Growth in transport sector CO$_2$ emissions in Tunisia: an analysis using a bounds testing approach

Souhir Abbes*

Laboratory of Research on Economics and Development,
University of Sfax,
Airport Street km 4, 3018, Tunisia
and
Laboratory of CEARC/OVSQ,
University of Versailles Saint-Quentin-en-Yvelines,
11 Bd. D'Alembert-OVSQ 78280 Guyancourt, France
Email: souhir.abbes@icloud.com
*Corresponding author

Julie Bulteau

Laboratory of CEARC/OVSQ,
University of Versailles Saint-Quentin-en-Yvelines,
11 Bd. D'Alembert-OVSQ 78280 Guyancourt, France
Email: julie.bulteau@uvsq.fr

Abstract: This paper analyses the dynamic impacts of GDP growth, motorisation rate, transport pollution coefficient and energy intensity, on CO$_2$ emissions from the transport sector in Tunisia. Empirical results from the ARDL approach show that over the 1971–2014 period, energy intensity and pollution coefficient were the most significant variables. The elasticities of motorisation rate to CO$_2$ emissions were also significant and had the expected sign. These results not only contribute to advancing the existing literature but also provide important policy recommendations: to control transport emissions, policy-makers should invest in public transportation and reinforce the legislation on environmental standards of vehicles. Finally, the statistically insignificant effects of per capita GDP on transport carbon emissions in the long run suggest that it is possible to control these emissions without disrupting economic growth. This can be achieved by developing short sea shipping between the biggest cities to reduce road congestion and carbon emissions.

Keywords: transport sector; CO$_2$ emissions; ARDL; energy efficiency; economic growth; Tunisia.

Biographical notes: Souhir Abbes is an Associate Professor of Economics at the University of Sfax, Tunisia and Associate Researcher in the laboratory of CEARC/OVSQ, University of Versailles, France. She received his PhD from the Department of Economics at the University of Nantes, France, in 2008. Her research and teaching program focuses on the general area of transport economics with an emphasis on policies of sustainable transport, transport

systems performance and transport and energy. She is the author of a number of book chapters, conference papers and journal articles.

Julie Bulteau is an Associate Professor in Economics at the University of Paris Saclay (University of Versailles, Laboratory of CEARC/OVSQ) since 2012. She combines university education and applied research activities at national and international level. Her research activities link the environmental and transportation economics and focus on economic policies for sustainable mobility, microeconomic modelling tools to promote sustainable transport (congestion charges, tradable emission permits), evaluation of transport policies and projects (urban mobility plan, road infrastructure, multimodal platform) and spatial heterogeneity of sustainable transportation.

1   Introduction

In recent years, the contribution of energy to human life has been very significant. Almost every aspect of human life needs energy and the resulting pollution has become a pressing issue that affects the whole planet and the decision-making basis. For any modification or process, whether political or economic, social or industrial, the way it will affect the environment has to be taken into account. Many sectors are involved in this issue. However, our focus will be on the transport sector and its significant contribution to the increase in CO_2 emissions in Tunisia.

The transport sector plays a key role in Tunisia's economic development representing 6% of GDP, contributing about 31% of the added value generated by services and employing roughly 4% of the workforce.

Regarding energy consumption, the transport sector in Tunisia was responsible for 56% of the whole national energy consumption in 2014 (National Agency of Energy Control, 2014) and is, accordingly, the largest energy consumer. The analysis of the gross emissions in Tunisia in 2014 shows that the energy sector was the main contributor to national CO_2 emissions (38.7%), followed by the transport sector (25.2%) and industrial activities (21.3%). Transport sector emissions multiplied by more than six from 0.88 million tons in 1971 to 6.58 million tons in 2014 (Figure 1) with a robust average annual growth rate of 5%. These statistics include only CO_2 emissions from domestic aviation and navigation, and road and rail transport.

Despite the efforts of the Tunisian government to reduce the continuing increase in GHG emissions in the country[1], no special measures have been taken through transport policies. Since 1990, there has been a clear shift from rail towards road. This is the result of a planning model adopted by the Ministry of Transport, which encouraged the acquisition of cars and other motorised vehicles to meet the growing demand for the mobility of passengers and goods. This has led, in turn, to the development of more roads and highways. Unfortunately, fewer investments have been made in public transport, especially in urban areas. The continuing decline in the quality of public transport services, the steady increase in private motorised vehicles and the absence of a rigorous control of vehicle age and emissions have resulted in a rise in pollution and congestion problems.

Figure 1   Trends in CO_2 emissions (in million tons)
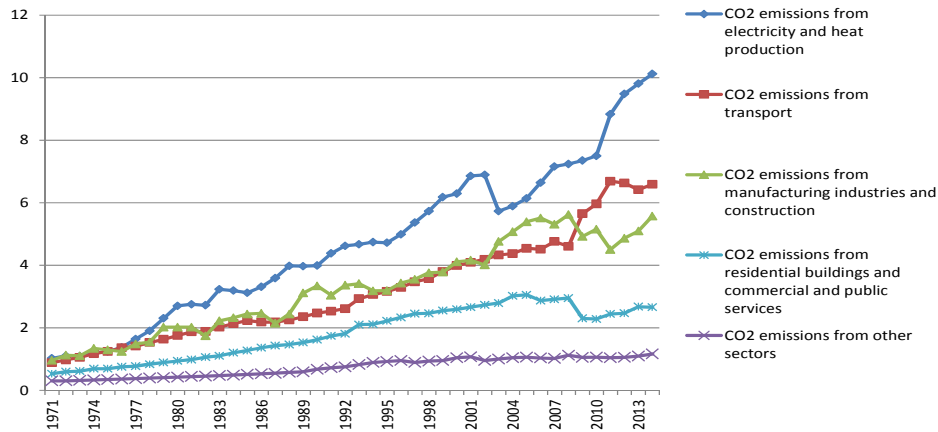
Source: Compiled from the World Bank Databank, Tunisia

Transport activity and the resulting CO_2 emissions could significantly increase in the coming years along with economic growth. Therefore, identifying the key factors of transport CO_2 emissions is of primary importance to assist in designing effective policies. With this aim, this article investigates the factors affecting transport sector CO_2 emissions in Tunisia over the 1971–2014 period.

Whereas the only two previous studies about Tunisia estimated long- and short-run elasticities using the cointegration and error-correction framework (Ben Abdallah et al., 2013; Shahbaz et al., 2015), this study applies the ARDL bounds testing approach of cointegration recently developed by Pesaran and Shin (1999) and Pesaran et al. (2001). Another difference is that it uses a larger database and introduces new variables to study the causes of CO_2 emission increase. These variables are: (i) Gross Domestic Product, (ii) motorisation rate, (iii) pollution coefficient and (iv) energy intensity.

The remainder of the paper is organised as follows. Section 2 examines the potential factors driving transport sector CO_2 emission growth over the last 45 years. This is followed by a review of empirical studies (section 3). Section 4 outlines the modelling framework and data collection. Empirical estimations and interpretations are provided in section 5. The last section concludes and gives some policy implications.

2   Potential factors driving the growth in transport sector CO_2 emissions

This section examines a wide range of key factors that are thought to contribute to CO_2 emissions produced by the transport sector. Our focus is on the interrelated economic, demographic and technological factors reported in the literature.

2.1   *Economic growth*

One of the key factors explaining the increase in gross CO_2 emissions is the level of economic activity. In fact, GDP growth is inseparable from increases in both energy

demand and CO$_2$ emissions. This subject has been mostly examined by economists within the framework of the Environmental Kuznets Curve (EKC) in order to prove a relationship between environmental pollution and per capita income. The majority of studies confirm a close relationship between energy consumption or CO$_2$ emissions and economic growth (Odhiambo, 2009; Shahbaz et al., 2013b; Saboori and Sulaiman, 2013; Jalil and Mahmud, 2009; Zhang and Nian, 2013, Chang, 2010; Farahani et al., 2014; Timilsina and Shrestha, 2009a).

Tunisia is a small-sized economy and recorded an overall real growth rate of around 2.1% in 2014. Figure 2 shows that CO$_2$ emissions from transport and GDP per capita presented a similar long-run evolution and were characterised by a general upward trend during this period.

Figure 2 Plots of CO$_2$ emissions from transport, total CO$_2$ emissions and GDP per capita
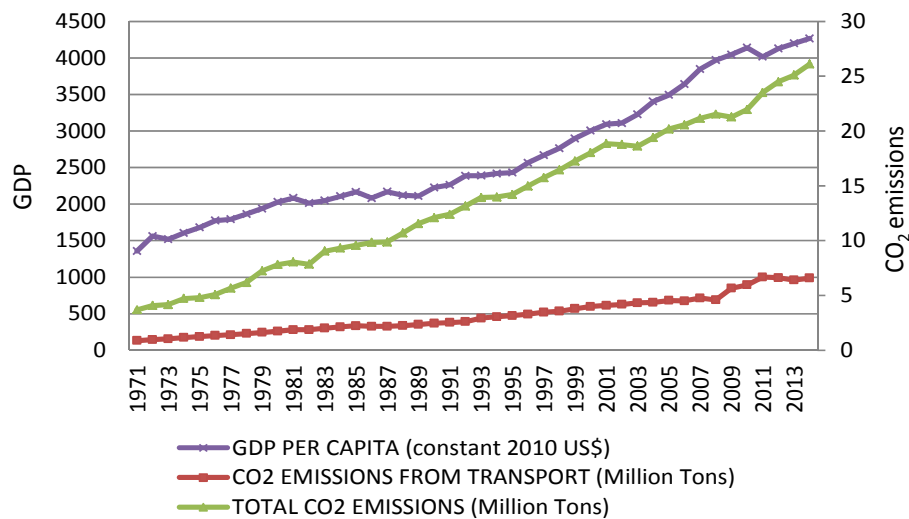
Source: Compiled from the World Bank Database, Tunisia

2.2   *Motorisation, energy prices and modal shift*

The demand for passenger and freight transport and mode choice are affected by several factors, including lifestyles, income, the labour structure, travel costs and time and urban development patterns. Factors reflecting changes in transport demand, such as motorisation rate, energy prices and modal shift, have been included in several studies (Papagiannaki and Diakoulaki, 2009; Scholl et al., 1996; Wang et al., 2011; Ben Abdallah et al., 2013). Rail was an important mode of transport in Tunisia until the 1980s. However, since the 1990s, Tunisia has experienced significant growth in its road transport fleet, particularly in urban areas. Given the present-day modal composition of traffic in the country, the importance of road transportation in the economy is clear. In fact, road transport covers 75% of freight transport against 19% for rail, 3% for air and 3% for maritime transport. Moreover, road is the main mode of passenger transport in Tunisia (95%), against only 5% for rail transport.

This phenomenon is the result of subsidised energy prices[2] and low interest rates for car loans (popular vehicles) provided by the government in the 1990s together with increasing incomes. The private car is considered an indicator of wealth and social status by Tunisians. The deterioration in the quality of public transport services further encouraged people to replace rail and public transport by the private car. Overall, motor vehicle ownership (vehicles per 1000 people) increased from 42 in 1985 to 173 in 2014, an increase of about 312% (Table 1). In Tunisia, taxis are also involved in urban and inter-urban collective transportation because of an irregular and ineffective public service.

**Table 1**   Motorisation rate and fuel prices in Tunisia

Year	Motorisation rate (vehicles per 1000 people)	Pump prices (US $ per litre)	
		Diesel fuel	Gasoline
1971	22.90	n.a.	n.a.
1985	42.35	n.a.	n.a.
2000	85.14	0.29	0.49
2014	172.93	0.68	0.91

Sources: Compiled from the World Bank Database and the Tunisian Ministry of Transport

2.3   Population growth and urbanisation

As a country continues to grow and urbanise, increasing motorisation can be expected to generate higher levels of CO_2 emissions and put additional stress on the transport infrastructure (Timilsina and Shrestha, 2009a, 2009b; Wang et al., 2011, Lu et al., 2007). The rate of urbanisation is especially fast in developing countries. In Tunisia, the urban population rose from 50% of the total population in 1980 to 66.6% in 2014.

Figure 3   Plots of transport CO_2 emissions and the urban population
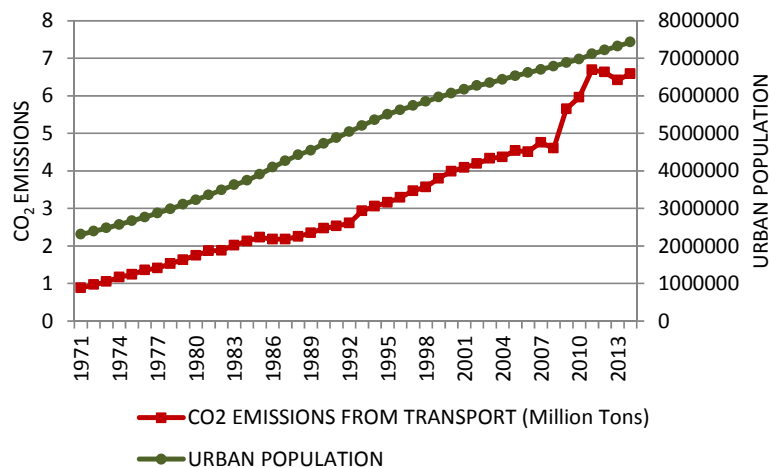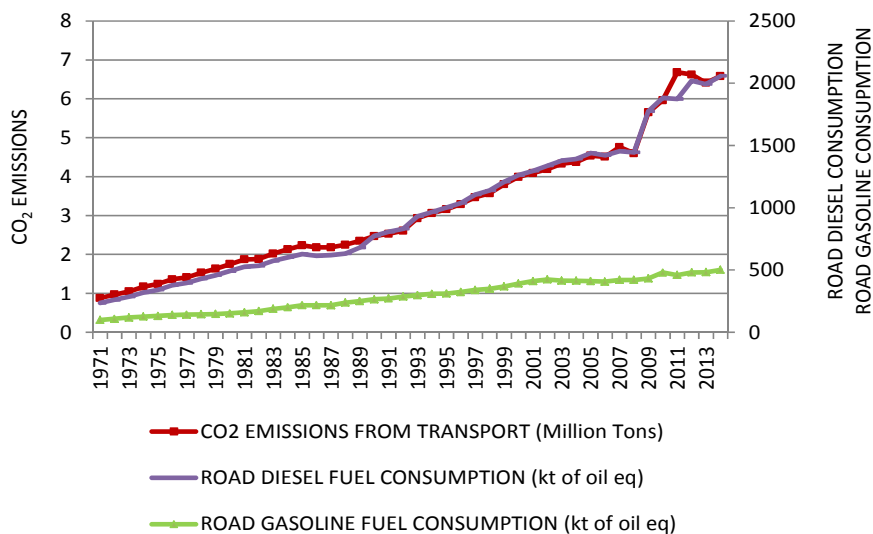

Source: Compiled from the World Bank Database, Tunisia

Population growth and the extension of urbanised zones has led to large public investments in road infrastructure (highways and freeways, particularly). Investments in road infrastructure increased from 30 Million TND in 1997 to 750 Million TND in 2016. However, fewer investments were made in the rail network, which was halved between 1980 and 2014 (decrease throughout the period from 2047 km to 1119 km).

2.4 *Transportation energy consumption and fuel mix*

Changes in the fuel mix and energy consumption are other factors that explain the growth in transport sector CO_2 emissions (Shahbaz et al., 2015; Scholl et al., 1996; Wang et al., 2011). In Tunisia, the transport sector depends on fossil energy for up to 99% of its needs. There are very limited fuel choices for land transportation: gasoline and diesel are the main ones. Figure 4 provides details of road transport fuel consumption between 1971 and 2014. It shows a marked replacement of gasoline by diesel in Tunisia. On average, diesel usage by the road sector increased significantly by 5% during the study period.

Figure 4   Plots of transport CO_2 emissions, road diesel consumption and road gasoline consumption

Source: Compiled from the World Bank Database and the National Agency of Energy Control, Tunisia

Another interesting aspect is revealed by the trend of diesel consumption and transport CO_2 emissions. Figure 4 suggests a close link between these two variables. It is generally recognised that diesel has a slightly higher carbon content than gasoline. However, we cannot conclude that the replacement of gasoline by diesel has changed CO_2 emissions significantly as diesel provides better fuel economy than gasoline.

2.5   *Intensity of carbon dioxide and energy intensity*

The intensity of carbon dioxide effect (or the pollution coefficient effect) and energy intensity interact to determine the overall changes in carbon emissions. The intensity of CO_2 effect is generally defined by the ratio of CO_2 emissions to energy use. It reflects changes in abatement technology, fuel quality and fuel switching. It is also named the "carbonisation index" in some studies (e.g. Mielnik and Goldemberg, 2000). The energy intensity effect, which is the ratio of the total fuel consumption in an economy to its gross domestic product, refers to changes in the structure and efficiency of the energy system. Such variables were included in the studies of Wang et al. (2011), Timilsina and Shrestha (2009a), Papagiannaki and Diakoulaki (2009) and Andreoni and Galmarini (2012).

The effects of energy and carbon dioxide intensity are a major concern of the National Agency for Energy Control (NAEC), which has recently fixed various objectives for 2030 (NAEC, 2014), particularly regarding the development of renewable energies and the control of energy demand. Nevertheless, in the case of the transport sector, there are no clear rules regarding car emissions since all vehicles are imported[3] and in 2012 the authorities increased the maximum age of imported vehicles from 3 to 5 years.

As can be seen in Table 2, there was a noticeable deterioration in total energy intensity from 1971 to 2014 in Tunisia. However, there was no clear trend over the long term for CO_2 intensity.[4] For the transport sector, CO_2 intensity is defined as the ratio of transport CO_2 emissions to energy use in the sector. Energy intensity in transport can be calculated as the ratio of fuel consumption in the sector to GDP (Timilsina and Shrestha, 2009a; Andreoni and Galmarini, 2012).

Table 2   Evolution of energy intensity and CO_2 intensity in Tunisia

Year	Energy intensity (kg of oil/GDP 2005 constant	CO₂ intensity (kg per kg of oil equivalent energy use)
1971	0.19	2.54
1985	0.32	2.86
2000	0.45	2.72
2014	0.51	2.74

Source: Compiled from the World Bank Database, Tunisia

3   Literature review

In the last twenty years, an increasing number of scientists have focused on the factors influencing the total national CO_2 emissions, emissions by activity sector and energy consumption.

The first branch of the current literature provides elements about the relationship between economic growth and CO_2 emissions; the so-called Environmental Kuznets Curve (EKC). These studies include Grossman and Krueger (1995), Selden and Song (1995), Jalil and Mahmud (2009), and Shahbaz et al. (2013a).

The second branch uses cointegration, Granger causality or bounds testing methods to analyse the correlations between national CO_2 emissions, energy consumption and economic growth (Chang, 2010; Saboori and Sulaiman, 2013). Farahani et al. (2014) and Halicioglu (2009) also included a "trade" variable for the cases of Tunisia and Turkey, respectively. Shahbaz et al. (2013b) examined the links between CO_2 emissions, economic growth, energy consumption, financial development and international trade in the case of Indonesia. Other new variables, such as foreign direct investment, were also incorporated in the analysis (Chandran and Tang, 2013, in five ASEAN economies from 1971 to 2008).

The third branch examines the factors influencing CO_2 emissions or emission intensities of the different sectors in the economy. Various studies focus on the manufacturing and power sectors (e.g. Schipper et al., 2001; Chang and Lin, 1998; Shrestha and Marpaung, 2006; Liu et al., 2007, Liaskas et al., 2000) while others examine the transport sector, in particular.

In the literature, four major methods have been used. The most applied one is the decomposition technique based on the Logarithmic Mean Divisia Index method (LMDI; Ang and Choi, 1997) and the refined Laspeyres extension (Sun, 1998). The first one gives complete decomposition results while the second allocates the residuals on the basis of the "jointly created and equally distributed" principle. To explain transport CO_2 emissions (called aggregate in a decomposition model), economists assume that this variable is the sum of CO_2 emissions from each transportation mode. To deepen the analysis, other subscripts, i, j and t for example, can be used at a sub-category level to denote CO_2 emissions of the ith transportation mode based on fuel type j in year t. Other variables, like economic growth, population, energy consumption, transportation service per mode (activity), network, and motorisation, can be introduced into these sub-categories to represent the different "effects" that contribute to transport CO_2 emissions. Timilsina and Shrestha (2009a) used the LMDI to examine the growth of transport sector CO_2 emissions in twelve Asian countries from 1980 to 2005. To identify the driving factors, they decomposed the emission growth into fuel switching, changes in emission coefficients, per capita economic growth, transportation energy intensity, modal shifting and population growth. Timilsina and Shrestha (2009b) used the same technique to identify the factors affecting CO_2 emissions in twenty Latin American countries and the Caribbean. In 1997, Lakshmanan and Han investigated the relative contributions of population, GDP and growth in people's propensity to travel to the change in transport sector CO_2 emissions in the US from 1970 to 1991. The LMDI index was also used by Papagiannaki and Diakoulaki (2009) to explain CO_2 emissions from passenger cars in Greece and Denmark for the period 1990–2005. The factors taken into account were: the population effect; the ownership effect; the distance effect (reflecting changes in the average annual mileage); the fuel mix effect; the size effect (measured by changes in engine capacity) and finally "the technology effect" which reflects changes in car technology (classified by European standards). Lu et al. (2007) attributed changes in CO_2 emissions from highway vehicles in Germany, Japan, South Korea and Taiwan to changes in emission coefficient, vehicle fuel intensity, population, economic growth and vehicle ownership. Wang et al. (2011) also used the Divisia Index to analyse transport CO_2 emissions in China from 1985 to 2009. The per capita economic activity and transport modal shifting effects were found to be primarily responsible for driving

transport CO_2 emission growth. The Adaptive Weighted Divisia was applied by Greening et al. (1999) to explain the causes of carbon intensity evolution in ten OCDE countries. Andreoni and Galmarini (2012) decomposed CO_2 emissions of the aviation and water sectors in European countries using the refined Laspeyres extension. The energy intensity effect (which refers to energy consumption per unit of output in the economy); the CO_2 intensity effect, measured by the ratio of CO_2 emissions to energy use; the structural changes effect (reflecting changes in the relative position of a sector in an economy) and economic activity growth were the four components of the decomposition index. Lastly, in 1996, Scholl et al. investigated the relative contribution of changes in the transport activity, modal composition and the energy intensity of each mode to changes in CO_2 emissions from passenger transport in nine OCDE countries from 1973 to 1992.

The second method is the econometric technique. Various options are available in conducting the cointegration analysis, including the residual-based approach proposed by Engle and Granger (1987), the maximum likelihood-based approach discussed by Johanson and Juselius (1990) and the fully modified OLS procedure. As mentioned above, these methods have been particularly used to analyse national CO_2 emissions. In the specific case of transport CO_2 emissions, Gonzalez and Marrero (2012) analysed the effect of dieselisation on passenger car emissions in Spain. Two studies used time series data for Taiwan: Lu et al. (2010) predicted the development trends of the motor vehicle population, vehicular energy consumption and CO_2 emissions while Liao et al. (2011) detected significant emissions from inland container transport. Panel data from 2000 to 2012 and non-parametric additive regression models were used to examine the key influencing factors of CO_2 emissions in the transport sector in China (Xu and Lin, 2015). Factors included urbanisation, energy efficiency and economic growth. Saboori et al. (2014) investigated the long-run nexus between economic growth and transport sector CO_2 emissions in OECD countries. Tolon-Becerra et al. (2012) examined the distributed dynamic CO_2 emission reduction targets for EU countries. Meyer et al. (2007) estimated passenger car demand and associated CO_2 emissions in 11 world regions.

The third method is the bottom-up sector-based analysis. Vedantham and Oppenheimer (1998) investigated aviation emissions and demand using a dynamic system model. Bellasio et al. (2007) developed the COPERT III methodology to analyse the emissions from road traffic in Italy. Moran and Gonzalez (2007) applied an input-output methodology to analyse the structure of CO_2 emissions from land transport in several European Union countries.

Finally, the fourth method is system optimisation. This has been widely used in forecasting energy demand and CO_2 emissions (Hickman and Banister, 2007; Si et al., 2012; Ahanchian and Biona, 2014; Motasemi et al., 2014; Shakya and Shrestha, 2011); in analysing integrated energy planning for sustainable development (Szendro and Torok, 2014); and in the analysis of policy effect (Almodovar et al., 2011).

Despite the significant problems associated with growing transport pollution and congestion in Tunisia, only two studies have been conducted to identify the factors affecting transport sector CO_2 emissions in this country. Ben Abdallah et al. (2013) applied the Johansen cointegration technique to detect short- and long-run causalities between the transport added value, road transport-related energy consumption, road infrastructure, fuel price and transport CO_2 emissions over the 1980–2010 period. They found a long-run mutual causal relationship between them. Empirical findings also refuted the hypothesis of an inverted U-shaped EKC for transport CO_2 emissions in

Tunisia. The authors suggested that policy-makers should integrate socio-economic and environmental dimensions in their transport policy because their analysis showed that transport planning, price policy and land planning have a significant impact on energy saving from road transport. Recently, Shahbaz et al. (2015), using the same variables as Ben Abdallah et al. (2013) for the period 1980–2012, applied the newly developed combined cointegration test proposed by Bayer and Hank (2013). The robustness of the cointegration result was assessed by applying bounds testing. They found a significant cointegration relationship between transport CO_2 emissions, road energy consumption, fuel prices, road infrastructure and transport sector added value. The EKC was validated in the long run but was insignificant in the short run. Given the empirical results, the authors suggested that the government review its energy subsidy program to improve energy efficiency in the sector and control CO_2 emissions. Furthermore, as the value added and road infrastructure increased CO_2 emissions in the model, the authors invited the government to build new infrastructure to support economic growth while encouraging the use of alternative technologies for road transportation.

Our work differs from the previous studies in three aspects. First, it includes other variables, such as the pollution effect, motorisation and energy intensity effect. Second, our study is based on the whole sector perspective rather than specifically transport. Lastly, apart from using a larger database (from 1971 to 2014), we applied the recently developed Autoregressive Distributed Lag (ARDL) approach suggested by Pesaran et al. (2001), which is less sensitive to the size of the sample than multivariate cointegration and provides unbiased long-run estimates and valid t-statistics (Narayan, 2005).

4   Econometric specification and data

Our model specification is based on the STIRPAT (STochastic Impacts by Regression on Population, Affluence and Technology) model proposed by Dietz and Rosa (1997). It was developed from the IPAT model (I=PAT), which analyses the effect of economic activity on the environment (Ehrlich and Holdren, 1971; Chertow, 2000; Feng et al., 2009). The STIRPAT model is given by the following equation:

$$I = aP^b A^c T^d e$$

where I denotes the effects on the environment of human activities, P is the population, A the affluence (per capita GDP), T the technological factor and e the error term. The constant a scales the model; b, c and d are the exponents of P, A and T. Additional factors can be added to the basic STIRPAT model as long as they are conceptually appropriate (York et al., 2003).

After taking logarithms, the model takes the following form:

$$\ln I = a + b \ln P + c \ln A + d \ln T + \varepsilon$$

The original purpose of STIRPAT was to estimate the effects of driving forces on environmental impacts. A coefficient of a driving force in the logarithmic form of STIRPAT represents the elasticity of the driving force, i.e. the percentage change in environmental impacts if the driving force changes by 1%. The coefficient is called "ecological elasticity" (EE) and can be interpreted as the marginal environmental impacts of the corresponding driving forces.

Consequently, to analyse the CO_2 emissions in the transport sector in Tunisia, our model takes several variables into account. We attribute the growth of transport CO_2 emissions ($CO2\_TR$), corresponding to *I*, to four factors:

(i)   *GDP*, the per capita economic growth in constant US dollars, is incorporated to measure the social economic activity (*A* in the STIRPAT model);

(ii) *MOT*, the motorisation rate (i.e. the number of private vehicles per 1000 people in the country), is incorporated to measure the effect of population growth, urbanisation and modal shift in the transport sector (*P* in the STIRPAT model).

Lastly, the technological factor *T* in the STIRPAT model is decomposed into two variables: *PC* and *EI:*

(i)   *PC* stands for the pollution coefficient of the transport sector defined as the ratio of transport CO_2 emissions to fuel consumption of the sector.

(ii) *EI* is the energy intensity and calculated as the ratio of total fuel consumption in transport to GDP.

To calculate the marginal environmental impact of each factor (elasticity of the driving force), we estimate the following equation:

$$CO2\_TR_t = \alpha_0 + \alpha_1.GDP_t + \alpha_2.MOT_t + \alpha_3.PC_t + \alpha_4.EI_t + \varepsilon_t \qquad (1)$$

where t and α_0 denote the time and the fixed country effect, respectively. The residuals ε_t are assumed to be normally distributed and white noise. Data for the last 44 years (1971–2014) were obtained from the World Bank Development Indicators and the National Agency of Energy Control. The motorisation rate was obtained from the Tunisian Ministry of Transport.

In this research, we use the Auto-Regressive Distributed Lag (ARDL) developed by Pesaran and Shin (1999) and later extended by Pesaran et al. (2001). The ARDL bounds testing approach to cointegration has a number of distinct econometric advantages compared to other cointegration procedures. First, it can be applied regardless of whether the underlying regressors are integrated of order one I(1), order zero I(0), or fractionally integrated. Secondly, the small sample properties of the bounds testing approach have been shown to be much better than those of multivariate cointegration (Narayan, 2005). Thirdly, the ARDL technique generally provides unbiased estimates of the long-run model and valid t-statistics, which solve the problems of serial correlation and endogeneity associated with the Engle-Granger method (Pesaran and Pesaran, 1997; Pesaran et al., 2001).

Once it is established that none of the variables is I(2) or beyond using unit root tests, a long-run cointegration relationship can be tested for the following ARDL (p,q,r,s,w) specification.

$$\Delta CO2\_TR_t = \beta_0 + \sum_{i=1}^{p} \beta_1.\Delta CO2\_TR_{t-i} + \sum_{j=0}^{q} \beta_2.\Delta GDP_{t-j} + \sum_{k=0}^{r} \beta_3.\Delta MOT_{t-k}$$

$$+ \sum_{l=0}^{s} \beta_4.\Delta PC_{t-l} + \sum_{m=0}^{w} \beta_5.\Delta EI_{t-m} + \beta_6.CO2\_TR_{t-1} + \beta_7.GDP_{t-1} + \beta_8.MOT_{t-1} \quad (2)$$

$$+ \beta_9.PC_{t-1} + \beta_{10}.EI_{t-1} + \mu_t$$

where Δ denotes a first difference term.

The bounds testing approach to cointegration requires the F-test to be carried out on the selected ARDL models including appropriate lags of selection criteria such as the Akaike Information Criterion (AIC) and the Schwarz Information Criterion (SC). The calculated F-statistics value is then compared to two sets of critical values provided by Pesaran et al. (2001). One set assumes that all the variables are I(0) and the other assumes they are I(1). If the calculated F-statistics exceed the upper critical value, then the null hypothesis of no cointegration cannot be accepted and there is a long-run cointegration relationship between the variables in the model.

Once we established that a long-run cointegration relationship existed, it was possible to perform for the selected ARDL representation a general correction model (ECM) of Eq. (2).

$$\Delta CO2\_TR_t = \beta_0 + \sum_{i=1}^{p} \beta_1.\Delta CO2\_TR_{t-i} + \sum_{j=0}^{q} \beta_2.\Delta GDP_{t-j} + \sum_{k=0}^{r} \beta_3.\Delta MOT_{t-k}$$
$$+ \sum_{l=0}^{s} \beta_4.\Delta PC_{t-l} + \sum_{m=0}^{w} \beta_5.\Delta EI_{t-m} + \lambda ECM_{t-1} + \xi_t \tag{3}$$

where λ is the error correction parameter, ECM_{t-1} is the residuals that are obtained from the estimated cointegration model and ξ_t is the disturbance term assumed to be uncorrelated with zero means. *ECM* integrates short-run adjustments with long-run equilibrium without losing information.

We defined the lagged residuals estimated in the following equation as the error correction term (ECM_{t-1}) then we estimated the parameters related to the long-run model:

$$ECM_{t-1} = CO2\_TR_{t-1} - \alpha_1.GDP_{t-1} - \alpha_2.MOT_{t-1} - \alpha_3.PC_{t-1} - \alpha_4.EI_{t-1} \tag{4}$$

Finally, we tested the stability of the model using the Brown et al. (1975) technique of CUSUM and CUSUMSQ and the Ramsey RESET test (Ramsey, 1969).

5   Empirical results and discussion

5.1   Unit root tests

The time series properties of the variables in equation (1) were implemented through two unit root tests: the ADF of Dickey and Fuller (1979, 1981) and the PP of Phillips and Perron (1988). The results reported in Table 3 show that all the series appear to contain a unit root in their levels, except for MOT which appears to be stationary at a 5% level of significance. Overall, the results were somewhat inconclusive, and this is precisely the situation for which ARDL modelling and bounds testing are designed.

Table 3   Unit root tests

		CO_2_TR	GDP	MOT	PC	EI
ADF	Level	−3.146693 (0.1008)	−2.451175 (0.3496)	−0.395017 (0.9845)	−1.776328 (0.6988)	−1.645622 (0.7578)
	First difference	−6.815117*** (0.0000)	−9.048967*** (0.0000)	−7.841934*** (0.0000)	−6.886557*** (0.0000)	−7.308137*** (0.0000)
PP	Level	−3.146530 (0.1089)	−2.564259 (0.2977)	−4.033556 (0.0148)**	−1.862155 (0.6565)	−1.538148 (0.8004)
	First difference	−6.814699*** (0.0000)	−8.720318*** (0.0000)	−8.245260*** (0.0000)	−6.879314*** (0.0000)	−7.389807*** (0.0000)

Notes: ADF and PP examine the null hypothesis of non-stationarity.

For ADF, Eviews 9 software was used to select the optimal lag length, which is the lag level that maximises the Schwarz Info Criterion (SIC). For PP, Bartlett Kernel was used as the spectral estimation method. The truncation lags were based on Newey and West (1987) bandwidth.

The choice of the appropriate models for the level and first difference was based on the decision procedure suggested by Dolado et al. (1990), p.4.

*, ** and *** denote statistical significance at 10%, 5% and 1% level of significance, respectively.

Applying the unit root tests to the first-differences of each series led to a very clear rejection of the hypothesis that the data are $I(2)$.

5.2   Cointegration-ARDL bounds testing procedure

In the first step of the ARDL analysis, we tested for the presence of long-run relationships in equation (2). At this stage, as we used annual data, the maximum lags in the ARDL were set equal to 2. The calculated F-statistics are reported in Table 4. In the model, $F_{CO2\_TR} = 14.25$ is higher than the upper bound critical value. This provides sufficient evidence that there is a strong long-run relationship between the variables.

Table 4   ARDL bounds test

	K = 4	F-statistic = 14.25644
Critical value bounds		
Significance	*I(0) Bound*	*I(1) Bound*
10%	2.45	3.52
5%	2.86	4.01
2.5%	3.25	4.49
1%	3.74	5.06

Note: Critical value bounds are those that are calculated by Pesaran et al. (2001) for the model with an unrestricted intercept and no trend.

The adjusted Akaike Information Criterion (AIC), Schwarz Criterion (SC) and Hannan Quinn (HQ) criterion were used to find the coefficients of the level of the variables. The results were almost identical indicating that an ARDL (1,1,1,1,1) is the best model (Figure 5).

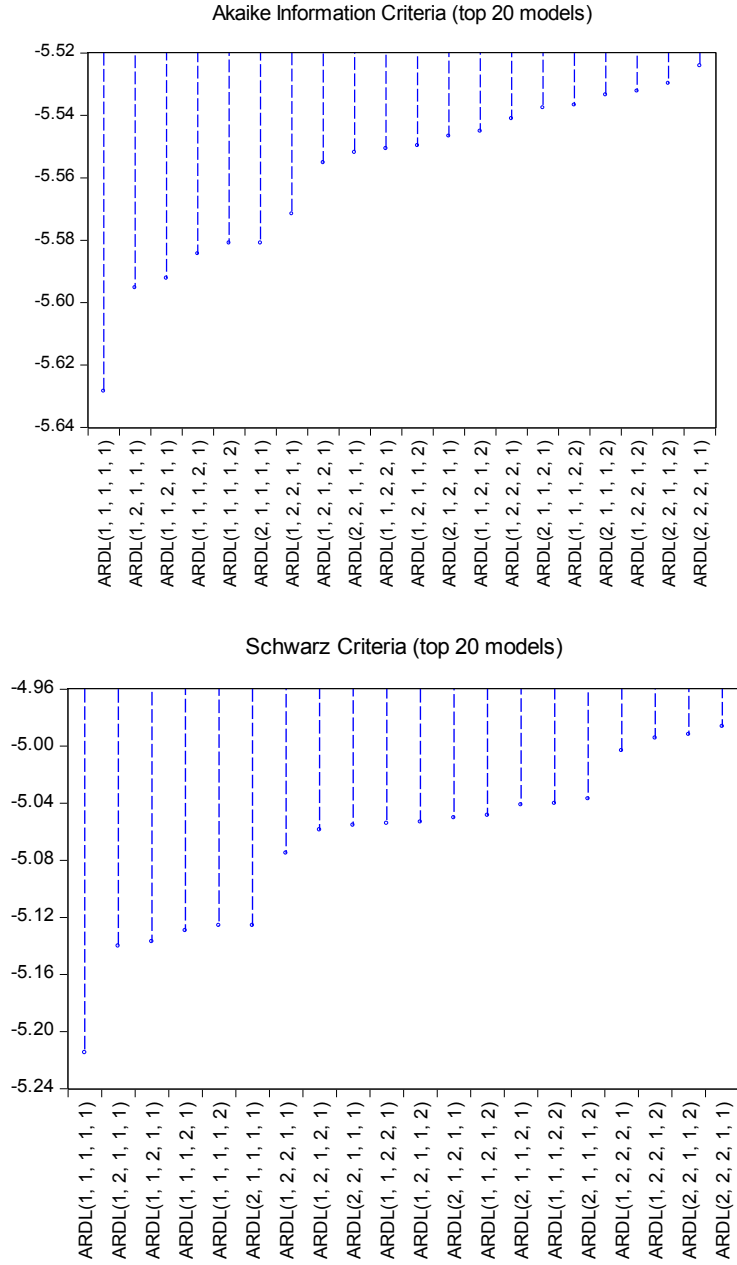**Figure 5** Choice criteria for selecting the order of optimal lags (p,q,r,s,w)
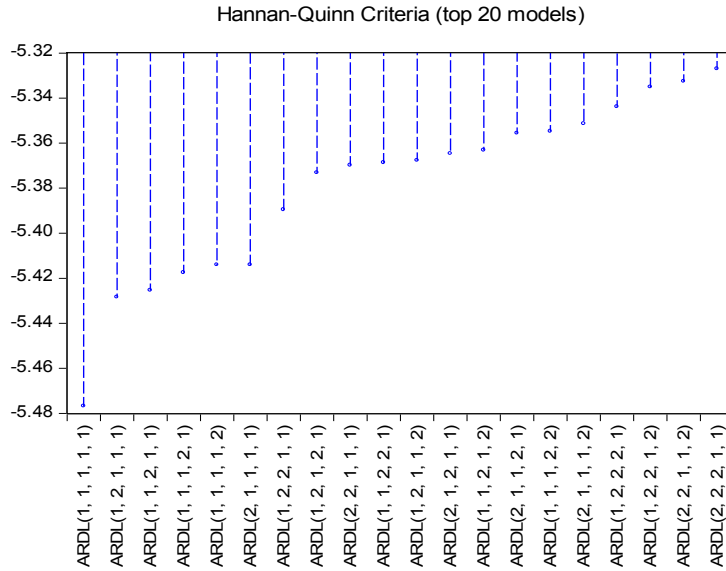
Figure 5   Choice criteria for selecting the order of optimal lags (p,q,r,s,w) (continued)

Hannan-Quinn Criteria (top 20 models)

5.3   *Cointegration and the long-run form*

Following the ARDL cointegration methodology, equation (2) was estimated to obtain the long-run estimates.

The error correction term ECM_{t-1} represents the speed of adjustment of $CO2\_TR$ to its long-run equilibrium following a shock. The coefficient of -0.1827 was significant at the 5% level with a negative expected sign, suggesting that a deviation from the long-run equilibrium level of transport CO_2 emissions in 1 year would be corrected by 18.27% over the following year. Moreover, a significant error correction confirmed the existence of a stable relationship between the regressors (GDP, MOT, PC, EI) and the dependent variable CO2_TR.

The diagnostic test statistics did not suggest the presence of any serial correlation (the *Q*-statistic and the LM test) or heteroskedasticity (the Breusch-Pagan-Godfrey test: Breusch-Pagan, 1979; Godfrey, 1978). The estimated model also passed the diagnostic tests of normality. The very high value of R^2 for ECM-ARDL model shows that the fit of the ARDL model was extremely good. The F-statistics, which measure the joint significance of all regressors in the models, were statistically significant at the 1% level and the Durbin-Watson statistic for the model was greater than two.

The results of the long-run and short-run dynamics are reported in Table 5. They indicate that per capita GDP had a short-run positive and significant impact on CO2_TR emissions. A 1% increase in real per capita GDP would increase CO_2 emissions by 0.87% in the short run. The long-run coefficient of GDP was positive but statistically insignificant suggesting that in the long run, the country could control carbon emissions from transport without disrupting economic activity. It is also evident from Table 5 that the remarkable growth of the vehicle fleet in Tunisia and the consequent increase in energy consumption during the study period had a significant impact on transport CO_2

emissions. The contribution of the motorisation rate (MOT) was significant in the short and the long run (0.42% and 0.83%, respectively). Finally, the long-run elasticities of PC and EI on CO2_TR were positive and significant at 1% (2.03 and 1.49, respectively). PC and EI elasticities in the short run were also significant but smaller: 0.984% for PC and 0.988% for EI.

Table 5 Error correction model and long-run estimates for ARDL (1,1,1,1,1)

A. Dependent variable $\Delta CO2\_TR_t$			B. Cointegration vector: dependent variable $CO2\_TR_t$		
Regressors	Coefficients	t-stat	Regressors	Coefficients	t-stat
ΔGDP_t	0.875133***	9.970460 (0.0000)	GDP_t	0.548336	1.390822 (0.1736)
ΔMOT_t	0.422949***	9.567484 (0.0000)	MOT_t	0.837738**	2.288496 (0.0286)
ΔPC_t	0.984228***	16.617403 (0.0000)	PC_t	2.038408***	3.136611 (0.0036)
ΔEI_t	0.988620***	16.254411 (0.0000)	EI_t	1.492934***	5.599655 (0.0000)
Constant	37.831771***	2.933050 (0.0061)			
ECM_{t-1}	–0.182778**	–1.755023 (0.0185)			
$R^2 = 0.999518$; F = 7606.829***; DW = 2.09; SSR = 0.005681					

Notes: *, ** and *** denote statistical significance at 10%, 5% and 1% level of significance, respectively.

DW indicates Durbin-Watson statistic. SSR stands for the sum of squared residuals.

Probabilities are in ( ).

5.4 Stability of the model

Hansen (1992) mentions that the estimated parameters of a time series may vary over time. Parameter tests are important since unstable parameters can result in model mis-specification, which has the potential to bias the results. This study applied CUSUM and CUSUMSQ techniques based on the ECM of Eq. (2). As can be seen from Figure 6, the plots of CUSUM and CUSUMSQ statistics are well within the 5% critical bounds of parameter stability, implying that all the coefficients in the model are stable.

As a further check on parameter stability, the Ramsey RESET (Regression Specification Error) test proposed by Ramsey (1969) was employed. This is useful when the question under investigation is whether or not the specified model is appropriate for capturing a stable relationship. It tests for variable omission, incorrect functional form (including variables with power) and correlation between the regressors and the disturbance vector.

Figure 6   Plots of the cumulative sum of recursive residuals (CUSUM) and the cumulative sum of squares of recursive residuals (CUSUMSQ)
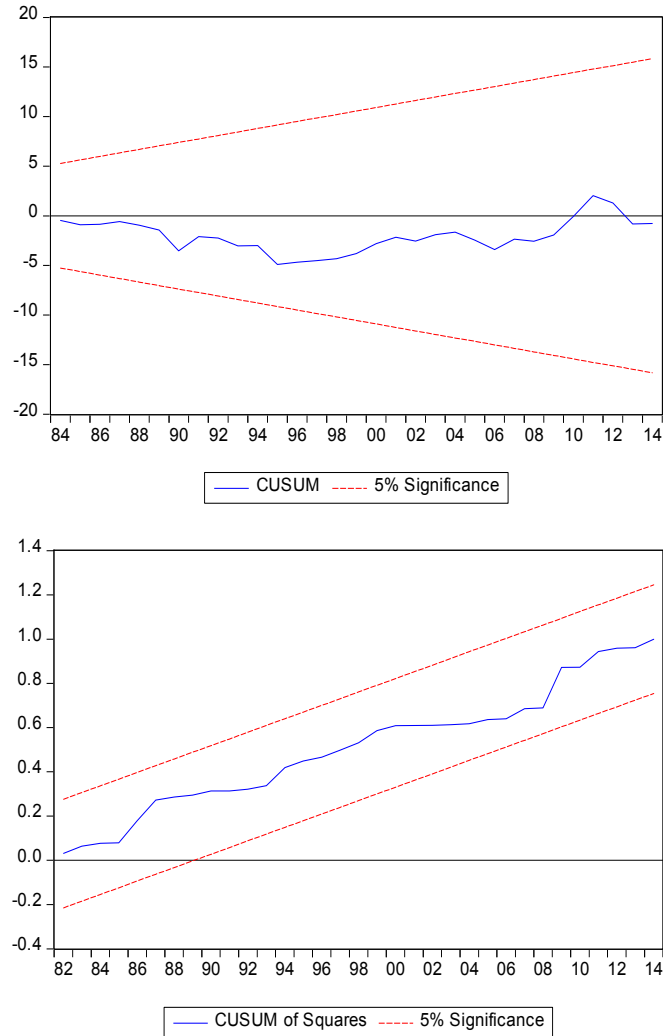
The test results and their probability values are reported in Table 6. They provide evidence of model and parameter stability since the probability values are greater than 0.05. Thus, the results of the Ramsey RESET test corroborated those of the CUSUM and CUSUMSQ tests.

Table 6   Ramsey RESET test for parameter stability

Test	Value	Probability
t-statistic	1.056686	0.2997
F-statistic	1.116585	0.2997

6   Conclusions and policy implications

This study examined the dynamic relationship between CO$_2$ emissions, economic activity, motorisation, pollution coefficient, and energy intensity in the transport sector in Tunisia for the 1971–2014 period. Several meaningful and interesting results were revealed by our empirical analysis.

The first finding is that the energy intensity and pollution coefficient are critical factors in the growth of transportation sector CO$_2$ emissions in Tunisia, in both the long and the short run. For energy intensity, the elasticity ranges from 0.98% to 1.49%. For the pollution coefficient, it is between 0.98% and 2.03%. In our opinion, this may be attributable to two causes: on one hand, road transport by private cars, when compared with public transport by bus or rail, is an intensive pollutant. In Tunisia, public transport is irregular and of poor quality. On the other hand, no improvements in engine quality or time regarding the renewal of the fleet have been imposed. Therefore, economic growth has been accompanied by a larger growth in energy consumption and ineffective policies to reduce emissions. To control CO$_2$ emissions, the Tunisian government should widely invest in public transportation to ensure a modal shift. It should then review its policies of energy subsidy and popular cars at low interest rates. Setting standards on vehicle fleet age and consumption and encouraging the importation of electric vehicles may also have the potential to lower CO$_2$ emissions.

The second finding is the expected positive influence of per capita GDP growth in the short run. A 1% increase in real per capita GDP will increase CO$_2$ emissions by 0.87%. There are at least two channels linking income to CO$_2$ emissions: economic activities require an enormous amount of energy resources and material inputs, which increases environmental damage. Since the 1990s, rising income levels have encouraged ownership of vehicles. The lack of a clear transport policy has led to uncontrollable fleet and congestion problems. To meet the objective of limited transport CO$_2$ emissions, Tunisia should find ways to "decouple" pollution from economic growth. For example, the transport of passengers and goods by short sea shipping and sea motorways should be developed since most of the large cities in the country are situated on the coast. The positive but insignificant relationship between per capita GDP and CO$_2$_TR in the long run suggests that it is quite possible to control carbon emissions from transport without affecting economic growth.

The effect of the motorisation rate is significant but smaller than the other variables. This can be explained by the various interactions between ownership and economic growth, on one hand, and ownership, fuel switch and energy intensity, on the other hand. As mentioned above, the increase in the motorisation rate could be reflected either in the deterioration of transportation energy intensity or in higher levels of income. The clear shift from gasoline to diesel consumption in the transport sector could also impact the net effect of the vehicle fleet increase since diesel offers better fuel efficiency.

Finally, the finding of high long-run coefficients rather than short-run ones for all the explanatory variables suggests that the Tunisian government should focus on socio-economic and environmental policies in the long run: investments in public and maritime transport infrastructure and the use of fiscal instruments and technology standards to reduce fuel consumption are the most urgent political initiatives that can be undertaken by the government to help address energy consumption and associated emissions from the transport sector.

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Notes

1   Ratification of the Kyoto protocol in 2003; the National Solar Energy plan launched in 2009; the implementation of a network of sensors to detect pollutants from fixed and mobile sources since 2007, etc.

2   Average prices in the European Union, for example, are as follows: 0.68 US$ for diesel and 0.76 US$ for gasoline in 2000; 1.6 US$ for diesel and 1. 8 US$ for gasoline in 2014.

3   For example, according to the Euro 6 directive (September 2015), all mass-produced cars in the European Union need to meet several emissions requirements (this includes nitrogen oxide, NOx; carbon monoxide, CO; hydrocarbons, THC and NMHC; and particulate matter, PM). The aim is to reduce levels of harmful car and van exhaust emissions, both in petrol and diesel cars.

4   Note that these measures of energy intensity and CO$_2$ intensity take into account energy consumption by all the sectors and total CO$_2$ emissions. Specific measures for the transport sector are used in our empirical analysis.