DIGITALES ARCHIV

ZBW – Leibniz-Informationszentrum Wirtschaft
ZBW – Leibniz Information Centre for Economics

Manel, Daldoul; Ahlem, Dakhlaoui

Article

The direct rebound effect and energy efficiency policy : an econometric estimation in the case of Tunisian transport sector

Provided in Cooperation with:
International Journal of Energy Economics and Policy (IJEEP)

Reference: Manel, Daldoul/Ahlem, Dakhlaoui (2021). The direct rebound effect and energy efficiency policy : an econometric estimation in the case of Tunisian transport sector. In: International Journal of Energy Economics and Policy 11 (5), S. 235 - 243. https://www.econjournals.com/index.php/ijeep/article/download/11456/6020. doi:10.32479/ijeep.11456.

This Version is available at:
http://hdl.handle.net/11159/7837

Kontakt/Contact
ZBW – Leibniz-Informationszentrum Wirtschaft/Leibniz Information Centre for Economics
Düsternbrooker Weg 120
24105 Kiel (Germany)
E-Mail: *rights[at]zbw.eu*
https://www.zbw.eu/econis-archiv/

Standard-Nutzungsbedingungen:
Dieses Dokument darf zu eigenen wissenschaftlichen Zwecken und zum Privatgebrauch gespeichert und kopiert werden. Sie dürfen dieses Dokument nicht für öffentliche oder kommerzielle Zwecke vervielfältigen, öffentlich ausstellen, aufführen, vertreiben oder anderweitig nutzen. Sofern für das Dokument eine Open-Content-Lizenz verwendet wurde, so gelten abweichend von diesen Nutzungsbedingungen die in der Lizenz gewährten Nutzungsrechte.

https://zbw.eu/econis-archiv/termsofuse

Terms of use:
This document may be saved and copied for your personal and scholarly purposes. You are not to copy it for public or commercial purposes, to exhibit the document in public, to perform, distribute or otherwise use the document in public. If the document is made available under a Creative Commons Licence you may exercise further usage rights as specified in the licence.

ZBW Leibniz-Informationszentrum Wirtschaft
Leibniz Information Centre for Economics

Mitglied der Leibniz-Gemeinschaft

International Journal of Energy Economics and Policy

ISSN: 2146-4553

available at http: www.econjournals.com

International Journal of Energy Economics and Policy, 2021, 11(5), 235-243.

The Direct Rebound Effect and Energy Efficiency Policy: An Econometric Estimation in the case of Tunisian Transport Sector

Daldoul Manel*, Dakhlaoui Ahlem

Polytechnic School of Tunisia, LEGI and Faculty of Economics and Management of Nabeul, University of Carthage, Tunisia.
*Email: daldoul_manel@yahoo.fr

Received: 29 March 2021 **Accepted:** 20 June 2021 **DOI:** https://doi.org/10.32479/ijeep.11456

ABSTRACT

In this paper, we estimate the sensitivity of the fuel and travel demand with respect to the fuel price and the income variation, in the case of the road transport in Tunisia, during the 1987-2016 period, resorting to two different econometric approaches: the error correction model (ECM) and the dynamic model. The price and income elasticity estimation, in the long term and the short term, allow the assessment of the direct rebound effects. We shall show that (1) the dynamic model is considered to be the most appropriate approach for our database; (2) the fuel price increase, in both the short term and long the long term, has a negative impact on the energy consumption. Hence, we recommend the public decision-maker to review his/her energy subsidies, in order to improve the energy efficiency in the road transport sector and to control the CO_2 emissions; (3) an increase of the income entails an increase of the energy consumption and, hence, the travel demand; (4) the rebound effects from the fuel price increase will be compensated in the form of a more significant fuel use indicate that if the energy efficiency increases by 1%, 0.21% and 0.29% of the savings resulting.

Keywords: Fuel and Travel Demand Elasticities, The Rebound Effect, The Error Correction Model, The Dynamic Model
JEL Classifications: L91, Q43, Q54, R48

1. INTRODUCTION

The transport sector in Tunisia is considered to be one of the most fossil-energy-consuming sectors, 2.2 million (metric) tons of oil equivalent (TOE) and 55% of the petroleum product consumption[1], which could reach 5 million tons in 2030. Thus, the energy conservation in the transport sector represents, henceforth, a national priority. To reach this goal, the public authorities and, particularly, the National Agency for Energy Conservation (NAEC), in Tunisia, has implemented several incentive policies about improving the energy efficiency in the road transport sector (energy audits and program contracts, motor vehicle diagnosis stations, trainings about rational driving in the transport sector, etc.). However, the expected energy efficiency gains would be partly annihilated by the adverse effects of individual behavior adjustment. A classic illustration is the motorist who replaces his/her old vehicle by a more efficient model and who profits from his fuel savings for a more frequent and farther travel (Gossart, 2010; Sorrell, 2009). This definition is the simplest illustration of what is called the "rebound effect." Thus, during the gain assessment, in terms of energy consumption, following the improvement of the energy efficiency in the transport sector in Tunisia, the public decision maker should not neglect this rebound effect. The econometric estimation of the rebound effect constitutes the basis for the efficient environmental and transport development policies. Yet, to estimate the rebound effect, it is necessary to firstly assess the elasticity of the price and both short- and long-term income.

In that respect, we estimate the elasticity of the fuel and transport demand, with respect to the fuel price and the incomes in Tunisia. Besides, we draw the direct rebound effects. To estimate the elasticities, we use the error correction model (ECM) as well as

1 Source: National Agency for Energy Conservation (2017)

This Journal is licensed under a Creative Commons Attribution 4.0 International License

the dynamic model that are applied on the chronological serial data for the 1987-2016 period. Thus, the main goal is to get reliable elasticity estimation that can be used to orient the economic policies towards the optimal energy conservation instruments in the road transport, while taking into consideration the eventual rebound effect.

The rest of this paper is organized as follows. Section 2 presents a synthesis of the rebound effect economic literature. The econometric model estimation is the subject of third section. The fourth section analyses the different short-term and long-term elasticities, as well as the rebound effect and its political implications. The conclusion and the discussions will be drawn in the final section.

2. LITERATURE REVIEW

The international literature about the rebound effect estimation in the energy economy field is abundant (Turner and Katris, 2017; Yang and Li, 2017; Li and Jiang, 2016; Lin and Du, 2015; Lin and Zeng, 2013; Michaels, 2012; Sorrell et al., 2009; Wadud et al., 2009 etc.).

In the road transport, the rebound effect stimulates, today, increasing debates. For the direct rebound effect in the transport sector, a variety of studies have examined the way travel and fuel demand relate to the fuel price and the income (Dahl and Sterner, 1991; Espey, 1998; Fouquet and Pearson, 2012; Odeck and Johansen, 2016; Goodwin, 1992; Graham and Glaister, 2002; Goodwin et al., 2004). Dahl and Sterner (1991) have shown that the average long-term elasticities are −0.53 for the fuel prices and 1.16 for the income. The average short-term elasticities were approximately half of the long-term ones. In Australia, Samimi (1995) finds that the short-term price-elasticities of the fuel demand in the road transport are not significant.

In the case of the US, during the 1949-2014 period, Wadud et al. (2009) have found that the price-elasticities of the fuel demand and the income elasticities are significant in the period that extends after 1978 (−0.09 and −0.45, respectively). Eltony and Al-Mutairi (1995) have examined the price-elasticities of the fuel demand and the income elasticity in Kuwait, during the 1970-1989 period, and found that the income effect is more significant than the price effect. Such result has also been affirmed by Ramanathan (1999). Odeck and Johansen (2016) estimated the elasticities of fuel and travel demand with respect to fuel prices and income in the case of Norwegian transport sector over the period 1980-2011.They found that short-run and long-run rebound effects were 26% and 6%. Lin and Zeng (2013) have observed that the price-elasticity of the fuel demand in China is between −0.497 and −0.196 in the short term, whereas the mid-term income elasticities are between 1.01 and 1.05. The traditional literature overflights have been completed by Espey's first (1998) meta-analysis, explaining the differences in the elasticity values. The meta-analysis was made on 277 long-term demand price-elasticity estimations and 363 short-term price-elasticity estimations, covering the 1929-1993 period. The short-term fuel demand price-elasticity is between 0 and −1.36, with an average of −0.23. The long-term price-elasticity varies, however, between 0 and −2.72, with an average of −0.58 and a median of −0.43.

With regard to the rebound effect, Sorrell et al. (2009) provided the most recent literature on this mechanism. More recent studies provide specific estimations to each country, such as the one of Matos and Silva (2011). Their contribution consists of estimating the rebound effect in the merchandise road transport in Portugal, during the 1987-2006 period. Results show that the energy efficiency improvement entails a rebound effect of 0.24. Small and Van Dender (2007) have estimated a rebound effect for the motor vehicles in the US of 0.045 in the short term and 0.22 in the long term, in the 1966-2001 period. Wang et al. (2012) have assessed the direct rebound effect for the passenger transport in China, and have also studied the relation between the extent of the direct rebound effect and the household expenditures. They have found that the direct rebound effect for the passenger transport tends to decrease by 0.35 in the 2002-2009 period, with the increase of the household consumption per capita. According to Sorrel (2007), the direct rebound effect empirical estimations converge towards an average of 0.1 in the short term and an average of 0.2-0.3% in the long term. Zhang et al. (2017) estimated the direct and indirect CO_2 rebound effects for China's private cars using a two-stage Almost Ideal Demand System (AIDS) model. They concluded that the direct CO_2 rebound effect plays a dominant role in the total CO_2 rebound effect in most provinces. Dimitropoulos et al. (2018) have presented a meta-analysis of 74 primary studies containing 1120 estimates of the direct rebound effect in road transport to evaluate its magnitude and identify its determinants. They have found that the magnitude of the rebound effect in road transport is, on average, about 10-12% in the short run and about 26-29% in the long run. Zhang and Lin (2018) estimated city-level national-wide rebound effect for China's road transport system using a novel stochastic frontier model. They found that fuel rebound amounts averagely from 7.2% to 82.2% across various regions. Du et al. (2020) employed a CGE model to investigate the energy rebound effect derived from a simulated energy efficiency improvement in different transportation modal subsectors, namely rail, road, water, and air travel. The results suggest that improving overall transportation energy efficiency by 10% manifests a rebound effect of 30% in the Chinese transport sector. Patwary et al. (2021) have assessed the potential rebound effect from improved energy efficiency in the U.S. road freight sector. The results suggest that the average rebound effect of the U.S. road freight sector ranges from 6.9% to 8.8%, a level considerably less than that found for several industrialized countries and emerging economies.

As for the national literature, the only study that estimated the rebound effect in the electricity sector is the one of Labidi and Abdessalem (2018) which measured the direct rebound effect in the electricity sector in Tunisia. The found results show that the direct rebound effect converges towards 81.7% in the long term and it is 46.8% in 1995, reaching 168.8% in 2010. Thus, our work is based on the previous literature, and makes many contributions to the transport and planning economy literature in Tunisia. The first contribution that should be highlighted is that the econometric works have often under/overestimated the energy efficiency elasticities, due to the omission of the rebound effect. Secondly,

there are no previous studies that estimate both the fuel demand and the travel elasticities, with respect to the income and the fuel price in Tunisia. Thirdly, in Tunisia, the studies in the transport field are scarce, and the studies that address the energy efficiency of the above-mentioned sector, particularly, are even scarcer. Therefore, to our knowledge, our study is considered to be the first study that estimates the rebound effect. This study can help the decision makers implement energy efficient policies that take into consideration the existence of the rebound effect and lines up, hence, with the global policies, that are oriented towards the implementation of a sustainable transport system featuring in a broader global tendency of sustainable development.

3. REBOUND EFFECT ECONOMETRIC ESTIMATION IN THE ROAD TRANSPORT SECTOR IN TUNISIA

3.1. Model and Methodology

In order to model the household demand of fuel and travel, we have followed most of the econometric studies (Odeck and Johansen, 2016; Wadud et al., 2009) that used modeling in the form of Cobb-Douglas within the hypothesis of constant elasticities. We suppose that the fuel and travel demand per capita (measured by VKM) can be expressed according to the fuel price, income per capita and the vehicle stock per capita. According to Akinboade et al. (2008), Alves and De Losso da Silveira Bueno (2003) and Wadud et al. (2009), the price and income are the only variables explaining the fuel and travel demand. However, according to Gossart (2010), the vehicle stock variable should be included as an expressing variable, for the fuel and travel demand can depend on the number of vehicles per capita.

The fuel demand and VKM equations can, therefore, be written as follows:

$$F_t = \beta_0 + \beta_R R_t + \beta_P P_t + \beta_V V_{t-1} + \xi_t \quad (1)$$

$$VKM_t = \lambda_0 + \lambda_R R_t + \lambda_P P_t + \lambda_V V_{t-1} + \zeta_t \quad (2)$$

This is where all the variables are in their logarithmic forms; V_{t-1} is the vehicle stock per capita in the previous year; β_s and λ_s are the parameters to be estimated; and ξ_t and ζ_t are respectively the error terms of the fuel demand and travel demand at the moment t.

3.1.1. The error correction model

Econometrically, the first step in estimating a model consists of studying the stochastic effects of the variables that form it. We use the habitual unit root test of the Dickey-Fuller (ADF) and Phillips-Perron (PP) test. A series is said to be non-stationary if its expectation and its variance are modified over time. This first step is essential, for it allows us to deduce the integration order. Secondly, if the stationarity order is found, the following step consists of testing the co-integration, which exists if the ξ_t and ζ_t residues are stationary as well. Engle and Granger (1987) have shown that all co-integrated series can be represented by an error correction model (ECM) that includes two components: long-term common tendency (represented by the level variables) and a short-term correction (represented by the variables in first difference).

The long-term elasticities are determined based on the parameters in the equations (1) and (2):

$$\frac{\partial F_t}{\partial R_t} = \beta_R, \frac{\partial F_t}{\partial P_t} = \beta_P, \frac{\partial F_t}{\partial V_{t-1}} = \beta_V$$

$$\frac{\partial VKM_t}{\partial R_t} = \lambda_R, \frac{\partial VKM_t}{\partial P_t} = \lambda P, \frac{\partial VKM_t}{\partial} = \lambda_V$$

Once the long-term relations are determined, the short-term dynamics are estimated based on the ECM that includes the estimated residues of the long-relation $\hat{\xi}_{t-1}$ and $\hat{\varsigma}_{t-1}$. The short-term error correction models of the fuel and travel demand are formulated as follows:

$$\Delta F_t = \alpha_0 + \sum_{i=0}^{m} \alpha_{R_i} \Delta R_{t-i} + \sum_{i=0}^{n} \alpha_{P_i} \Delta P_{t-i} + \sum_{i=0}^{o} \alpha_{V_i} \Delta V_{t-1-i} + \sum_{i=0}^{p} \alpha_{F_i} \Delta F_{t-i-1} + \alpha_{res} \xi_{t-1} + \varepsilon_t \quad (3)$$

$$\Delta VKM_t = \delta_0 + \sum_{i=0}^{m} \delta_{R_i} \Delta R_{t-i} + \sum_{i=0}^{n} \delta_{P_i} \Delta P_{t-i} + \sum_{i=0}^{o} \delta_{V_i} \Delta V_{t-1-i} + \sum_{i=0}^{p} \delta_{VKM_i} \Delta VKM_{t-i-1} + \delta_{res} \zeta_{t-1} + \mu_t \quad (4)$$

The coefficients of ΔR, ΔP and ΔV are the short-run elasticities.

3.1.2. The dynamic model

In order to test the elasticity sensitivity, with respect to the model choice, we have estimated a dynamic model.

These dynamic models can be formulated as autoregressive models with distributed lags of the fuel and travel demand. They can be written, respectively, as follows:

$$F_t = \lambda_0 + \sum_{i=0}^{m} \lambda_{Ri} R_{t-i} + \sum_{i=0}^{n} \lambda_{Pi} P_{t-i} + \sum_{i=0}^{o} \lambda_{Vi} V_{t-i} + \sum_{i=0}^{P} \lambda_{Fi} F_{t-i-1} + \varepsilon_t \quad (5)$$

$$VKM_t = \pi_0 + \sum_{i=0}^{m} \pi_{Ri} R_{t-i} + \sum_{i=0}^{n} \pi_{Pi} P_{t-i} + \sum_{i=0}^{o} \pi_{Vi} V_{t-i} + \sum_{i=0}^{P} \pi_{VKMi} VKM_{t-i-1} + \varepsilon_t \quad (6)$$

The short-term elasticities are directly determined based on R_t, P_t and V_t for i=0. However, the long-term elasticities are obtained as follows: $\frac{\lambda_{ki}}{1-\lambda_F}$ et $\frac{\pi_{ki}}{1-\pi_{VKM}}$

3.2. The Direct Rebound Effect

Berkhout et al., (2000) define the rebound effect as the increase of the energy consumption that is induced by the utilization unit

price decline, which is allowed by the technical progress: It is the energy efficiency lost by the utilization increase. In the transport field, the particular car efficiency pushes the individuals to drive even more, given the lowered costs of the traveled kilometer. The increase of the fuel consumption, following the improvement of the car fuel efficiency, is often mentioned in literature as a typical example of the direct rebound effect. Hence, it is crucial that the decision makers who implement policies aiming to reduce the vehicle use or the fuel consumption take into account the eventual rebound effects.

The rebound effect measurement in the transport sector relies on the service demand (vehicle traveled kilometers) or the fuel demand (the road transport annual energy consumption). On the basis of Khazzoom (1980), the fuel consumption elasticity, with respect to the energy efficiency, (η_E(F)) can be expressed as follows:

$$\eta_E(F) = -\eta\ (VKM) - 1$$

This is where $\eta_{P_{VKM}}(VKM)$ is the travel demand elasticity (VKM) with respect to the fuel costs, and - $\eta_{P_{VKM}}(VKM)$ is used as an approximate measurement of the rebound effect.

On the basis of fuel demand elasticity, with respect to its price, the fuel consumption elasticity, with respect to the energy efficiency, can be re-written this way: $\eta_E(F) = -\eta_{P_F}(F) - 1$. This is where η_{P_F} is the fuel demand elasticity with respect to its price and $-\eta_{P_F}(F)$ is a measurement of the direct rebound effect. The rebound effect value is, therefore, directly deducted from the fuel/travel price-elasticity. The rebound effect is equal, in terms of greatness, to this elasticity, but it takes the opposite sign. In this article, we shall estimate both $-\eta_{P_{VKM}}(VKM)$ and $-\eta_{P_F}(F)$ elasticities, which are, respectively, the travel and fuel demand price-elasticity. Both rebound effect measurements will be estimated in the last section of our article.

3.3. Presentation of Statistic Data

In our study, we used chronological series from the 1987 to 2016 period. We collected statistic data regarding the vehicle-kilometer number by year (VKM), the road transport energy consumption per capita (F), the real fuel price (P), the national available income per capita (R) and the number of vehicles per 1000 people (V).

The statistic data about VKM, come from a survey conducted by the Ministry of Equipment (the civil engineering management) and it is expressed in millions of vehicle/km. The observations relative to the road transport energy consumption per capita (F) are acquired from the World Bank base (WDI, 2017), and they are expressed in kilotonnes of oil equivalent (KTOE). Regarding the data relative to P, R and V, their respective sources are the National Agency for Energy Conservation (NAEC), the National Institute of Statistics (NIS) and the Technical Agency of Land Transport (ATTT). Table 1 gives the descriptive statistic of the data used in our study.

4. EMPIRICAL RESULTS AND DISCUSSION

4.1. The Error Correction Model Results

4.1.1. Stationarity and co-integration test

The first step consists of using the statistic tests in order to check the stationarity for all the variables. We use the usual unit root test of Dickey-Fuller (ADF) and of Phillips-Perron (PP). The results of both ADF and PP stationarity tests for the variables in level and in first differences are summed up in Table 2. We conclude that the series are not stationary in level, but stationary in first difference. Hence, all the studied variables are integrated with a (I (1)) order. Afterwards, we check the eventual existence of a co-integration relation.

The optimal delay choice is founded by the information criteria to be minimized, notably, the Akaike and Schwartz information criteria. The calculation of the information criteria for the delays, ranging from 1 to 3, gives the following results in Table 3.

The number of the selected delay according to the minimum of the Akaike and Schwartz criteria equals 2 (p=2).

The analysis of the co-integration between integrated variables of order (1) allows highlighting the existence or non-existence of the long-term relation. The co-integration test result is synthesized in the following Table 4.

By reference to the trace and the maximum eigenvalue tests, we find that results confirm the presence of a single co-integration relation to the threshold of 5%, which means that the variables have a long-term balance relation.

4.1.2. Estimation of the error correction model

Every co-integrated system implies the existence of an error correction mechanism that prevents the variable from deviating too much from their long-term balance.

The estimation of the error correction model gives us the following results:

According to Table 5, the error correction term (the restoring force towards the long-term balance) is negative and significant (−1.732 (1st equation) and −0.196 (2nd equation)). This confirms the existence of a long-term relation and allows, thus, to validate the error correction model. In fact, this model is globally satisfying, for the Fisher probability (F-statistic = 0.024 (1st equation) and 0.001 (2nd equation)) is <0.05.

The results indicate that the fluctuations of household fuel demand (LNF) and the annual vehicle mileage (LNVKM) are respectively expressed to 61.5% and of 74.00% by the model variables. We find that the adjustment parameter indicates that it is possible to adjust, respectively, 41.1% and 60.2% of the imbalance between the desired level and the actual one of LNF and LNVKM.

Table 1: Summary statistics

Variables	Variables description	Minimum	Maximum	Mean	Standard deviation
VKM	The number of vehicle-kilometers per year	6046.000	33747.12	19161.21	9525.747
F	Per capita road transport energy consumption	84.32283	201.2549	141.6473	36.14062
P	The real price of fuel	0.432000	1.421000	0.810185	0.321441
R	The real income per capita	1163.724	8201.360	3857.708	2171.326
V	The vehicle stock per 1000 capita	25.85050	108.5479	61.37306	26.47986
Observations	30	30	30	30	30

Table 2: Results of ADF and PP unit root tests[1]

Variables	Augmented dickeyfuller (ADF)		Philipps-Perron (PP)	
	Level	First difference	Level	First difference
LNVKM	1.792-	4.671-	71.11-	4.773-
LNF	0.383-	6.070-	0.300-	76.15-
LNP	0.206-	5.661-	31.13-	25.53-
LNR	0.662-	6.268-	0.718-	86.35-
LNV	1.143-	14.32-	1.174-	4.308-
Critical values at 5%	2.951-	2.954-	2.951-	2.954-

4.1.3. Analysis of the short-term and long-term elasticities

The price-elasticities of the long-term fuel and travel demand are, respectively, −0.429 and −0.452 (Table 6), less than the results found in the literature, estimated between −0.6 and 0.8[2]. Thus, a fuel price increase by 1% is translated by a decrease of the demand by 0.4%. The households, therefore, adapt, in the long term, their fuel consumption to a price increase. This reveals the price signal important efficiency and comforts the policies that are using this instrument.

For the short term, the price-elasticity varies by −0.098–−0.580 for the household car mobility and by −0.183–−0.555 for the fuel demand (Table 6). In other words, the price impact on the fuel and travel demand variation, for a year n, is much more sensitive to the variations of year n-2 than to relative variations of year n-1.

In the short term, the household fuel consumption adjustment is delicate, it goes, mainly, through a decrease of traveled kilometers. However, in the long term, the adjustment is easier, though costlier. It is reflected by the demand (vehicle change, closer transport networks etc.) and by the offer (improvement of the public transport etc.).

Thus, a price increase has a negative impact on the energy consumption. This result is consistent with those found in literature[3], and it is expected, as the fuel prices in Tunisia are subsidized. According to the Ministry of Finance, the oil product subsidies have increased from 430 million TND in 2009 to 3734 million TND in 2013. The subsidies of gas, diesel, natural gas and of combustible liquified oil, in particular, have undesired effects, such as the energy consumption increase and the CO_2 emissions. Hence, in Tunisia, the energy subsidy program must be reviewed, in order to decrease the transport CO_2 emissions.

2 See Graham and Gleister (2002), Goodwin et al. (2004) and Espey (1998)

3 See Graham and Gleister (2002) or Goodwin et al. (2004)

As per the long-term household fuel and car mobility demand income elasticities, they are assessed, respectively, to be 1.744 and 1.696 (Table 6). In the short term, the fuel demand varies from 1.238, for the first period, to 1.581, for the second period, following a household income variation. This result corroborates the works of Dahl and Sterner (1991).

Regarding the annual vehicle mileage, the short-term income elasticity is 0.591 for the first period and 0.717 for the second period. We note that the demand price-elasticities, in both the short term and the long term, are generally lower (in absolute value) than the income elasticity values. This result is also brought to light in other works (Dahl and Sterner, 1991; Graham and Glaister, 2002). As expected, and as reported in the literature, the fuel is a normal good, but a staple: the income increase entails an increase of the demanded energy quantity, and, hence, of travel. In the short term, this income elasticity is lower than in the long term. In fact, there should be some time for the consumers to react to a variation of their income. In the short term, habits are what impose the energy consumption rhythm.

The long-term elasticity of the vehicle stock per capita is 2.012 for the fuel demand and 1.577 for the travel demand. We notice that, in the long term, this elasticity is higher for the fuel demand than for the travel demand, and, therefore, it corroborates the literature results; see, for example, Goodwin et al. (2004). In the short term, these elasticities vary from 0.402 to 2.733 for the energy demand and from 0.820 to 2.237 for the vehicle traveled kilometers. These elasticities have very significant values, for the Tunisian vehicle fleet is characterized by a significant private car property annual growth of 6.57%, because of the private car acquisition credits, particularly the "popular cars" and the lease credits. Such increase, will, undoubtably, have impacts on the energy consumption in the transport sector in Tunisia and the on the number of traveled kilometers.

4.2. The Dynamic Model Results

The estimation of the dynamic model gives us the following results, presented in the Table 7.

The resulting models have two lags for the fuel demand and three lags for the travel demand, but no lags for the income or the price. The short-term elasticities are directly determined based on R_t, P_t, and V_t. They are respectively 0.758, −0.210 and 0.427 for the fuel demand and 0.155, −0.088 and 0.309 for the travel demand. Thus, we notice that the fuel demand elasticities are much higher than those of the travel demand.

The long-term elasticities are obtained based on equations (5) and (6) as follows: $\frac{\lambda_{ki}}{1-\lambda_F}$ et $\frac{\pi_{ki}}{1-\pi_{VKM}}$. A comparison of short-term and long-term elasticities is provided by Table 8.

Table 3: Selection of lag length

Lag length	Equation 1			Equation 2		
	1	2	3	1	2	3
AIC criterion	−18.152	−18.105	−18.621*	−18.160	−18.073	−19.042*
Schwarz criterion (SC)	−15.994	−16.820*	−15.718	−15.962	−16.827*	−16.139

Table 4: Results of Johansen cointegration tests

H_0: r	Equation 1			Equation 2			Critical values at 5%	
	Eigen value	Trace	λ- max	Eigen value	Trace	λ- max	Trace	λ- max
0	0.772	80.635	40.030	0.694	69.383	32.034	47.816	27.584
1	0.636	26.605	20.312	0.542	27.349	18.117	29.797	21.131

Table 5: The error correction model

Parameter	ΔLNFt			ΔLNVKMt		
	Coefficient	SE	t-value	Coefficient	SE	t-value
Long run estimation						
LNP_{t-1}	−0.429	0.124	−11.450	−0.452	0.170	−3.246
LNR_{t-1}	1.744	0.085	15.746	1.696	0.276	−5.782
LNV_{t-1}	2.012	0.146	10.159	1.577	0.405	1.626
Constant	3.046			1.756		
Short-run estimation						
ΔLNF_{t-1}	0.551	0.277	1.985	-	-	-
ΔLNF_{t-2}	0.053	0.191	0.279	-	-	-
$\Delta LNVKM_{t-1}$	-	-	-	0.605	0.194	3.113
$\Delta LNVKM_{t-2}$	-	-	-	0.067	0.179	0.375
ΔLNP_{t-1}	−0.183	0.288	−1.816	−0.098	0.164	−3.208
ΔLNP_{t-2}	−0.555	0.294	−0.888	−0.580	0.225	−2.575
ΔLNR_{t-1}	1.238	0.505	2.038	0.591	0.324	2.738
ΔLNR_{t-2}	1.581	0.430	1.374	0.717	0.308	2.327
ΔLNV_{t-1}	0.402	0.596	0.674	0.820	0.430	1.906
ΔLNV_{t-2}	2.733	0.674	1.088	2.237	0.488	0.486
γ0	−1.732	0.418	−4.138	−0.196	0.037	−5.235
constant	0.107	0.057	1.887	0.112	0.039	2.848
Test diagnostic						
R-squared		0.615			0.740	
Adjusted R-squared		0.411			0.602	
Prob.		0.024			0.001	
N		27			27	

Table 6: Estimation of short- and long-run elasticities

Elasticities	D(LNCETRPH)	D(LNVKM/AN)
Short-run elasticities		
ΔLNP_{t-1}	−0.183	−0.098
ΔLNP_{t-2}	−0.555	−0.58
ΔLNR_{t-1}	1.238	0.591
ΔLNR_{t-2}	1.581	0.717
ΔLNV_{t-1}	0.402	0.82
ΔLNV_{t-2}	2.733	2.237
Long run elasticities		
LNP_{t-1}	−0.429	−0.452
LNR_{t-1}	1.744	1.696
LNV_{t-1}	2.012	1.577

Source: Authors' calculation

The long-term fuel and travel demand price-elasticities are respectively −0.289 and −0.255. This result contradicts the affirmation of Graham and Glaister (2002), which says that the long-term price-elasticities, in general, vary between −0.6 and −0.8. As per the long-term income elasticities of the household fuel and car mobility demand, they are assessed to be, respectively, 1.044 and 0.450. We notice that, just like in the error correction model, the short-term and long-term price-elasticities of the demand are, generally, lower than the corresponding values of the income elasticities. This result is also brought to light by the works of Dahl and Sterner (1991).

The above-described examinations corroborate the following results: (1) the long-term elasticities are higher than the short-term elasticities; (2) the price-elasticities of the fuel consumption are higher than the price-elasticities of the travel demand, as measured by VKM; and (3) the income elasticities are, generally, higher than the price elasticities.

A comparison between the elasticities provided by both econometric approaches used in this article shows that the long-term elasticities of the error correction model are much higher than those of the dynamic model. Therefore, the adequate econometric approach choice can, sensitively, influence the found elasticity values.

4.3. What is the Best Model?

In this study, in order to estimate the sensitivity of the fuel and travel demand with respect to the fuel price and income variation,

Table 7: Estimation of dynamic model

Parameter	LNF_t			$LNVKM_t$		
	Coefficient	SE	t-value	Coefficient	SE	t-value
LNP_t	-0.210*	0.099	-2.114	-0.088	0.086	-1.015
LNR_t	0.758*	0.269	2.815	0.155	0.252	0.614
LNV_{t-1}	0.427***	0.313	1.364	0.309	0.302	1.022
LNF_{t-1}	0.600*	0.178	3.361	----------	----------	---------
LNF_{t-2}	-0.326***	0.179	-1.822	----------	----------	---------
$LNVKM_{t-1}$	-------	-------	-------	0.596*	0.220	2.480
$LNVKM_{t-2}$	--------	-------	--------	0.401***	0.199	0.675
$LNVKM_{t-3}$	--------	-------	--------	-0.341***	0.201	-1.695
γ_0	0.929	0.969	0.958	0.738	0.928	0.795
Test diagnostic						
Adjusted R^2	0.976			0.997		
Breusch–Godfrey LM test for autocorrelation	2.092 (prob = 0.124)			0.467 (prob = 0.385)		
JB test for residual normality	1.46(prob = 0.07)			0.940 (prob = 0.624)		
Engle's LM test for ARCH	3.042 (prob = 0.093)			0.633 (prob = 0.433)		
Ljung-Box Q test for white noise	1.089 (prob = 0.297)			0.041 (prob = 0.839)		
N	28			27		

***P<0.01. ** P<0.05. *P<0.1

two different econometric approaches were used: the error correction model (ECM) and the dynamic model. As these two approaches gave us different results, it is useful to choose the best approach.

The dynamic model presents the highest adjustment parameter and the lowest standard deviations (Tables 5 and 7). Therefore, we can affirm that the dynamic model is the best approach.

In order to confirm this finding, we will resort to the Bayesian information criterion (BIC), which is a measurement of the quality of a statistic model that was proposed by Gideon in 1978. The model that will be selected is the one that minimizes the BIC criterion.

This criterion is calculated as follows: (Odeck and Johansen, 2016):

$$IC\left(M_j\right) = N\ln(1-R_j^2) + \ln\left(N\right)(K_j - 1) \qquad (7)$$

R_j^2, N and K_j refer, respectively, to the adjustment parameter of model M_j, to the sample size and to the number of parameters to be used.

Based on the BIC calculation results, which are presented in the Table 9, we choose the dynamic model, which presents the lowest BIC criterion.

4.4. Direct Rebound Effect Analysis

The rebound effect calculation method has been discussed thoroughly in section 3.2. The direct rebound effect magnitudes are presented in the spreadsheet below.

Regarding the error correction model, the Table 10 indicates that, in the long term, 0.43% and 0.45% of the planned fuel savings, following the fuel price increase, will lag, respectively, in the form of a bigger fuel consumption and more mobility, if the energy efficiency is improved by 1%. In the short term, the rebound effect for the fuel demand is 0.18% for the first period and 0.55% for the second period. Regarding the travel demand, this effect equals 0.10% and 0.38% for the first period and second period, respectively. As for the dynamic model, which is judged to be the most adapted model to our database, the noticed short-term rebound effects are, respectively, 0.09 and 0.21 for the travel and fuel demand. In the long term, we find a decrease of the

Table 8: Comparison of elasticity estimates

Elasticities	Dynamic model	
	Fuel	VKM
Short-run elasticities		
Price	−0.21	−0.088
Income	0.758	0.155
Vehicule stock	0.427	0.309
Long-run elasticities		
Price	−0.289	−0.255
Income	1.044	0.45
Vehicule stock	0.588	0.898

Source: Authors' calculation

Table 9: Bayesian information criterion (BIC) test for the best model

Bayesian information criterion (BIC)	F	VKM
BIC_ECM	15.390	4.756
BIC_Dynamic model	−77.774	−130.480

Table 10: The direct rebound effects

Rebound effect	Error correction model		Dynamic model	
	Fuel (%)	VKM (%)	Fuel (%)	VKM (%)
Short-run rebound effect				
The first period	0.18	0.1	0.21	0.09
The second period	0.55	0.38		
Long-run rebound effect	0.43	0.45	0.29	0.26

Source: Authors' calculation

rebound effect with respect to the error correction model results. These results indicate that the decision makers must take into consideration the rebound effect phenomenon while elaborating policies, for ignoring it can lead them to ineffective policies.

Based on the found rebound effect values, it is possible to calculate the elasticities of the fuel and travel demand with respect to the energy efficiency. This energy efficiency elasticity is estimated by taking the found rebound effect value and subtracting one from it. Let us take the example of the fuel demand rebound effect, which is 0.43%, for a price elasticity of −0.43%: the fuel demand elasticity with respect to the energy efficiency can, therefore, be estimated as follows: 0.43–1=−0.57. Thus, the fuel demand only diminishes by 0.57% if the energy efficiency is improved by 1%.

5. CONCLUSION

Knowing the determinants of the fuel and travel demand is fundamental for understanding the energy consumption evolution in the road transport sector and for assessing the economic and environmental policy impacts. In this article, we brought to light the main determinants of the fuel demand and travel demand in Tunisia, and we have measured their impact on consumption. In other words, in this article, we focused on the estimation of fuel and travel demand elasticities with respect to the fuel price and incomes, then we have deduced the direct rebound effects. Two different econometric approaches were compared, the error correction model (ECM) and the dynamic model, in order to determine which of these approaches produces the most reliable results.

The main results of this study can be summed up as follows:

- In the long and in the short term, a fuel price increase has a negative impact on the energy consumption, this confirms the results found in literature (Graham and Gleister, 2002). The households adapt their fuel consumption to a price increase.
- The Tunisian vehicle fleet is characterized by a significant annual growth of the private car property, which explains the important values of the elasticity of the vehicle stock per capita in the long and in the short term.
- Regarding the rebound effect, which makes the fundamental aim of our article, the results of the dynamic model, that we considered as the most appropriate model for our data, showed that, in the long term, 0.29% and 0.26% of the fuel savings, resulting from the fuel price increase, will be compensated, respectively, by a higher fuel consumption and more mobility, if the energy efficiency increases by 1%.

Thus, at the end of this work, some recommendations are made. In terms of public policy, there must be major undertakings, as the rebound effect is of great importance when it comes to designing energy-sustainable road transport policies in Tunisia. First, the environmental tax is considered to be a very important instrument to limit the private car travel and urge the users to use renewable energies. Also, our results revealed that the fuel pricing policy, in Tunisia, characterized by the presence of the general subsidy, has a significant rebound effect. For that reason, the fuel subsidy program must be reformed in order to fight this rebound effect preponderance in the Tunisian road transport.

Therefore, to conclude, we showed that the methodological approach choice can affect the magnitude of the rebound effect and, thus, the policy choice. In fact, the rebound effect estimation has clear political implications, for the researchers and the decision makers need reliable information about the rebound effect magnitude, in order to evaluate the welfare and energy savings following energy efficiency policies.

REFERENCES

Akinboade, O.A., Ziramba, E., Kumo, W.L. (2008), The demand for gasoline in South Africa: An empirical analysis using co-integration techniques. Energy Economics, 30, 3222-3229.

Alves, D.C.O., De Losso da Silveira Bueno, R. (2003), Short-run, long-run and cross elasticities of gasoline demand in Brazil. Energy Economics, 25, 191-199.

Berkhout, P., Muskens, J., Velthijsen, J. (2000), Defining the rebound effect. Energy Policy, 28, 425-432.

Dahl, C., Sterner, T. (1991), Analysing gasoline demand elasticities: A survey. Energy Economics, 13, 203-210.

Dimitropoulos, A., Oueslati, W., Sintek, C. (2018), The rebound effect in road transport: A meta-analysis of empirical studies. Energy Economics, 75, 163-179.

Du, H., Chen, Z., Zhang, Z., Southworth, S. (2020), The rebound effect on energy efficiency improvements in China's transportation sector: A CGE analysis. Journal of Management Science and Engineering, 5, 249-263.

Eltony, M.N., Al-Mutairi, N.H. (1995), Demand for gasoline in Kuwait: An empirical analysis using cointegration techniques. Energy Economics, 17, 249-253.

Engle, R.F., Granger, C.W.J. (1987), Co-integration and error correction: Representation, estimation, and testing. Econometrica, 55, 251-276.

Espey, M. (1998), Gasoline demand revisited: An international meta-analysis of elasticities. Energy Economics, 20, 273-295.

Fouquet, R., Pearson, P.J. (2012), The long run demand for lighting: Elasticities and rebound effects in different phases of economic development. Economics Energy Environmental Policy, 1(1), 83-100.

Gideon, S. (1978), Estimating the dimension of a model. The Annals of Statistics,6(2), 461-464.

Goodwin, P. (1992), A review of new demand elasticities with special reference to short and long run effects of price changes. Journal of Transport, Economics and Policy, 26, 155-163.

Goodwin, P., Dargay, J., Hanly, M. (2004), Elasticities of road traffic and fuel consumption with respect to price and income: A review. Transport Reviews, 24(3), 275-292.

Gossart, C. (2010), Quand les technologies vertes poussent à la consommation. Le Monde Diplomatique, 2010, 20-21.

Graham, D.J., Glaister, S. (2002), The demand for automobile fuel. A survey of elasticities. Journal of transport, Economics and Policy, 36(1), 1-26.

Khazzoom, J.D. (1980), Economic implications of mandated efficiency in standards for household appliances. Energy Journal, 1, 21-40.

Labidi, E., Abdessalem, T. (2018), An econometric analysis of the household direct rebound effects for electricity consumption in Tunisia. Energy Strategy Reviews, 19, 7-18.

Li, K., Jiang, Z.J. (2016), The impacts of removing energy subsidies on economy-wide rebound effects in China: An input-output analysis. Energy Policy, 98, 62-72.

Lin, B.Q., Du, K.R. (2015), Measuring energy rebound effect in the

Chinese economy: An economic accounting approach. Energy Economics, 50, 96-104.

Lin, C.Y.C., Zeng, J.J. (2013), The elasticity of demand for gasoline in China. Energy Policy, 59, 189-197.

Matos, F.J., Silva, F.J. (2011), The rebound effect on road freight transport: Empirical evidence from Portugal. Energy Policy, 39(5), 2833-2841.

Michaels, R.J. (2012). Energy Efficiency and Climate Policy: The Rebound Dilemma. Washington DC, USA: Institute for Energy Research.

NAEC. (2017), National Agency for Energy Conservation.

NIS. (2017), National Institute of Statistics.

Odeck, J., Johansen, K. (2016), Elasticities of fuel and traffic demand and the direct rebound effects: An econometric estimation in the case of Norway. Transportation Research Part A, 83, 1-13.

Patwary, A.L., Edward, Y.T., English, B.C., Hughes, D.W., Cho, S.H. (2021), Estimating the rebound effect of the U.S. road freight transport. In: Transportation Research Record: Journal of the Transportation Research Board.

Ramanathan, U.R. (1999), Short- and long-run elasticities of gasoline demand in India: An empirical analysis using cointegration techniques. Energy Economics, 21, 321-330.

Samimi, R. (1995), Road transport energy demand in Australia: A cointegration approach. Energy Economics, 17, 329-339.

Small, K.A., Van Dender, K. (2007), Fuel efficiency and motor vehicle travel: The declining rebound effect. Energy Journal, 28, 25-51.

Sorrel, S. (2007), The Rebound Effect: An Assessment of the Evidence for Economy-wide Energy Savings from Improved Energy Efficiency. United Kingdom: UK Energy Research Centre.

Sorrell, S. (2009), Jevons' paradox revisited: The evidence for backfire from improved energy efficiency. Energy Policy, 37(4), 1456-1469.

Sorrell, S., Dimitropoulos, J., Sommerville, M. (2009), Empirical estimates of the direct rebound effect: A review. Energy Policy, 37(4), 1356-1371.

Turner, K., Katris, A. (2017), A "Carbon Saving Multiplier" as an alternative to rebound in considering reduced energy supply chain requirements from energy efficiency? Energy Policy, 103, 249-257.

Wadud, Z., Graham, D.J., Noland, R.B. (2009), A cointegration analysis of gasoline demand in the United States. Applied Economics, 41(26), 3327-3336

Wang, H., Zhou, P., Zhou, D.Q. (2012), An empirical study of direct rebound effect for passenger transport in urban China. Energy Economics, 34(2), 452-460.

WDI. (2017), World Development Indicators. Washington, DC: IBRD, World Bank.

Yang, L.S., Li, Z. (2017), Technology advance and the carbon dioxide emission in China-empirical research based on the rebound effect. Energy Policy, 101, 150-161.

Zhang, S., Lin, B. (2018), Investigating the rebound effect in road transport system: Empirical evidence from China. Energy Policy, 112, 129-140.

Zhang, Y.J., Liu, Z., Qin, C.X., Tan, T.D. (2017), The direct and indirect CO_2 rebound effect for private cars in China. Energy Policy, 100, 149-161.