistical tests, was subject to criticism. Stern (2004) and Copeland and Taylor (2004) casts doubt about the empirical relevance of several studies, suggesting more rigorous time-series or panel data applications. In particular, the functional form of the parametric panel approaches is subject to criticism. As a consequence, researchers have started to conduct nonparametric estimations for better approximating the real functional forms and for comparing the nonparametric to the parametric findings (Paudel et al. 2005; Azomahou et al. 2006; Poudel et al. 2009; Paudel and Poudel 2013). Therefore, the empirical analysis, conducted in this article, of the EKC on nitrogen surplus at county level in Germany applies rigorous panel estimations, considering both parametric, including first difference estimation to control for omitted variable bias, and nonparametric estimations, as well as relevant statistical tests to overcome the empirical issues mentioned by Stern (2004, 2017). Furthermore, instead of the mean per capita and levels of income, we use the median per capita and the logarithms of wages, respectively, as suggested by Stern (2017), as independent variable. Nitrogen surplus of the soil surface budget is calculated from the difference between nitrogen input and output of the utilized agricultural area (UAA) at county level in Germany (Haeussermann et al. 2020). It contains N input into the soil, excluding NH_3 losses from manure, digestates and mineral fertilizers applied to agricultural land; N_2, NO_X and N_2O emissions from the soil due to nitrification and denitrification; N losses from soil organic matter in marshy and moor soils linked to agricultural land use.

The article is organized as follows. Section 2 describes the empirical approach used in this article. Section 3 presents the data and provides descriptive statistics. In section 4, we present the estimation and test results. In section 5, we discuss the results in a regional context and highlight possible regional differences. Finally, the conclusions are drawn in section 6.

2. Estimating the EKC for nitrogen surplus in Germany

We use a standard EKC model that uses the logarithms of income per capita and an additional quadratic term of the logarithm of income per capita to examine the presence of the inverted U-shaped EKC. The model follows the standard structure (Stern 2004, 2010):

$$N_{it} = a_i + \gamma_t + \beta_1 Y_{it} + \beta_2 Y_{it}^2 + \varepsilon_{it}, \qquad (1)$$

where N denotes the nitrogen surplus measured in kilogram per hectare for the different counties and years, and Y stands for the median wage per capita (CPI adjusted, base year 2015). N and Y are both in natural logarithms. i and t are indices of county and year, respectively. a and γ are intercept parameters which vary across counties and years, respectively. ε is the error term. The turning point of income is calculated by $\exp(Y^*) = \exp(-\beta_1/(2\beta_2))$.

Based on this equation, we estimate fixed-effects models, which use the within regression estimator (e.g., Wooldridge 2020). Furthermore, following Beck and Katz (1995) we also use an approach where ordinary least squares (OLS) parameter estimates are applied, but where the OLS standard errors are replaced with panel-corrected standard errors (PCSE) to control for heteroskedasticity. The PCSE estimator is found to be very accurate and efficient in Monte Carlo simulations and outperformed the OLS estimator, if the assumption of homoscedastic errors and/or no serial correlation was violated, but provides standard errors similar to the OLS estimator, if the assumptions are not violated (Beck and Katz 1995). Additionally, we use the first difference transformation of the fixed-effects model, Equation 1, to remove time-constant unobserved effects to account for possible omitted variable bias that could potentially affect N:

$$\Delta N_{it} = \beta_1 \Delta Y_{it} + \beta_2 (\Delta Y_{it})^2 + \Delta \varepsilon_{it}, \qquad (2)$$

where a_i is considered a parameter and shows the average of the individual-specific intercepts (Wooldridge 2020, p. 467). Fixed effects estimation is usually more efficient than first-difference estimation if the ε_{it} are serially uncorrelated; however, if ε_{it} follows a random walk, meaning "substantial positive serial correlation", then first-difference estimation is more efficient given that the difference $\Delta\varepsilon_{it}$ is serially uncorrelated (Wooldridge 2020, p. 467). The parametric panel data model is then tested against the nonparametric model (Paudel et al. 2005; Azomahou et al. 2006; Poudel et al. 2009; Paudel and Poudel 2013) using the Davidson and MacKinnon (1981) approach.

3. Data and descriptive statistics

The data structure is a balanced panel of 401 counties over the period from 1999 to 2018.[1] Table 1 provides descriptive statistics and takes into account the panel structure of the sample by reporting overall, between and within county magnitudes.

The German Environment Agency provided the nitrogen surplus series, measured in kilogram per hectare (kg/ha) (Haeussermann et al. 2020). The nitrogen surplus from the soil surface is equal to the difference of nitrogen (N) input and output of the UAA. It contains N input into the soil, excluding

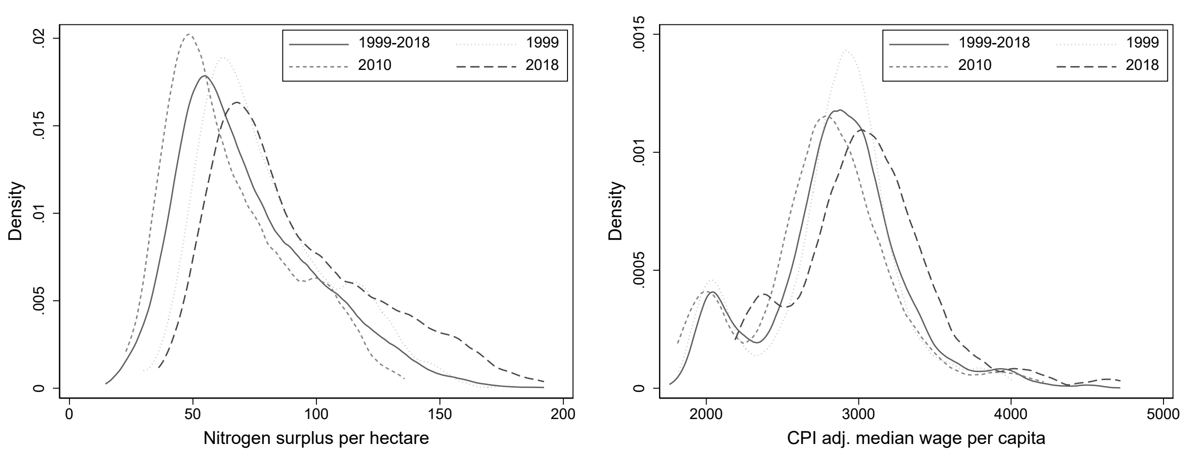
[1] The administrative reforms of the counties/city states that took place between 1999 and 2018 in Germany have been taken into account. For counties/cities that changed their ids and/or names, the old ids/names have been replaced with the new ids/names for all the years considered. The main reforms were those in Mecklenburg-Western Pomerania in 2011 and in Saxony and Saxony-Anhalt in 2008. If several counties were merged to one county, then the time-series of the county that closely followed the time-series trend of the merged county after the reform was used. The counties not considered anymore were dropped from the analysis for all years.

NH_3 losses from manure, digestates and mineral fertilizers applied to agricultural land; N_2, NO_X and N_2O emissions from the soil due to nitrification and denitrification; N losses from soil organic matter in marshy and moor soils linked to agricultural land use. A detailed description of the methodology can be found in Haeussermann et al. (2020). The descriptive statistics of N surplus show that nitrogen surplus per hectare varies from 14.5 (the level of Mainz) to 192.2 kg (the levels of Bottrop, Gelsenkirchen, Recklinghausen). The between standard deviation for nitrogen surplus is approximately two times larger than the within standard deviation. Figure 1a shows the Kernel density using the Epanechnikov kernel for nitrogen surplus at the left hand side. It is visible that nitrogen surplus follows a slightly right skewed normal distribution with a long tail to the right. Furthermore, Figure 1a shows that the extreme values of nitrogen surplus have increased over time.

Table 1. Descriptive statistics

Variables		Mean	Std. Dev.	Min	Max	Observations
Nitrogen surplus	overall	72.4	28.3	14.5	192.2	N = 8020
(kg/ha per county)	between		26.0	26.7	148.8	n = 401
	within		11.3	36.5	149.0	T = 20
CPI adj. per capita wage	overall	2856.6	448.3	1759.1	4717.6	N = 8020
(median per county)	between		437.9	1897.6	4218.3	n = 401
	within		98.5	2284.4	3508.9	T = 20
Year				1999	2018	N = 8020

Source: Authors.



(a) (b)

Figure 1. Kernel density estimates for (a) nitrogen surplus and (b) median wage for the period from 1999-2018, 1999, 2010 and 2018 using the Epanechnikov kernel. Source: Authors.

The Federal Employment Agency provided the median per capita wage series per county, which include the median of the gross monthly per capita wage of full-time employees of the core group, who are subject to social security contributions. Grimm (2016) provides a detailed description of the methodology used to calculate the median per capita wage. A limitation of the data is that the income from self-employment not subject to social security contributions, part-time employment and other income sources are not included. We adjusted the median wage per capita series for inflation (base CPI=100 in 2015). The descriptive statistics show that the median wage per capita vary from 1759.1 Euro (Löbau-Zittau) to 4717.6 Euro (Ingolstadt). The between standard deviation for median wage is approximately four times larger than the within standard deviation. Figure 1b shows the Kernel density estimates using the Epanechnikov kernel for median per capita wage. It is shown that the median wage per capita series follows a normal distribution with some inconsistencies at low median wage per capita levels. Figure 1b also shows that median wage per capita is increasing and that more counties shift to higher median wages over time.

4. Results

Table 2 shows the estimation results for the presence of an EKC for the environmental pollutant of nitrogen surplus in Germany considering the period from 1999 to 2018. Columns 1 and 2 show the results from the fixed effects panel estimations without and with year fixed effects, respectively (Equation 1). Column 3 shows the first difference fixed effects panel estimation (Equation 2). Columns 4 and 5 show the results for the model with panel corrected standard errors (PCSE) without and with year fixed effects, respectively.

Table 2. Parameter estimates of nitrogen surplus, Germany 1999-2018

Variables	Ln nitrogen surplus[a]				
	(1) FE	(2) FE	(3) D.FE	(4) PCSE	(5) PCSE
Ln CPI adj. wage	2.860	4.431**		37.633***	37.539***
	(4.16)	(1.85)		(1.51)	(1.34)
Ln CPI adj. wage-square	-0.096	-0.298**		-2.347***	-2.344***
	(0.26)	(0.12)		(0.10)	(0.09)
D. Ln CPI adj. wage			3.044***		
			(0.15)		
D. Ln CPI adj. wage-square			27.199***		
			(9.13)		
Years	No	Yes	No	No	Yes
Constant	-12.479	-11.943*	-0.010***	-146.578***	-145.768***
	(16.34)	(7.22)	(0.00)	(5.94)	(5.30)
Turning point	-	[€1708.84]	-	[€3033.61]	[€2998.37]
Observations	8020	8020	7619	8020	8020
Adjusted R^2	0.084	0.820	0.037	0.099	0.232

Notes: Robust standard errors are in parentheses. Ln refers to logarithm. FE stands for fixed effects, respectively. D.FE refers to the first difference fixed effects. PCSE refers to panel corrected standard errors. a) For the model (3), the first

difference of the logarithms of nitrogen surplus is used.
* p<0.10, ** p<0.05, *** p<0.010
The test results from the standard fixed effects model are: FE versus RE Hausman test: chi2 (2) = 90.1 (p-value: 0.00), Heteroskedasticity: chi2 (401) = 28360.04 (p-value: 0.00), Autocorrelation (Wooldridge test): F (1, 400) = 1.128 (p-value: 0.2889); Pesaran's test of cross sectional independence: 0.516 (p-value: 0.6055).
Source: Authors.

At the bottom of Table 2, we report the statistical test results. The Hausman test indicates that the fixed effects panel model is preferred over the random effects panel model. Therefore, we focus on the fixed effects panel model and conduct the relevant tests for cross-sectional dependence, heteroskedasticity, autocorrelation, and stationarity. The Pesaran test finds no cross-sectional dependence in the model. The null of homoskedasticity (or constant variance) is rejected, indicating the presence of heterogeneity in the data. The Wooldridge test for autocorrelation shows that the data has no serial correlation. The unit root tests (Levin-Lin-Chu (LLC)) with the optimal lag level chosen by AIC, indicate that both time series have unit roots in most of the specifications considered. However, if we control for cross-sectional correlation by removing cross-sectional means, the LLC test rejects the hypothesis that the series for the logarithm of nitrogen surplus has a unit root. Similarly, the Fisher-type unit-root tests based on the augmented Dickey-Fuller (ADF) tests (Choi 2001) with drift and two lags strongly reject the hypothesis that the logarithm of nitrogen surplus and the CPI adjusted median wage series have unit roots. In contrast, the same ADF tests with trend fail to reject the hypothesis that both series contain unit roots. Therefore, the results from the unit-root tests provide no straightforward results.

The R^2 for the models in levels is understood as the amount of time variation in the explanatory variables. In the estimations without year dummy variables (Columns 1 and 4 in Table 2), the R^2 is much lower than in the models with year dummy variables (Columns 2 and 5 in Table 2). The reason is that in the estimations with year dummy variables, a year dummy variable is included for each year from 1999 to 2018 (base year); the 19 additional year dummies largely increase explanatory power of the respective models (see also Wooldridge 2020, p. 466 on the usually very high R^2 in dummy variable regression). By changing the model through differencing (Column 3 in Table 2), we also change the total variance for calculating the R^2; therefore, the R^2 in the first difference estimation cannot be directly compared to the models in levels. The R^2 in the first difference specification is usually lower because it eliminates the portion that is explained from the within time variation in the explanatory variables.

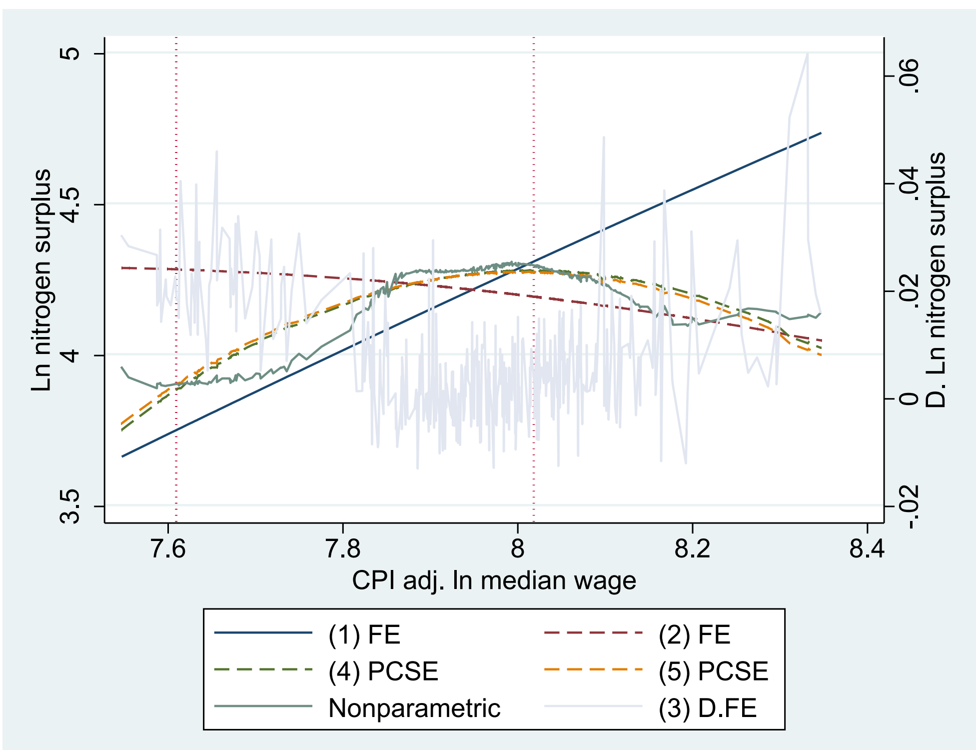
Our estimation results, as shown in Table 2, provide evidence for a spurious display of an EKC for nitrogen surplus in Germany. It is spurious because of the different results obtained from the estimations. While the fixed effect model without year fixed effects (Column 1) shows insignificant wage and wage-square coefficients, the fixed effects model with year fixed effects (Column 2) show statistically significant wage and wage-square coefficients with the expected signs (a positive wage coefficient and a negative wage-square coefficient confirm the presence of an EKC). The estimated turning point is 1708.84 € (Table 2). The results indicate that in the fixed effects specification, the year dummy variables explain most of the variation in the regression. Given that the wage and wage-square coefficients change from being insignificant to being significant with the additional year dummy variables, they are most likely correlated with the year dummy variables, possibly linked to unobserved heteroscedasticity and/or unit root issues in the standard errors. We suspect heteroscedasticity and/or a unit root because the test results show neither cross-sectional dependence nor autocorrelation in the time series, but reject the homoskedasticity assumption and provide no straightforward results for the unit root tests.

To control for heteroscedasticity in the standard errors, we estimate an OLS model with panel corrected standard errors (PCSE) based on Beck and Katz (1995). The results from the PCSE estimations with and without year dummy variables (Columns 4 and 5) strongly confirm the fixed effects estimations with year dummy variables (Column 2). The estimated turning points range from roughly 2998.37 € to 3033.61 € (Table 2). Using the PCSE approach provides more accurate standard errors, if the standard errors vary from the underlying assumptions in OLS models (homoscedasticity, no serial correlation), but provide standard errors similar to OLS, if the underlying assumptions in OLS models are met (Beck and Katz 1995). However, while the PSCSE approach controls for heteroscedasticity and serial correlation in the standard errors, it is not clear how unit roots are addressed with the PCSE, which is most likely another issue in the fixed effect estimations.

To take care of the unit root issue, we estimate the first difference fixed effects model that controls for potential omitted variable bias (Column 3). The results suggest opposite findings to the ones obtained from fixed effects estimation with year dummy variables and the ones obtained with the PCSE estimator. The first difference estimations provide statistically significant evidence for a U-shape relationship (the opposite to the inverse U-shape of the EKC) between the median wage and nitrogen surplus; thus, strongly discarding the presence of an EKC for nitrogen surplus in Germany.

Additionally, we included a cubic term of the logarithm of CPI adjusted wage into the models but the estimation results were not convincing; therefore, we have not considered the cubic term in the estimations. The Davidson and MacKinnon (1981) approach found no conclusive results of whether the parametric or the nonparametric model, which will be illustrated in Figure 2, is preferred.

Figure 2 shows the predicted values from the estimations as given in Table 2 and the nonparametric plot.[5] Following the estimation results of Table 2, Figure 2 further illustrates that nitrogen surplus displays a spurious EKC in Germany because the predicted curves differ greatly among each other and only the predictions from the estimations with the PSCE estimator and to some extent the nonparametric plot show the inverse U-shape relationship of the EKC. The predictions from the fixed effects estimations without year dummy variable show a positive linear relationship between median wage and nitrogen surplus, while the predictions from the fixed effects estimation with year dummy variables indicate a slightly downward sloping relationship between the two. The predictions from the first difference estimation show the most spurious results with no clear relationship between median wage and nitrogen surplus.



[5] The nonparametric estimation is based on Cattaneo and Jansson (2018).

Figure 2. Spurious Environmental Kuznets Curve for nitrogen surplus in Germany.

Note: x-axis: CPI adj. ln median wage stands for the logarithm of the CPI adjusted median per capita wage in the county, y-axis: Ln nitrogen surplus stands for the logarithm of the nitrogen surplus in kilogram per hectare in the county. (1) FE, (2) FE, (3) D.FE, (4) PCSE, (5) PCSE refer to the parametric estimations as given in the respective columns in Table 2. Nonparametric refers to the nonparametric estimation. The vertical lines illustrate the estimated turning points of 1708.84 Euro (exp(7.44)) and 3033.61 Euro (exp(8.02)).
Source: Authors.

In this way, our findings of the presence of an EKC for nitrogen surplus are not as straightforward as suggested by the literature (e.g., Li et al. 2016, Paudel and Poudel 2013, Singh and Narayanan 2015, Zhang et al. 2015). The results also show that even though there seems to be a clear presence of an EKC at first sight, it is necessary to conduct first difference estimation to control for omitted variable bias, which has led to opposite results in our analysis. Furthermore, we plot the 401 individual counties for the years from 1999 to 2018 with the logarithm of nitrogen surplus at the y-axis and the CPI-adjusted median monthly wages at the x-axis. The time plots show no evidence for an improvement of nitrogen surplus with additional wage at county level over time.[6] The tracing of individual county paths over time provides no indication of an EKC of nitrogen surplus in Germany and shows that the affected counties remain in a self-reinforcing equilibrium that they cannot break out of in the course of the EKC, at least not without political intervention.

5. Discussion

The EKC has been used as an important indicator for environmental policy despite its criticism (e.g., Stern 2004, 2017). Even though for the specific pollutant of nitrogen some evidence for an EKC is found in some world regions (e.g., Li et al. 2016, Paudel and Poudel 2013, Singh and Narayanan 2015, Zhang et al. 2015), theoretical explanations for a significant relationship between environmental pollution and economic growth are largely missing (Dasgupta et al. 2002).

Pasten and Figueroa (2012) describe a classical theoretical framework considering macroeconomic theory for the presence of an EKC, which is based on an intersection between utility and production functions. This macroeconomic reasoning, however, fails to provide microeconomic explanations that are crucial for country specific studies and policy making. In Germany, the supply and demand curves are not determined at regional level; regional markets do not exist but would be a prerequisite for an EKC to emerge from demand and supply side mechanisms. Germany is a leading exporting country

[6] The results are available upon request.

and its regions are highly interconnected economically. As the formal laws and regulations to combat environmental pollution are also largely the same across Germany, differences in formal regulations cannot explain the different positions of counties on the EKC for nitrogen surplus in Germany.

With this article, we analyse the EKC for the environmental pollutant of nitrogen surplus considering 401 counties in Germany for the period from 1999 to 2018. The reason for choosing Germany is linked to the high groundwater nitrogen pollution levels in the country (European Commission 2018, 7) and the negative environmental and health consequences for the affected people. Our fixed effects and panel corrected standard error (PCSE) estimations provide evidence that nitrogen surplus displays an EKC in Germany; however, the first difference estimations strongly discard the presence of an EKC for nitrogen surplus in Germany. The question arises whether previous studies that confirm the presence of EKCs have rigorously considered potential omitted variable bias through estimating first differences? We find that this is not the case for most of the studies reviewed in this article; therefore, we follow Stern´s (2004, 2017) critical stance on the theoretical and empirical studies linked to the EKC.

Our findings provide evidence that in Germany economic growth has not cleaned up the environmental damage from excessive nitrogen surplus. It appears that the now problematic regions will not get "better" with additional economic growth through an increase in wages. Breaking path dependencies could be the key for reducing environmental pollution from nitrogen surplus, though it requires huge scientific effort to better understand the complexity and interlinkages of the underlying behavioural, cultural, social, economic, institutional and innovation dynamics.

Specifically, if we take a look at the counties with high nitrogen surplus and low wages ("the worst affected in the ecological and social domains"), the majority can be found in many northern and north-western regions as well as in some counties in the south without any considerable improvement over the considered period of our study from 1999 to 2018. These counties are also the main regions of cattle husbandry in Germany, located mainly in Schleswig-Holstein, Lower Saxony and Bavaria (see Agethen 2019). Due to the high amount of manure, more nitrogen is possibly applied in these counties than the crops are able to absorb and convert into biomass (Wilke 2015). For example, in Northwest Germany, pig and poultry farming is concentrated, in particular in the Oldenburger Münsterland (Tamásy 2014), where approximately 120,000 hectares of agricultural land is missing for providing appropriate fertilization (phosphate) or a regulatory allocation (nitrogen) of the regionally occurring nutrients (LWK 2013). The nutrient requirement of the available area is, thus, in an obvious disproportion to the nutrient accumulation from animal husbandry and biogas plants (Tamásy 2014). A similar situation is observable in Bavaria. The Bavarian State Office for the Environment (LfU 2019) reports that nitrogen, which the crops can no longer utilize, is discharged from the soil as surplus and can be found, for example, as nitrate in the groundwater and can cause diverse negative effects on the natural balance, such as acidification, eutrophication, water pollution and impairment of biological diversity (e.g., nutrient inputs from agricultural activities in the Altmühl river (Mehdi, et al. 2015)).

Parallel to the dynamic development of livestock husbandry, a large number of traditional medium-sized companies developed in the upstream and downstream sectors ranging from slaughterhouses to meat processing companies. In total, approximately a third of the employees subject to social insurance contributions in the Oldenburger Münsterland in 2012 worked in the so-called "Agribusiness-Clusters", especially in slaughterhouses and meat processing (Tamásy 2014, p. 205). The German meat industry is characterized by relatively low wages and a precarious employment situation linked to subcontracting of workers from Eastern Europe (Tamásy 2014; Wagner and Hassel 2016). This provides evidence for a complex interlinkage of ecological and social issues linked to nitrogen overuse in intensive livestock production.

Based on our findings as highlighted earlier, we make the claim that there is not enough evidence for an EKC for nitrogen surplus in Germany. Economic growth can, thus, not clean up the environmental damage caused by nitrogen surplus. The most affected regions that are mainly located in the northern, north-western, and southern areas of the country are best advised to employ additional local measures to combat nitrogen surplus alongside the official regulations (e.g., CAP, Nitrate Directive, Water Directive, and Fertilizer Ordinance). As of 01. January 2021 the nitrate vulnerable zones (Nitratkulissen) are put in place in many states and together with behavioural changes and sustainable innovations could bring positive environmental change. However, the complexity and interlinkages of the underlying behavioural, cultural, social, economic, institutional and innovation dynamics require better understanding and further research.

Finally, we want to point out the data limitations in our study. Haeussermann et al. (2020) have already stressed possible weaknesses for calculating the nitrogen surplus that would equally apply here. Regarding the wage data, the monthly median per capita wage data are limited to the median of the gross monthly per capita income of full-time employees of the core group, who are subject to social security contributions; however, income from self-employment not subject to social security contributions, part-time jobs and other income sources are not included, which could bias the results.

6. Conclusion

In this article, the EKC, an inverse U-shape relationship between environmental pollution and per capita income, is analysed with panel data for nitrogen surplus as an environmental pollutant and monthly median wage during the period from 1999 to 2018 for 401 counties in Germany. Parametric and nonparametric panel estimations as well as first difference estimations are conducted. The estimation results show that nitrogen surplus displays a spurious EKC in Germany. We argue that the EKC is spurious because the inverse U-shape relationship produced by parametric and non-parametric panel regression of nitrogen surplus on median wage is rejected by first difference regression and tracing of individual county paths. We conclude that in Germany economic growth has not cleaned up the environmental damage from excessive nitrogen surplus. It seems that more regenerative, sustainable, and problem based policy measures are required to overcome environmental issues from nitrogen surplus in Germany.

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