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When reduced working time harms the environment: A panel threshold analysis for EU-15, 1970–2010

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ABSTRACT

Conventional wisdom has it that less working time is good for mitigating environmental pressure. Only a few studies have documented contradictory evidence. In this paper, we use panel threshold model, which is arguably the first of its kind in environmental analysis, to further document nonlinear relationships between working time and environmental pressure in EU-15 countries between 1970 and 2010. We find that the sign of this relationship shifts from positive to negative, as the working hours per worker decreases; France, Denmark, Germany, and the Netherlands experienced more environmental pressure with shorter working week. To the backdrop of reduced working time during our research period, our paper sheds new light on the traditional view of "the less, the better," as curtailing working time beyond certain thresholds may inadvertently incur exacerbation of environmental pressure.

1. Introduction

Mounting scientific evidences suggest that anthropogenic activities have done great devastation to the global environment since the inception of the Industrial Revolution. These human impacts are exacerbated by population boom and economic expansion (Ehrlich and Holdren, 1971). For instance, CO_2 emissions, a widely used measure of environmental pressure, reached 36.24 Gt in 2014, almost quadrupling the 1960 level (GCA, 2016). This growth strategy, at its heart, is a public goods game, where short-term gains in profits are prioritized over long-term public goods, most notably the environment and natural resources. What are the policy instruments to transition from a public goods game to a coevolutionary game (Perc and Szolnoki, 2010; Perc et al., 2012)? One option has to do with working time, which we explore in this paper.

The growth-critiquing communities (Speth, 2008) and the de-growth group (Latouche, 2010; Kallis, 2011; Kallis et al., 2012) enthusiastically support working time reduction (WTR) policies, which regained momentum in the wake of the 2007-09 Global Financial Crisis. Fig. 1 shows a generally downward trend of average annual working time per worker over the period of 1970–2010 in EU-15 countries. We can see that Greece surpassed Ireland to become the country with longest work hours in 1996 and that the Netherlands usually has the shortest work hours among the 15 countries. Fig. 2 illustrates that reduced working hours are not always accompanied by decreasing environmental burden; on the contrary, it is not difficult to see the opposite trend, such as Austria during 1983–2004 as well as Greece, Ireland, and Spain during almost the entire research period. Furthermore, we observe nonlinear relationships for each of the EU-15 countries: while there is a generally declining trend for working hours, the values of the environmental indicators fluctuate. Supporters of WTR policies believe that shorter workweek provides an antidote to over-consumption by scaling back both reduction capacity and spending power; they claim that there would be less environmental pressure due to more leisure time spent doing less energy-intensive activities (Gorz, 1994; Latouche, 2010; van den Bergh, 2011).

Existing empirical studies apply a variety of methodologies to cross-national and household micro-level data and identify a significantly positive effect of working hours on environmental pressure (Schor, 2005; Rosnick and Weisbrot, 2006; Hayden and Shandra, 2009; Nässén et al., 2009; Knight et al., 2013; Shao, 2015). These studies indicate that shorter working week is an effective policy option to alleviate environmental burdens, which is in line with de-growth views (Ashford and Kallis, 2013).

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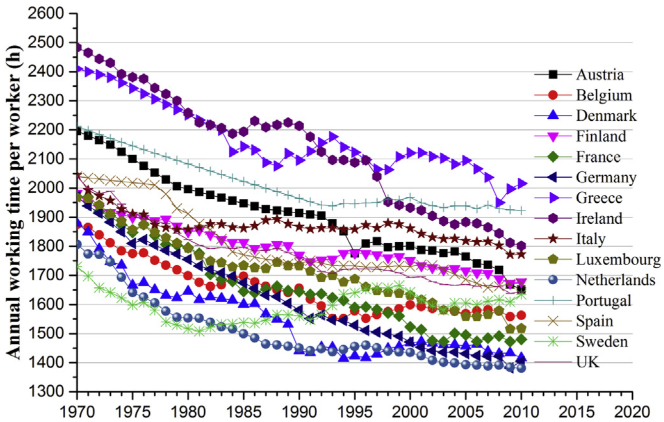

Fig. 1. Historical changes of the average annual working time per worker for EU-15 during the period 1970–2010 (unit: hours).
Source: TCB (2016).

Nevertheless, outside EU countries, working hours have been prolonged in many advanced industrial economies, such as Australia, Japan, Canada, and the U.S., but environmental pressure has not always increased as a result (TCB, 2016). Some empirical studies even identify a significantly negative correlation with more comprehensive data samples and advanced statistical methodology (e.g., Shao and Rodríguez-labajos, 2016). If this finding is substantiated, when annual hours worked per employee in a specific country are below or above certain thresholds, the relationship will switch from a positive one to one that is negative, vertically asymmetric, and nonlinear. To extend on this front, this study examines how the threshold effect (i.e., the degree separating positive and negative relationships) of working hours affect environmental burden.

Building upon extant works that explore the nexus between working hours and environmental pressures, our paper makes two major contributions. First, we employ a threshold model to account for nonlinearity in the data and specify the level at which the positivity of the relationship experiences reversal. Most existing researches focus extensively on linear models. However, the conflicting results on the worktime-environment nexus suggest that it is necessary to introduce nonlinearity into empirical methodology. As well demonstrated in Fig. 2, which plots the trends in working time, carbon emissions, and energy use for each of the EU-15 countries, the relationship between working hours and environmental pressures is far from linear. To avoid classifying countries arbitrarily, we split our sample endogenously using the panel threshold model developed by Hansen (1999). This technique selects appropriate threshold values and divides the sample into classes accordingly. In our application, we use estimated thresholds to bin EU-15 countries into different working time regimes. We then estimate environmental pressure elasticities for each working time regime for comparison. To our knowledge, this is the first empirical specification of its kind to account for nonlinear environmental processes. Besides working time, we also consider per capita GDP as a threshold variable. According to extant literature, income can play a dominant role in the relationship between hours of work and environmental impact. The logic is this: people living in wealthy countries are more likely to afford high energy-consuming activities in their leisure time, such as long-distance traveling, while people in less developed economies prefer cheaper activities that often require less energy consumption (Nørgård, 2013; Nässén and Larsson, 2015; Shao and Rodríguez-labajos, 2016). In light of this, to make our results more robust, we use per capita GDP as another threshold variable. Second, based on our model results, we identify the countries whose environmental pressures exacerbate when working hours are scaled back. We estimate threshold values first; specify country regimes using these values; and then calculate the elasticities in different regimes. These empirical results will yield critical policy implications and we discuss them in the last section of this paper.

The remainder of this paper is organized as follows. Section 2 reviews relevant empirical studies on the effect of working time on environmental pressure. Section 3 describes the data and methodology. Section 4 presents results and discussions. Section 5 concludes with implications of our research outcomes and directions for future research.

2. Literature review

Since the publication of seminal works by Schor (1995) and Hayden (1999) that draw the connection between working time and environmental pressures, several empirical studies followed suit with the then consensus that reduced working time could reduce harm to the environment. Some works focus on a single country. For instance, Spangenberg et al. (2002) demonstrated that reduced working time, coupled with technological innovation, social security system, and green taxes, was needed for Germany to attain economic competitiveness and a high employment rate and to ease the country's environmental pressures between 1994 and 2000. Conducting survey research in France in 2001, Devetter and Rousseau (2011) found that longer working hours only served to encourage goods and energy consumption by fostering conspicuous consumption and unsustainable lifestyles. By analyzing time use in Catalonia from both gender and age perspectives, D'Alisa and Cattaneo (2013) found that labor shift from the market to the household led to less intensive use of energy and argued that work-sharing at the household level was an essential way to reduce energy use. Nässén et al. (2009) using micro-level household data in Sweden in 2006, found that decreasing work time by 10 percent would induce an average 8 percent reduction in energy use and GHG emissions, while accounting for the income effect and the time effect. Subsequently, Nässén and Larsson (2015) confirmed previous findings that income plays a dominant role in the relationship between environmental impact and hours of work; a 10 percent decrease in working time on average reduced energy use and GHG emissions by 7 percent and 8 percent, respectively. Further, they forecast a gradual reduction towards 30 h of work per week by 2040 that would halt the growth of energy demands in the long run. Moreover, shorter working week is also strongly upheld by degrowth proponents as an effective way to "kill two birds with one stone" when complemented by a working sharing program, since more people are employed and energy consumption is reduced thanks to shorter working hours (Sekulova et al., 2013; Kallis, 2013).

Other scholars have focused on the linear effect of working time on environmental pressures based on cross-national analyses (Dahl and Gonzalez-Rivera, 2003). Schor (2005) ran a multiple linear regression to account for ecological footprint in eighteen OECD countries and found significantly positive correlation between working hours and environmental burdens. Rosnick and Weisbrot (2006) simulated environmental impacts of European countries if their economic models were to approximate that of the United States. They found that as working time increases, economic production and consumption increase accordingly, and so does energy consumption. Specifically, they argued that a 1 percent increase in working time leads to a 1.32 percent increase in energy consumption, while holding other factors equal. Hayden and Shandra (2009) also identified a significantly positive relationship

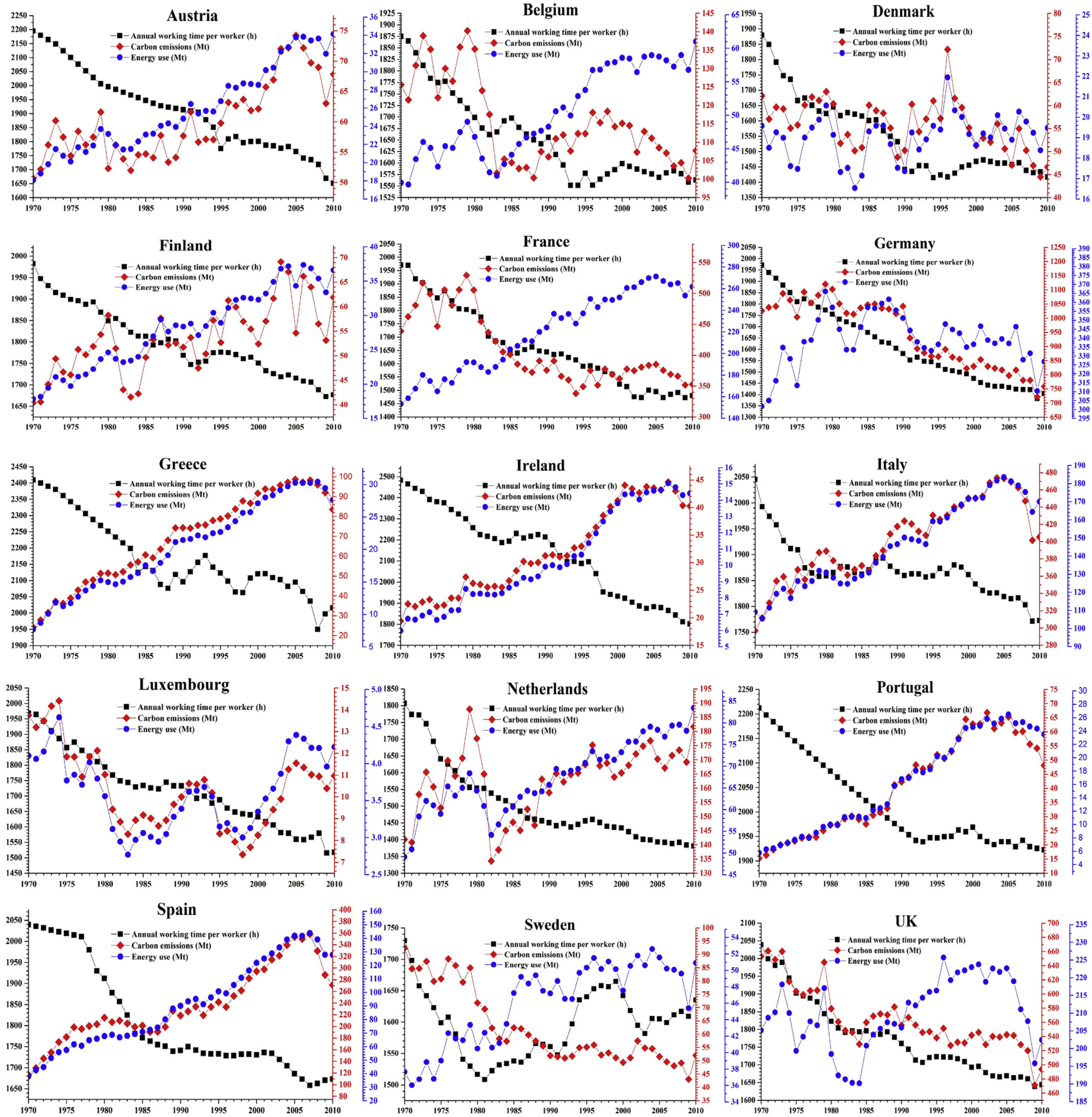

Fig. 2. The non-linear relations of annual working time per worker, total carbon emissions and primary energy use for EU-15 countries from 1970 to 2010, respectively. **Sources**: TCB (2016), World Bank (2016), GCA (2016).

between working time and ecological footprint based on a structural equation model covering data from 45 countries across the globe, a finding that still holds after controlling for employment rate, labor productivity, and other relevant variables. Later, in the spirit of economic de-growth theory for developed countries on working time, Knight et al. (2013) examined the effects of working hours on three typical environmental indicators: ecological footprint, carbon footprint, and carbon dioxide emissions. They used a first-difference panel regression on data from 29 high-income OECD countries and discovered that working time has a significantly positive relationship with environmental pressures based on multiple model specifications, except when using carbon dioxide emissions as the dependent variable and GDP per capita as a control variable. Hence, they concluded that WTR policies may contribute to environmental sustainability. In a similar vein, Fitzgerald et al. (2015) confirmed the increasing effects of working hours on energy consumption both in developed and developing countries. Table 1 illustrates the elasticities of environmental burdens with

Table 1
Studies estimating elasticities of environmental burdens with respect to changes in working time.

Study	Environmental indicators	Elasticity	Method and data structure
Rosnick and Weisbrot (2006)	Energy consumed per capita	1.33	Multivariate regression analysis; 48 countries; 2003–2005
Nässén et al. (2009)	Energy use	0.83	Micro-data analysis, linear regression; Sweden, 2006
	GHG emissions	0.85	
Knight et al. (2013)	Ecological footprint	1.37	First difference panel regression; 29 OECD countries; 1970–2007
	Carbon footprint	1.30	
	Carbon emissions	0.50	
Rosnick (2013)	GHG emissions	0.50	Illustrative scenarios, MAGICC; world-wide economies; 1990-2100
Nässén and Larsson (2015)	Energy use	0.70	Micro-data analysis, scenario analysis; Sweden, 2006
	GHG emissions	0.80	
Fitzgerald et al. (2015)	Energy consumption	0.32	Praise-Winsten regression model; 52 countries; 1990–2008

respect to changes in working time. It is not hard to tell that the impact of working hours on environmental pressures varies under different methodological specifications as well as the size and composition of data samples.

Different from aforementioned studies, Shao and Rodríguez-labajos (2016) re-examined the effects by setting carbon emissions per capita as the dependent variable and applying advanced dynamic panel data approach (i.e., system Generalized Method of Moments, sys-GMM) to a comprehensive data from 55 countries worldwide over the period 1980–2010. Challenging the conventional view, their results suggest that the relationship between working time and environmental impact is insignificant in developing economies and that environmental burden may rebound for developed countries, as the correlations between the two indicators turned from being positive during 1980–2000 to being negative during 2001–2010. Shao and Rodríguez-labajos (2016) explained that “more leisure time does not guarantee a lower environmental impact,” echoing Nørgård (2013), which suggested that “the extra leisure time will tend to require more energy, but the amount will depend on how leisure is spent” (p.67). Specifically, a simple reallocation of time from paid work to leisure might result in heavier environmental pressure, since having more leisure time tends to encourage more energy-intensive activities in certain cases, such as long-distance car traveling and vacation abroad (Druckman et al., 2012). More often than not, this situation applies to high-income countries, as the magnitude of the effect of work-time policies on the environment hinges upon income level (Pullinger, 2014). For instance, people from developing economies tend to spend their extra leisure hours doing things that do not require much energy consumption, such as staying with their families, doing sports, or just resting at home; by contrast, rich communities prefer expensive travel and recreational activities, which usually bring about higher environmental impacts. Following this line of research and building upon prior studies, we want to explore: if the “rebound effect” exists, at which level of working time does carbon emission cease to be reduced further and begin to increase instead? This is especially critical and it comes with important policy implications. By undertaking these estimations, we can distinguish countries that already show negative environmental impact under WTR policies from those who still have the potential to alleviate their environmental burdens by promoting shorter working weeks.

While the aforementioned empirical studies bear their merits, two outstanding issues beg further examination. The first issue concerns the use of ecological footprint as the dependent variable. Ecological footprint converts the flows of energy and matter originating from an activity into corresponding land area that is required to support such flow. Many authors have voiced concern over the appropriateness and effectiveness of ecological footprint as an indicator of environmental pressure. Conceptually, carbon footprint – without a clear and uniform definition – is often used to reflect greenhouse gas emissions (Wiedmann et al., 2006). Methodologically, van den Bergh and Grazi (2014a,b) documented eight major shortcomings, from misspecification of hypothetical land area to misinterpretation of ecological deficit as support for anti-trade sentiments, rendering ecological footprint futile for offering useful information for public policy. Fiala (2008, p.519) calls ecological footprints “bad economics and bad environmental science”.

The second issue concerns sample selection; namely, some existing studies incorporate several industrialized countries into their samples without accounting for the fact that these countries demonstrate diverging trends in working hours. While most countries in Europe (e.g., France, Germany, Denmark) have shown a decline in working time, several non-European countries (e.g., Australia, Canada, the United States) have not (Schor, 2005; TCB, 2016). As Temple (2000) rightfully warns, “one should probably be careful about extrapolating findings from one set of countries to another.” Based on these two considerations, we rule out ecological footprint as a valid indicator of environmental pressure in our analysis. Furthermore, we draw our data from EU-15 countries, who share relatively similar socioeconomic trends.

3. Data and methods

This study examines the nonlinear relationship between annual working time per worker and environmental pressure in EU-15 countries. The assumption here is that both working time and per capita GDP have one or more threshold values, giving rise to asymmetric upper and lower boundaries in a nonlinear manner. In this section, we briefly introduce the definitions and sources of data as well as methods used for regression analysis.

3.1. Data

3.1.1. Dependent variables

Due to controversies surrounding the effectiveness of ecological footprint, as detailed in the previous section (van den Bergh and Grazi, 2014b; Wackernagel, 2014), we use two other commonly used and widely recognized measures – carbon emission and primary energy consumption – as dependent variables (e.g., Rosnick and Weisbrot, 2006; Knight et al., 2013). Carbon emissions mainly originate from the burning of fossil fuels, manufacturing of cement, and other processes that involve the consumption of solid, liquid, and gas fuels as well as gas flaring. We use the CO_2 emissions (in thousand metric tons) dataset from the World Bank (2016). For Germany, such data is unavailable in the World Bank data depository before the German reunification in 1990; we thus supplement it by using 1980–1989 data from the Energy Information Administration (EIA, 2016). The second dependent variable, energy consumption, refers to the use of primary energy before transformation to other end-use fuels. It is calculated by adding indigenous production, imports, and stock changes and then subtracting exports and fuels supplied to ships and aircraft engaged in international transport. Primary energy consumption data, measured in thousand metric tons of oil equivalent, comes from the World Bank (2016).

3.1.2. Independent variables

Following Hayden and Shandra (2009), we disaggregate GDP per capita into three components to test their effects on the dependent variables: annual working time per worker, labor productivity, and percentage of population employed (i.e., $\frac{GDP}{Population} = \frac{Worktime}{Workers} \times \frac{GDP}{Worktime} \times \frac{Workers}{Population}$, Knight et al., 2013, p.697; Shao and Rodríguez-labajos, 2016, p.230). To be specific, annual working time per worker refers to the total number of hours worked as a worker or as a self-employed person in a given year. Labor productivity is measured as GDP in USD per hour of work in 2013, adjusted for purchasing power parity (PPP). Percentage of population employed refers to the percentage of workers in a given population. All data of the three variables are from The Conference Board Total Economy Database (TCB, 2016). TCB, developed by the Groningen Growth and Development Centre (GGDC) in the early 1990s, is a comprehensive database that includes important indicators, such as annual GDP, population, employment, labor productivity, and so on, covering as many as 123 countries worldwide. Particularly, its country-year data of annual working hours per employee are used widely in related works (Knight et al., 2013; Shao, 2015).

In addition, GDP per capita, measured in constant 2005 USD, is the sum of gross value added by all resident producers in the economy, plus any product taxes, and minus any subsidies not included in the value of the products. Percentage GDP that comes from trade is the percentage of GDP that is contributed by the sum of exports and imports of goods and services. Percentage of GDP that comes from capital is the percentage GDP of gross capital formation, which consists of outlays, fixed assets of the economy, and the net changes in the level of inventories. Population and urban-population ratio are also included in our analysis. All data described in this paragraph come from the World Bank (2016).

We collected data for a time span of 41 years, from 1970 to 2010, and for all EU-15 countries, from the poorest (Greece) to the richest (Luxembourg) in terms of income. Before running regressions, we decrease the variability of our data and make them distribute normally by taking the log of all these variable values. Table 2 exhibits descriptive statistics and Table 3 shows correlation matrix of all the variables in this analysis. It is not difficult to tell that most variables are correlated with other variables, significant at the 1% level. For instance, we can see that working hour is negatively correlated with carbon emissions and energy consumption, implying that less working time may aggravate environmental burdens, which is in line with aforementioned Druckman et al. (2012), Nørgård (2013), and Shao and Rodríguez-labajos (2016) in Section 2. Further, we find working time is also negatively related to GDP per capita, which corresponds to the arguments of Kallis et al. (2013) that advanced, wealthy countries tend to have shorter working weeks.

3.2. Method

In order to analyze the influence of working time on environmental pressures, we propose a threshold panel approach, which is quite popular in financial and macroeconomics fields, to bin our sample of EU-15 countries into different regimes. Previous studies have followed a systematic, but somewhat arbitrary, classification of countries. For instance, Fitzgerald et al. (2015) divided 52 countries in their sample into developed and developing countries based just on income level. To improve on this front, we use the panel threshold technique, where a grid search performs the selection of appropriate threshold values. This technique employs threshold variables to generate several regimes endogenously so as to avoid potential errors originating from arbitrary determination of segmentation points (Hansen, 1999). It can produce one or multiple threshold level(s) to bin the data into two or more regimes depending on whether the threshold variable is above or below certain threshold values (Ben Cheikh and Louhichi, 2016). In our study, this technique allows us to split the sample into different classes based on the value of annual working hours per worker and per capita GDP.

First proposed by Tong (1978) as a viable econometric method, this technique has been developed into the widely used Threshold Auto-Regression (TAR) for nonlinear time-series data in economic and financial realms. Some studies have also used TAR to analyze cross-sectional panel data (see Tiao and Tsay, 1994; Potter, 1995; Martens et al., 1998). In TAR, the existence of threshold effects must be verified before estimates can be calculated. However, the presence of a nuisance parameter will result in a non-standard distribution of test statistics (the “Davies Problem”, see Davies (1987), Andrews and Ploberger (1994)). To tackle this issue, Hansen (1999) proposed a bootstrap method to generate test statistics with an asymptotic distribution. In this case, if the null hypothesis (H_0) is rejected and threshold effects do exist, there is super-consistency in the least squares estimators of thresholds and the asymptotic distribution of OLS estimators can be further deduced (Chan, 1993). However, non-standard distribution coexists with nuisance parameters. To solve this problem, Hansen (1999) explored the asymptotic distribution of statistics through a simulation of “likelihood ratio” (LR) test.

To estimate nonlinear threshold effects, a two-stage ordinary least squares (OLS) approach is proposed by Hansen (1999). In the first stage, threshold value γ, which is the corresponding sum of

Table 2
Descriptive Statistics for all variables in this study.

Variables	Mean	Sta. De.	Min	P25	P50	P75	Max
Carbon	11.5496	1.1976	8.9033	10.8382	11.2795	12.7755	13.8700
Energy	10.6817	1.2560	7.9266	9.8658	10.6627	11.7889	12.8105
Hours	7.4804	0.1277	7.2307	7.3881	7.4790	7.5659	7.8172
Labor productivity	3.5574	0.3938	2.3794	3.2846	3.6059	3.8517	4.4124
Emp. % population	−0.8413	0.1369	−1.2039	−0.9483	−0.8471	−0.7413	−0.3258
Trade. % GDP	4.2495	0.4988	3.2510	3.8937	4.1325	4.5970	5.8097
GDP per capita	10.1405	0.4106	8.8868	9.8648	10.1545	10.4073	11.3819
Cap. % GDP	3.1013	0.1705	2.4719	2.9903	3.0963	3.2136	3.7600
population	16.3261	1.3523	12.7343	15.4943	16.1201	17.8149	18.2287
Urban. %population	4.2708	0.1782	3.6585	4.1804	4.2973	4.4033	4.5794

Note: All variables are logarithmized; Sta. De is standard deviation; P25, P50 and P75 denote 25% percentile, median and 75% percentile, respectively.

Table 3
The correlation matrix of all variables in this study.

Variables		1	2	3	4	5	6	7	8	9	10
Carbon	1	1.00									
Energy	2	0.98*	1.00								
Hours	3	−0.29*	−0.37*	1.00							
Labor productivity	4	0.15*	0.20*	−0.79*	1.00						
Emp. % population	5	−0.20*	−0.11*	−0.53*	0.41*	1.00					
Trade. % GDP	6	−0.54*	−0.53*	−0.30*	0.54*	0.34*	1.00				
GDP per capita	7	0.05	0.12*	−0.74*	0.93*	0.63*	0.55*	1.00			
Cap. % GDP	8	−0.18*	−0.21*	0.47*	−0.53*	−0.10*	−0.25*	−0.49*	1.00		
population	9	0.94*	0.93*	−0.12*	−0.07	−0.29*	−0.71*	−0.29*	−0.05	1.00	
Urban. %population	10	0.19*	0.27*	−0.71*	0.68*	0.32*	0.28*	0.65*	−0.42*	−0.02	1.00

Note: All variables are logarithmized. Correlation is significant at the 0.01 level (2-tailed).

squared errors (SSR), is calculated via OLS; then threshold value $\hat{\gamma}$ is obtained using the minimum SSR based on presumed threshold values. In the second stage, coefficients are estimated for different segments that are separated by the threshold values.

3.2.1. Threshold model

A threshold model may contain multiple thresholds. In our case, we present a one-threshold model, which can serve as the basis for developing more complicated ones. According to Hansen (1999), the equation with one potential threshold for balanced panel data $\{y_{it}, q_{it}, x_{it}; 1 \le i \le N\}$ is:

$$y_{it} = \mu_i + \beta_1 x_{it} I(q_{it} \le \gamma) + \beta_2 x_{it} I(q_{it} > \gamma) + e_{it} \tag{1}$$

where y_{it} denotes environmental pressure for country$i$ in year t; μ_i represents country-specific effect; e_{it} is an independently and identically distributed (*i.i.d.*) random disturbance with mean of zero and variance of σ^2 (i.e., $e_{it} \sim i.i.d.(0, \sigma^2)$); x_{it} refers to various exogenous shocks; $I(.)$ is an indicator function that takes on the value of 0 or 1; q_{it} is the threshold variable; and γ is the assumed threshold value. The unknown coefficients, β_1 and β_2, represent the impact of the variable x_{it} on the dependent variabley_{it} for $q_{it} \le \gamma$ and $q_{it} > \gamma$, respectively. Eq. (1) can be expressed as follows:

$$y_{it} = \begin{cases} \mu_i + \beta_1 x_{it} + e_{it}\ , \ q_{it} \le \gamma \\ \\ \mu_i + \beta_2 x_{it} + e_{it}\ , \ q_{it} > \gamma \end{cases} \tag{2}$$

Further, if$x_{it}(\gamma) = \begin{pmatrix} x_{it} I(q_{it} \le \gamma) \\ x_{it} I(q_{it} > \gamma) \end{pmatrix}$ and$\beta = (\beta_1, \beta_2)'$, then Eq. (2) can be re-written subsequently in a more compact form that is convenient for analysis:

$$y_{it} = \mu_i + \beta x_{it}(\gamma) + e_{it} \tag{3}$$

The purpose of this study is to estimate unknown parametersγ and β, given x_{it} and y_{it} from sampled countries in a given time period.

3.2.2. Estimation of threshold model

Since Eq. (1) can be estimated within group, we can eliminate individual fixed effects μ_i by first calculating the average environmental pressure of each individual country:

$$\bar{y}_i = \mu_i + \beta \bar{x}_i(\gamma) + \bar{e}_i \tag{4}$$

where $\bar{y}_i = T^{-1}\sum_{t=1}^{T} y_{it}$, $\bar{e}_i = T^{-1}\sum_{t=1}^{T} e_{it}$

$$\bar{x}_i(\gamma) = T^{-1}\sum_{t=1}^{T} x_{it}(\gamma) = \begin{pmatrix} T^{-1}\sum_{t=1}^{T} x_{it} I(q_{it} \le \gamma) \\ T^{-1}\sum_{t=1}^{T} x_{it} I(q_{it} > \gamma) \end{pmatrix}$$

We subtract Eq. (3) from Eq. (4) to obtain the following equation:

$$y_{it}^* = \beta x_{it}^*(\gamma) + e_{it}^* \tag{5}$$

where $y_{it}^* = y_{it} - \bar{y}_i$, $x_{it}^*(\gamma) = x_{it}(\gamma) - \bar{x}_i(\gamma)$, $e_{it}^* = e_{it} - \bar{e}_i$

Then, usingY^*, $X^*(\gamma)$ and e^* to represent the data stacked over all individuals, Eq. (5) is equivalent to:

$$Y^* = X^*(\gamma)\beta + e^* \tag{6}$$

Therefore, for any given threshold valueγ, coefficient β can be calculated via OLS:

$$\hat{\beta}(\gamma) = \left(X^*(\gamma)' X^*(\gamma)\right)^{-1} X^*(\gamma)' Y^*$$

Now that $\hat{\beta}(\gamma)$ is obtained, we can easily estimate the value of residual:

$$\hat{e}^*(\gamma) = Y^* - X^*(\gamma)\hat{\beta}(\gamma)$$

And then we calculate the sum of squared errors (SSE):

$$\begin{aligned} S_1(\gamma) &= \hat{e}^*(\gamma)'\hat{e}^*(\gamma) \\ &= Y^{*\prime}\left(I - X^*(\gamma)'\left(X^*(\gamma)'X^*(\gamma)\right)^{-1} X^*(\gamma)'\right) Y^* \end{aligned} \tag{7}$$

Finally, we obtain estimated threshold value using the correspondingγ, according to the principle of minimizing SSE:

$$\hat{\gamma} = \arg\min_{\gamma} S_1(\gamma) \tag{8}$$

Now we get estimator coefficient$\hat{\beta} = \hat{\beta}(\hat{\gamma})$. The residual-vector estimator is$\hat{e}^* = \hat{e}^*(\hat{\gamma})$. The estimator for residual variance is:

$$\hat{\sigma}^* = \frac{1}{n(T-1)}\hat{e}^{*\prime}\hat{e}^* = \frac{1}{n(T-1)} S_1(\hat{\gamma}) \tag{9}$$

3.2.3. Threshold effects testing

For single-threshold model (Brana and Prat, 2016), we employ Hansen (1999) LR test ($LR_1 = (S_0 - S_1)/\hat{\sigma}_1^2$) to examine the hypothesis:

$$H_0^1 : \beta_1 = \beta_2,\ H_1^1 : \beta_1 \ne \beta_2$$

Obviously, under the null hypothesis (H_0), no threshold exists and this classic testing no longer provides standard distribution. Given that, we can obtain the empirical distribution of LR test through the bootstrap method, proposed by Hansen (1999) and referenced in Ben Cheikh and Louhichi (2016), to correct the non-standard distribution caused by the presence of the nuisance parameter. Suppose that LR_1 is larger than the empirical critical value, we can infer that significant threshold effects exist (Che, 2013). To further confirm threshold numbers, we use $LR_2 = (S_1 - S_2)/\hat{\sigma}_2^2$ and $LR_3 = (S_2 - S_3)/\hat{\sigma}_3^2$ to test the following hypotheses, based on which the number of threshold(s) can be confirmed:

$$H_0^2 = single - threshold,\ H_1^2 = double - thresholds$$

$$H_0^3 = double - thresholds,\ H_1^3 = triple - thresholds$$

3.2.4. Confidence interval of threshold estimators

Hansen (1999) points out that confidence interval can be built according to the following equation:

$$LR_0(\gamma) = (S_1(\gamma) - S_1(\hat{\gamma}))\Big/\hat{\sigma}^2 \tag{10}$$

We use Eq. (10) to test$H_0 : \gamma = \gamma_0$. H_0 is rejected if $LR_0(\gamma_0)$ is large enough. It should be noted that $LR_0(\gamma_0)$ is different from LR_1, since the former tests $H_0 : \gamma = \gamma_0$ while the latter tests $H_0 : \beta_1 = \beta_2$.

Hansen (1999) proved, under certain assumptions, that critical value can be calculated:

$$c(\alpha) = -2\log\left(1 - \sqrt{1-\alpha}\right) \tag{11}$$

According to Eq. (11), $H_0 : \gamma = \gamma_0$ can be rejected if $LR_0(\gamma_0)$ exceeds $c(\alpha)$ and threshold value $\hat{\gamma}$ is within the confidence interval.

4. Empirical analysis

4.1. Results and discussions of panel threshold models

As mentioned earlier, we examine the panel threshold effects by considering two threshold variables (i.e., annual working hours per worker and GDP per capita) on two environmental indicators (i.e., carbon emissions and energy consumption) in an effort to fathom the nonlinear relationship between working time and environmental pressures with asymmetric upper and lower boundaries. To achieve this, four models are presented in this study. Critical values of 10%, 5%, and 1%, along with F-test statistics and threshold values for each model, are shown in Table 4. We find that all models have two thresholds in the regression relationship at the 1% significance level except for the interaction of annual working hours per worker and energy consumption for the double-threshold effect. Therefore, we use two thresholds for our regression analysis. When working time is made the threshold variable, the threshold values are 7.592 and 7.727 for carbon emissions and 7.303 and 7.600 for energy consumption. When GDP per capita is set as the threshold variable, the threshold point estimates are 9.633 and 10.397 for carbon emissions and 9.633 and 10.601 for energy consumption.

The coefficients and t-values are reported in Table 5. We first examine the effect of control variables on the outcomes. Labor productivity has a positive effect, significant at the 1% level, in both Models 1 and 2. This reaffirms the “Jevons Paradox,” where production efficiency would aggrandize rather than mitigate environmental pressures as a result of price reduction and excessive consumption (Yu et al., 2013; Chitnis et al., 2014; Bourrelle, 2014; Ghosh and Blackhurst, 2014). Coefficients of employment-to-population ratio show significantly positive effects on dependent variables, indicating more negative environmental effects caused by workers than non-workers. This finding is consistent with Knight et al. (2013), who argued that employment-to-population ratios in OECD countries have a positive effect on total ecological footprint, carbon footprint, and carbon emissions, significant at the 1% level. Percentage of trade to GDP is significant only in the model predicting energy consumption, reflecting the important role of energy trade in Europe. Percentage of gross capital formation to GDP is insignificant across all estimations, it has a positive effect on carbon emissions and a negative one on energy consumption. Effects of GDP per capita are significantly negative, suggesting that wealthy countries among EU-15 possess more advanced environmental technologies and more effective regulations to tackle environmental problems. Population has an overall significantly negative effect on carbon emissions. During the time period of interest, most EU-15 countries experienced a gradual population growth; however, carbon emissions had declined partly thanks to the introduction of emissions reduction schemes. Lastly, we find the percentage of urban population to be positively related to both environmental indicators at 1% significance level, revealing that environmental pressures increased alongside urbanization.

We now discuss results from Model 1, where carbon emissions are the outcome variable. The two thresholds split annual working time per worker into three asymmetric phases: high-level working time (above 7.727), mid-level working time (between 7.592 and

Table 4
Testing for the threshold effects of working time and GDP per capita on environmental indicators.

Environmental indicators	Threshold variables	Threshold effects	F-statistics	Critical values			Threshold values	95% confidence interval
				10%	5%	1%		
Carbon emission	Annual working hours per worker	Single threshold	130.105***	36.236	53.698	99.934	7.592	(7.586,7.599)
		Double threshold	117.711***	36.845	49.980	88.907	7.727	(7.710,7.727)
		Triple threshold	15.702	12.632	17.299	33.223		
	GDP Per capita	Single threshold	230.786***	57.772	82.088	133.613	9.633	(9.600,9.633)
		Double threshold	68.550***	21.070	31.886	52.412	10.397	(10.394,10.411)
		Triple threshold	36.367	36.751	48.474	67.607		
Energy consumption	Annual working hours per worker	Single threshold	97.080***	35.065	47.634	86.131	7.600	(7.586,7.606)
		Double threshold	25.194**	21.027	28.923	55.212	7.303	(7.303,7.328)
		Triple threshold	12.804	19.161	27.425	45.698		
	GDP Per capita	Single threshold	213.656***	66.551	88.267	177.031	9.633	(9.628,9.641)
		Double threshold	118.860***	26.534	38.251	68.678	10.601	(10.584,10.603)
		Triple threshold	66.478	17.048	23.939	43.938		

Notes: (1)Six-hundred bootstrap replications are employed for each of the three bootstrap tests.
(2)***,** and * denote that variables are statistically significant at 1%, 5% and 10% respectively. Same apply to the following tables.

Table 5
Regression estimate results of working time as threshold variable.

Variables	Model 1: Carbon emission			Model 2: Energy consumption		
	Coefficients	t-ols	t-white	Coefficient	t-ols	t-white
Labor productivity	2.791	13.49***	4.26***	2.158	12.39***	3.08***
Emp. %population	3.528	14.68***	4.40***	2.145	10.49***	2.86**
Trade. % GDP	−0.0237	−0.50	−0.22	0.141	3.49***	1.72
GDP per capita	−2.743	−13.89***	−4.13***	−1.856	−11.25***	−2.78**
Cap. % GDP	0.0227	0.46	0.24	−0.0495	−1.19	−0.64
Population	−0.936	−4.30***	−1.95*	0.0185	0.11	0.04
Urban. %population	1.924	13.83***	4.66***	1.731	14.08***	4.76***
anu_lt	0.0372	12.10***	5.27***	−0.0153	−4.91***	−2.56***
anu_mt	3.490	14.10***	4.52***	2.396	10.89***	2.80***
anu_ht	−0.05	−10.57***	−6.62***	−0.0227	−8.07***	−2.56***

Notes: (1) anu_lt, anu_mt and anu_ht denote parameters of annual working time per worker in low-, mid- and high-level annual working time phases, respectively.
(2) t-ols denote t-values under homogeneous assumption, t-white denote t-values under heterogeneous assumption, same apply to the following.

7.727), and low-level working time (below 7.592). As the results show, for high-level working time phase, working hours have a negative effect on carbon emissions; in other words, reducing working time during this stage may lead to an increase of carbon emissions, while holding other factors constant. By contrast, countries in the mid-level working time regime had carbon emissions elasticity of 3.49%: a 1% decrease in working hours caused a 3.49% reduction in carbon emissions, a finding consistent with those in Hayden and Shandra (2009), Knight et al. (2013). Similarly, countries in the low-level phase exhibit a positive relationship between working hours and carbon emissions, significant at the 1% level, but the magnitude (coef = 0.04) is much smaller than that for the mid-level regime. This suggests that as working time shortens, there are diminishing returns to reducing working time in an effort to cut carbon emissions. To piece these together, the sign of the relationship between working time and carbon emissions shifts from negative to positive, as the length of working hours decreases. Reducing working hours has different effects on environmental burdens based on which working time regime a country belongs to.

We then discuss our results from Model 2, where energy consumption is the outcome variable. The two thresholds split annual working time per worker into three regimes: high-level (above 7.600), mid-level (between 7.303 and 7.600), and low-level (below 7.303). We observe a significantly negative relationship between working hours and energy consumption for high working time countries. The relationship turns significantly positive with an estimated coefficient of 2.40 for mid-level working time countries. For low-level working time countries, a significantly negative correlation between working hours and energy consumption, contrary to what we find in Model 1. Here when working hours are reduced beyond a certain point, shortening working hours can increase energy consumption, which echoes Nørgård (2013, p.67), who argued that “more leisure time does not guarantee a lower environmental impact.”

Based on the above analysis, environmental burdens can be aggravated via worktime reduction. To explain the discrepancy between the trends in energy consumption and carbon emissions for low-level working time countries, we reckon that one possibility lies in the outcome's sensitivity to shortened working time. One piece of evidence is that the coefficient of annual working time per worker for low-level working time countries (0.04) is much smaller than that for mid-level working time countries (3.49) in Model 1. If working time continues to decline, negative effect can be predicted. To further confirm the negative impact of shorter working time, we now set GDP per capita as the threshold variable.

Table 6 presents results of the effect of working time on carbon emissions and energy consumption, where GDP per capita is the threshold variable. Generally speaking, the significance and magnitude of control variables are very similar to those in Table 5, thus we skip this part and instead focus on explaining the panel threshold effect. For both Models 3 and 4, we observe correlations turning from being significantly negative at high per capita GDP phase into being significantly positive at mid per capita GDP phase. The relationship becomes negative again once working time crosses the lower threshold boundary, which is similar to the pattern in Model 2. One possible explanation is that people in rich countries tend to engage in leisure time activities that are more energy-consuming and carbon-intensive than working. By contrast, people from less well-off countries can only afford activities that do not require as much energy, causing comparatively smaller damages to the environment (Druckman et al., 2012).

Table 6
Regression estimate results of GDP per capita as threshold variable.

Variables	Model 3: Carbon emission			Model 4: Energy consumption		
	Coefficient	t-ols	t-white	Coefficient	t-ols	t-white
Labor productivity	0.267	4.15***	1.82*	0.488	10.72***	3.70***
Emp. %population	0.811	6.76***	3.15***	0.443	5.12***	2.05*
Trade. % GDP	0.0467	0.85	0.37	0.100	2.61***	1.10
Cap. % GDP	−0.00651	−0.12	−0.05	0.0168	0.41	0.24
Population	−0.653	−2.82***	−0.90	0.386	2.37**	0.81
Urban. %population	1.518	9.53***	4.30***	1.346	11.69***	3.65***
anu_lg	−0.0418	−11.06***	−3.26***	−0.0318	−12.15***	−3.85***
anu_mg	0.890	4.33***	1.38	1.242	8.60***	4.04***
anu_hg	−3.46	−8.31***	−3.46***	−0.0289	−10.68***	−3.52***

Notes: (1) anu_lg, anu_mg and anu_hg are parameters of annual working time per worker in low-, mid- and high-level GDP per capita phases, respectively.
(2) GDP per capita does not report in this table as control variable due to the application as threshold variable.

4.2. Number of countries in three phases for selected years

As previous discussions suggest, we find significant threshold effects in both cases, where working time and GDP per capita are used as threshold variables. Our threshold models indicate that there exist nonlinear relationships between working hours and environmental impacts. Setting working time as the threshold variable, the correlation between working time and carbon emissions shifts from being negative to being positive. However, in the case of energy consumption and in the scenario where GDP per capita is the threshold variable, the sign of correlation between working time and the outcome shifts from being negative to being positive and then back to being negative.

Fig. 3 reports the number of countries in each of the three phases (i.e., low-, mid-, and high-level annual working hours per worker, segmented by two threshold values using working time as the threshold variable) in 1970, 1975, 1980, 1985, 1990, 1995, 2000, 2005, and 2010, respectively. For carbon emissions, the number of countries in high- and mid-level working time phases gradually declined and no country has been at the high-level stage since 1980. Greece remained the only country in the mid-level phase until 2010; in fact, Greece has the longest annual working hours per worker at about 2016 h, higher than any other European country in our analysis.

As for energy consumption, Fig. 3 illustrates that the number of countries at high-level stage has decreased from seven in 1970 to one in 2010. By comparison, countries in the low-level phase increased from one in 1987 to four in 2010; namely, France, Denmark, Germany, and the Netherlands, whose workforce worked the least with annual working hours at 1480 h, 1417 h, 1404 h, and 1381 h, respectively. The significantly negative correlation illustrated in Model 2 implies that higher environmental burden induced by less working hours has already occurred in these four countries.

5. Conclusion, implication, and further research directions

Following Druckman et al. (2012), Nørgård (2013), and Shao and Rodríguez-labajos (2016), we further explore the possibility that shorter working week could aggravate environmental pressures under certain conditions. Our paper improves upon past works by specifying such conditions. We bin countries into different working time regimes, separated by thresholds of working time or per capita GDP, to investigate the threshold effect of working hours on environmental pressures measured by carbon emissions and energy consumption, using panel data from EU-15 between 1970 and 2010. After splitting our sample into three regimes with two threshold values, we identify significantly negative correlations between working time and environmental burden at low-level working time phase, with the only exception of using working hours as the threshold variable and carbon emissions as the outcome variable. Therefore, a sheer reduction in working hours will not necessarily translate into less environmental pressure, which reaffirms the arguments of Shao and Rodríguez-labajos (2016, p.233) that “reduced work hours might prove to be counter-effective and in turn impose heavier burdens on the environment.”

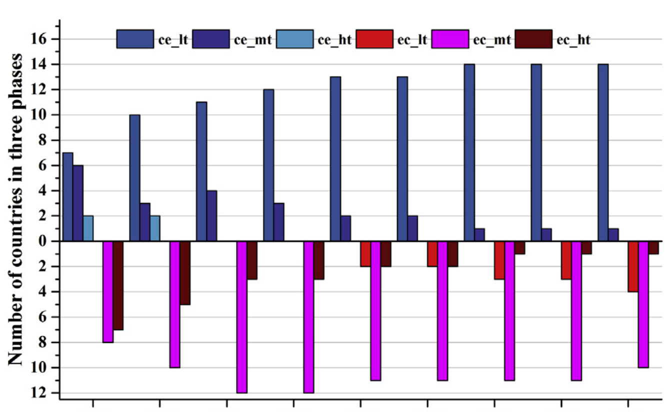

Fig. 3. Number of countries in three phases of annual working time per worker for selected years. Notes: (1) ce_lt、ce_mt、ce_ht denote low-, mid- and high-level annual working time phases when we regard carbon emission as environmental indicator; (2) ec_lt、ec_mt、ec_ht denote low-, mid- and high-level annual working time phases when we regard energy consumption as environmental indicator.

In addition, using working hours as the threshold variable, we find Greece to be the only country consistently having long working hours among EU-15; France, Denmark, Germany, and the Netherlands are at low-level working time phase, where shorter workweek led to more environmental pressure. In light of this, we may infer that income plays an essential role in the process (Pullinger, 2014). For countries that having more leisure time while commanding higher salaries meant the possibility of engaging in more expensive and energy-demanding activities, such as driving long distances and traveling by air. In comparison, people living in countries with lower incomes are more likely to engage in activities that are less harmful to the environment, such as playing sports, sleeping, watching television, and socializing (Nässén et al., 2009; Nørgård, 2013; Shao and Rodríguez-labajos, 2016). Therefore, short working week is not necessarily beneficial for the environment and its effect is compounded by various factors such as the income. This result gives rise to the important policy implication that “the less, the better” is too general a statement to hold true for worktime-environment nexus, where the relationship can go in either direction as working time decreases.

If the current trend continues, working hours in EU-15 countries will keep decreasing in the foreseeable future (see Fig. 1). Eventually, all of them will enter the phase where worktime reduction contributes to environmental deterioration. As we already demonstrated in this study, harmful environmental effects may result when working time decreases beyond a certain threshold level. Hence, one problem policy makers have to tackle is how to design working hour length (increase, if necessary) so that environmental damages can be minimized, especially for certain European countries with shorter working weeks.

To this end, more elaborations are needed for policy makers while difficulties are obvious. One obstacle is the rooted belief that there is a close linkage between shorter working time and higher employment rate, but this claim has so far received very little empirical support (Altavilla et al., 2005). Even if we were to believe that working time and employment rate go hand in hand, the observed unemployment rate reduction is still significantly lower than forecasts (Hunt, 1998; Logeay and Schreiber, 2004). Moreover, further working time reduction comes with high costs. A recent experiment of 6-h working day in a retirement home in Sweden, where nurses' work hours were reduced to merely 30 h per week, is a case in point. Although the nurses reported higher levels of happiness, the experiment was so costly that it would be unwise to replicate or expand it at the regional or national scale in the foreseeable future (Oltermann, 2017; Rogers, 2017).

Deep-rooted social and cultural norms that everyone has the right to rest and popular existing pro-rest policies pose more serious obstacles for countries to reverse decreasing working time. To protect the European workforce, EU countries subsequently adopted the Working Time Directive (WTD) under Article 118a of the Treaty of Rome since 1993. The aim of WTD is to “improve the working environment to protect workers' health and safety”

(Mommaerts, 2009). Toward this end, working hours are legally restricted: maximum permissible weekly working hours of no more than 48 h; a rest period of no less than 11 consecutive hours per day and 35 consecutive hours per week; minimum four weeks paid annual leave and no more than 8 h of night work in any 24-h period (Zbyszewska, 2013). However, certain member countries overcorrected the policies and further shortened the workweek in the name of reducing unemployment and improving well-being and negative effects thus generated, such as the high cost for business activities. In this light politicians tried to revise the WTR policies which are “based off” of WTD. Take France as an example, the government attempted to prolong the famous 35-h workweek via reforming labor regulations to reduce labor costs and improve French companies' international competitiveness. However, as this reform may empower employers to prolong legal working hours and reduce overtime pay, it can potentially jeopardize the welfare of the working people. Accordingly, this proposal instigated fierce nation-wide demonstrations and stagnated (Chazan, 2016). It is thus no easy task to pull people from leisure and push them back into work via plain changes to labor regulations, especially when working people are already accustomed to relatively short working weeks and are reliant on free time to release stress, improve personal well-being, and reboot productivity (Wunder and Heineck, 2013; Smedley, 2014; Mogielnicki, 2016; Artazcoz et al., 2016).

Among the policy tools, income tax cut stand by providing possibility for countries whose environment pressures exacerbate as the average working hours decrease to effectively increase working hours to benefit the environment. Historically, Europeans worked slightly more than Americans. Things began to change when the marginal tax rate in Europe rose faster than that in America, leading to shorter work weeks and longer vacations in Europe. The logic is two-fold. On the one side, there is a cultural preference for leisure among Europeans. Europeans were more unionized and were more likely to demand shorter working hours than higher wages (Landsburg, 2006). On the other side, higher income tax rates meant that larger portions of labor earnings were being taken away, so the marginal return to labor was lower, disincentivizing European workers to labor longer. If European governments are able to provide income tax cuts, workers are able to claim a larger share of their hourly work payoffs, incentivizing them to work longer and contributing ultimately to lessening environmental pressures.

This study lays the groundwork for future studies to further explore in at least four directions. First and foremost, researchers can take into account different socioeconomic, cultural, and historical contexts that may influence what is deemed as the optimum working hours. Second, future researchers can perform similar analyses for different geographic regions of the world instead of focusing just on EU countries. Moreover, researchers can use environmental indicators other than carbon emissions and energy consumption, such as ecological footprint. They can also employ another interesting working time indicator, such as annual working hours per capita rather than per worker. Third, future researchers may opt for dynamic threshold models to better control for temporal changes and test whether robust hold in this new framework, an example of which can be found in Vinayagathasan (2013). Lastly, future researchers may employ new threshold values or simultaneously use multiple threshold variables in their models (see Kuo et al., 2013) to explore effects on environmental pressure.

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Appendix A. Supplementary data

Supplementary data related to this article can be found at http://dx.doi.org/10.1016/j.jclepro.2017.01.115

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