Energy Sources, Part B: Economics, Planning, and Policy

ISSN: (Print) (Online) Journal homepage: https://www.tandfonline.com/loi/uesb20

A measure of the informal sector for the Turkish diesel market

H. Fatih Yaz, Nukhet Dogan & M. Hakan Berument

To cite this article: H. Fatih Yaz, Nukhet Dogan & M. Hakan Berument (2021) A measure of the informal sector for the Turkish diesel market, Energy Sources, Part B: Economics, Planning, and Policy, 16:7, 638-649, DOI: 10.1080/15567249.2021.1945168

To link to this article: https://doi.org/10.1080/15567249.2021.1945168

Published online: 09 Jul 2021.

ENERGY SOURCES, PART B: ECONOMICS, PLANNING, AND POLICY
2021, VOL. 16, NO. 7, 638–649
https://doi.org/10.1080/15567249.2021.1945168

A measure of the informal sector for the Turkish diesel market

H. Fatih Yaz [a], Nukhet Dogan [b], and M. Hakan Berument [c]

[a]Department of Econometrics, Gazi University, Ankara, Turkey; [b]Department of Econometrics, Ankara Hacı Bayram Veli University, Ankara, Turkey; [c]Department of Economics, Bilkent University, Ankara, Turkey

ABSTRACT
Measuring the size of the informal diesel market is important for determining tax revenue losses and identifying inefficiencies in tax policies. The conventional ways of assessing the informal sector entail either not allowing the measurement of the size of the informal sector across time or assuming a stable relationship between diesel consumption and a set of economic variables. This study assesses the informal sector of the Turkish diesel market by using the Kalman filter method. This method allows unobserved values to be estimated with observed variables. Using monthly interpolated GDP, official diesel consumption, and the number of diesel motor vehicles, Turkey's unobserved informal diesel fuel consumption between January 2005 and February 2020 is estimated. The results obtained with this estimation method reveal that the level of informal diesel consumption increased until 2012–2014; it then started to decline at the end of 2014 and started to increase again after 2018. These dates are associated with periods of economic recession, political developments, and the passing of anti-smuggling legislation.

KEYWORDS
Informal economy; diesel consumption; Kalman filter

1. Introduction

Diesel is one of the most important oil products consumed in the world and its consumption has been steadily increasing (IEA 2018). Due to both high tax rates on diesel (e.g., 51.2% in Turkey in 2017 [OECD 2018]) and high demand for it, any existing informal diesel consumption would create considerable tax losses for governments. The aim of this study is to assess how the informal diesel market has evolved over time in Turkey, an important emerging economy.

The energy market structure has been evolving due to new technological improvements in energy usage for motor vehicles, alternative usage of oil products, the use of unconventional oil production methods or untapped resources, and changing market price structures. Therefore, time-series analysis should be employed to capture the dynamic structure of the informal diesel sector. Thus, we could not use a survey-based approach that would provide a snapshot of the informal diesel market at one particular moment in time. We did not, however, use a time-invariant parameter model; instead, we used a time-varying parameter model to capture the dynamic relationship between diesel consumption and economic variables. The Kalman filter method allows the parameters of a model to be time-dependent to estimate the size of the informal diesel sector. A rolling regression method could also be used to capture the time-varying relationship between diesel consumption and diesel-consuming vehicles and sectors. However, the latter method is less responsive to changes in economic variables (Renzi-Ricci 2016). Therefore, in the present study, we estimate the level of informal diesel fuel consumption in Turkey using the Kalman filter approach proposed by Karanfil and Özkaya (2007). This is an estimation method that allows the measurement of unobservable variables through observed variables within a given dynamic specification. It effectively takes into account the possibility of time-varying relationships among the variables that affect informal diesel

CONTACT M. Hakan Berument berument@bilkent.edu.tr Department of Economics, Bilkent University, Ankara, Turkey

fuel consumption. The results obtained with this estimation method reveal that the level of informal diesel consumption increased until 2012–2014, started to decline at the end of 2014, and started to increase again after 2018.

To the best of our knowledge, this is the first study that estimates the size of the informal diesel sector directly rather than calculating the discrepancy between diesel demand estimates and observed data after estimating the diesel demand function first. The paper is structured as follows: In Section 2, we review the literature regarding how to assess the informal sector. The methodology and empirical evidence are reported and robustness checks are presented in Section 3. Section 4 presents the results and concludes the paper.

2. Review of the literature

An informal economy mainly consists of off-the-record activities pursued for various reasons including high taxes, governmental bureaucracy, social injustice or inequity, corruption, and weak rule of law (Medina and Schneider, 2018). Informal economies are difficult to measure; however, there is a large body of literature addressing the assessment of informal economies (e.g., Williams and Schneider 2016, and references therein). In general, there are three main approaches in the literature for measuring the size of an informal economy or sector, including direct (micro), indirect (macro), and model approaches.

The direct approach uses tax audit information (Witte 1987, and references therein) and surveys to gather information from voluntary participants (e.g., Mogensen 1995, and references therein). Since informal activities are hidden from government authorities, this method will not reliably measure the real dimensions of an informal economy. This approach is often applied at a micro level and at one particular point in time.

The indirect approach is based on the relationship between the informal sector and a macroeconomic variable. It is commonly applied for seven types of relationships or methods. The first is an indicator method that studies the difference between expenditure and income statistics to assess the informal sector (e.g., Paglin 1994, and references therein). The second method examines the discrepancy between official and actual labor force statistics. If it is assumed that total labor force participation is constant, then a decline in official labor force participation can show the size of the informal economy (e.g., Williams and Lansky 2013, and references therein). In the third method, assuming that money has a constant velocity or financial market indicator, the informal sector is proxied by the transaction volume of an economy to assess the sector by using trading value (e.g., Feige 1996). A fourth method, the currency demand method, considers the correlation between currency demand and economic variables (e.g., Schneider 1997, and references therein). The fifth is the physical input method, which uses electricity consumption as a proxy for an informal economy (e.g., Kaufmann and Kaliberda 1996; Lackó 1999). The sixth uses images taken from satellites to measure the informal sector (e.g., Ghosh et al. 2009; Tanaka and Keola 2017). The seventh method employs environmental data. The central premise of this final method is that energy consumption and associated CO_2 emissions will proxy the real economy level to allow an estimation of the informal economy as an unobserved variable (e.g., Karanfil and Özkaya 2007). This model approach employs multiple methods to simultaneously assess the informal economy, such as the Multiple Causes and Multiple Indicators (MIMIC) method (e.g., Dell'Anno and Schneider 2004, and references therein).

Several studies have estimated the size of the informal economy for Turkey, as well. While Davutyan (2008) uses a survey method, Derdiyok (1993) and Ilgın (2002) employ tax audit information. Kasnakoglu (1993), Ogunc and Yilmaz (2000), Temel, Şimşek, and Yazıcı (1994), and Us (2004) use currency demand and transactions methods. Us (2004) also uses electricity consumption and discrepancies between official and actual labor force statistics, while Karanfil and Özkaya (2007) use an environment-based method and Savaşan (2003) and Schneider and Savasan (2007) use the MIMIC method.

To the best of our knowledge, there is only one study that assesses the size of the diesel sector for Turkey. Yalta and Yalta (2016) estimate diesel demand with maximum entropy resampling-based interval estimates in a fixed-width rolling window framework. (Table 1) They then compare this estimate with a measure of the fleet trend of number of diesel vehicles. Their estimates end in 2012.

Table 1. Unit root test statistics.

		ADF[a]		Ng-Perron (MZ)[a]		KPSS[b]	
		Constant	Constant and trend	Constant	Constant and trend	Constant	Constant and trend
DIESELC[obs]	Level	−1.585	−1.655	−1.207	−4.249***	1.680***	0.065
	Difference	−12.764***	−12.843***	−3.983***	−4.433***	0.281	0.113
DIESEL VEHICLE	Level	−2.128	0.837	12.988	1.408	1.749***	0.343***
	Difference	−2.498	−3.333*	−7.071***	−7.655***	1.042***	0.107
GDP	Level	−0.518	−2.410	−0.139	−1.788	1.743***	0.151**
	Difference	−3.294**	−3.285*	−1.646*	−4.609***	0.019	0.016
TRUCKS	Level	−2.432	−3.511**	3.372	−0.457	1.673***	0.122*
	Difference	−3.411**	−3.778**	−5.931***	−7.347***	0.465**	0.193**
SMAL TRUCKS	Level	−2.794*	−0.680	13.219	2.622	1.696***	0.411***
	Difference	−2.859*	−4.044***	−5.102***	−8.158***	1.389***	0.180**
MINIBUSES	Level	−2.619*	−2.815	5.861	−0.370	1.720***	0.138**
	Difference	−5.922	−6.375	−4.241***	−5.265***	0.526**	0.185**
MOTORCYCLES	Level	−0.005	−4.727***	0.328	−0.069	1.477***	0.315***
	Difference	−3.669***	−5.515***	−3.563***	−4.456***	0.747***	0.294***
BUSES	Level	−3.377**	−1.983	0.943	0.198	1.245***	0.396***
	Difference	−4.461***	−5.302***	−3.790***	−4.467***	0.848***	0.067
CARS	Level	−3.032**	0.294	10.492	1.869	1.717***	0.390***
	Difference	−4.215***	−4.562***	−4.783***	−6.416***	1.241***	0.135*
SPECIAL PURPOSE VEHICLE	Level	−0.491	−1.311	5.832	−1.233	1.706***	0.309***
	Difference	−5.508***	−5.493***	−4.671***	−4.688***	0.165	0.170**
TRACTORS	Level	−0.628	−2.602	10.084	−1.248	1.754***	0.254***
	Difference	−2.424	−2.410	−3.802***	−4.272***	0.189	0.184***
MINING IP	Level	−2.170	−2.797	−1.537	−4.207***	1.578***	0.184**
	Difference	−4.663***	−4.841***	−2.072**	−2.510	0.193	0.060
NONMETALLIC MINERAL IP	Level	−1.615	−2.682	−1.461	−4.172***	1.493***	0.155**
	Difference	−3.106**	−3.150*	−2.277**	−1.844	0.500	0.500**
BASIC METAL IP	Level	−2.224	−3.321*	−1.000	−3.452***	1.336***	0.129*
	Difference	−3.516***	−3.638**	−4.153***	−3.843***	0.341	0.207**
FABRICATED METAL IP	Level	−0.999	−2.819	−0.773	−5.340***	1.647***	0.151**
	Difference	−2.829*	−2.821	−2.605***	−2.636	0.143	0.086
FACTOR of 8 VARIABLES	Level	−1.891	−1.100	8.933	0.394	1.746***	0.210**
	Difference	−3.455***	−4.812***	−4.576***	−6.007***	0.752***	0.133*
FACTOR of 12 VARIABLES	Level	−1.291	−3.547**	2.263	−2.362	1.743***	0.183**
	Difference	−2.176	−2.328	−3.856***	−2.287	0.500**	0.198**

Note: *** indicates the level of significance at 1%, ** at 5%, * at 10%.
[a])Null hypothesis: series has a unit root. [b]) Null hypothesis: series is stationary.

3. Methodology and empirical evidence

Monthly data covering the period from January 2005 to February 2020 for Turkey are used, the end period of the sample being set to avoid the effects of the COVID-19 pandemic. Diesel consumption data, considered as the observed data in this study, are data on official domestic consumption (in barrels) taken from the JODI World Database. Data on the number of motor vehicles using diesel fuel registered in traffic as well as related statistics and the real gross domestic product (GDP) fixed at 2009 prices are taken from the database of the Turkish Statistical Institute. GDP data are converted to the monthly frequency estimated via the linear interpolation method. All variables are used in natural logarithms in their first differences in the analyses, but we report the informal diesel consumption in log levels in the figures[1]

To see if there is a long-run relationship among official diesel consumption, number of motor vehicles, and GDP, the time-series properties of the variables are assessed with the Augmented Dickey-Fuller (ADF) test (Dickey and Fuller 1979), Ng-Perron (Ng and Perron 2001) unit root test, and Kwiatkowski, Phillips, Schmidt, and Shin (KPSS) (Kwiatkowski et al. 1992) stationarity test. For the

[1]As robustness analyses, we repeat our estimates in different specifications with additional variables. They are all gathered from the data delivery system of the Central Bank of the Republic of Turkey.

ADF and Ng-Perron tests, the null hypothesis in the series has a unit root (non-stationary), while for the KPSS test, the null hypothesis in the series is stationary.

We study the time-series properties of observed diesel consumption ($DIESELC_t^{obs}$), diesel vehicles, and GDP series. The null hypothesis of a unit root is rejected for both ADF and Ng-Perron tests in their first differences and their differences with a time trend. However, a unit root cannot be rejected in all series in the levels, but rather only for one series with level and trend. For the KPSS test, the null hypothesis of stationarity is rejected for all three series in the levels and the diesel vehicle and GDP series for the levels with a time trend. Thus, we can safely assume that all the series have a unit root.

Smith (1994) defines the underground or shadow economy as the "market-based production of goods and services, whether legal or illegal, that escapes detection in the official estimates of GDP." Similar to this definition, we assume that the difference between officially calculated diesel consumption ($DIESELC_t^{obs}$) and the true or corrected measure of unobserved diesel consumption ($DIESELC_t^c$) gives the size of informal diesel consumption. Following Karanfil and Özkaya (2007), the true diesel consumption $\left(DIESELC_t^c\right)$ is assumed as I(1) and $DIESELC_t^c$ is then estimated using the Kalman filter specification.

To see if there is a long-run relationship among the studied variables, the Johansen and Juselius (1990) method is employed to detect a cointegration relationship. The results of the Johansen test for$DIESELC_t^c$, $DVEHICLE_t$, and GDP_t are presented in Table 2. Both $\lambda - max$ and $\lambda - trace$ statistics suggest the existence of two cointegration relationships at the 95% confidence level, which means there is at least one long-term relationship among the variables.

Stock (1987) shows that the OLS estimation of the long-run parameters is consistent and highly efficient. Thus, the long-term relationship, or the "observation equation," can be estimated for the following:

$$DVEHICLE_t = \beta_0 + \beta_1 DIESELC_t^c + \beta_2 GDP_t + \omega_t \tag{1}$$

The estimates that use true diesel consumption ($DIESELC_t^c$) and real GDP are reported in Table 3. About 37% of vehicles run with diesel; thus, we assume that the true diesel consumption should increase with diesel-consuming vehicles and economic activities. Both economic performance and the number of diesel vehicles should therefore increase diesel consumption. These coefficients are positive and statistically significant, and these findings are parallel with those of Korkmaz and Akgüngör (2018) and Sen and Uzunoz (2017).

Kalman filtering requires that ω_t be *i.i.d.* with zero mean and constant variance in Equation (1). To assess the properties of ω_t we estimate $\omega_t = \delta + \varphi t + \vartheta_1 \omega_{t-1} + \vartheta_{12} \omega_{t-12} + u_t$. Here, the first lag captures the persistency and the 12$^{\text{th}}$ lag is for the seasonal pattern. The time trend possibly captures the effects of technological progress on fuel efficiency. Table 4 reports the properties of ω_t, and ω_t is not *i.i.d.* All estimated coefficients have the expected signs and are statistically significant. However, we assume that u_t is *i.i.d.* and substitute u_t for ω_t in Equation (1).

The following specification is then estimated for the dynamic relationship:

$$DIESELC_t^c = 0.063883 + DIESELC_{t-1}^c + \varepsilon_t \tag{2}$$

In this study, Equation (2) is expressed as the state equation and Equation (1) is the observation equation. The parameters of both equations are estimated within the Kalman filter specification setup. Since the $DIESELC_t^c$series possess the unit root suggested by the unit root tests, the coefficient of

Table 2. Johansen Test Statistics for the Number of Cointegration Relationships.

				Critical Values at 95%	
Eigenvalue	H_0:r[1]=	*L* Trace	*L* Max	*L* Trace	*L* Max
0.130**	0	51.675	24.725	29.797	21.132
0.120**	1	26.951	22.701	15.495	14.264
0.024**	2	4.250	4.250	3.841	3.841

[1]: r indicates the number of cointegration relationships.
** indicates rejection of the hypothesis at 5%.

Table 3. Estimates of the Diesel Vehicle Specification: $DVEHICLE_t = \beta_0 + \beta_1 DIESELC_t^c + \beta_2 GDP_t + \omega_t$.

Independent Variables	Coefficients	Standard Error	*t*-value	*p*-value
Constant	7.588***	0.301	25.186	0.000
$DIESELC_t^c$	0.196***	0.059	3.325	0.001
GDP_t	1.312***	0.072	18.093	0.000

*** indicates the level of significance at 1%.

Table 4. Estimate of the Diesel Vehicle Specification Residual: $\omega_t = \delta + \varphi t + \vartheta_1 \omega_{t-1} + \vartheta_{12} \omega_{t-12} + u_t$.

Independent Variables	Coefficients	Standard Error	*t*-value	*p*-value
Constant	0.021***	0.007	2.686	0.008
trend	−0.0001**	7.30E-05	−2.057	0.041
ω_{t-1}	0.528***	0.045	11.533	0.000
ω_{t-12}	0.437***	0.044	9.766	0.000

*** indicates the level of significance at 1%, ** at 5%.

$DIESELC_{t-1}^c$ is assumed to be one. Equation (2) is also estimated with alternatives such as time trend and non-unit root specifications. These estimates are not reported here because the added terms are not statistically significant. Here, the difference of $DIESELC_t^c$is regressed on 12 monthly dummies without a constant term, and then the averages of 12 monthly dummies are taken as the constant term for Equation (2) to address seasonality.

The Kalman filter (also called the state-space model) is a recursive system used to update a linear projection for a system. It is also used to form estimates of an unobserved variable from observed variables. This type of model was initially developed for a signal processing research procedure but it is also adopted by economists (Abid and Salha 2013). Consider a classical state-space model as follows:

$$x_t = A_t x_{t-1} + \eta_t \tag{3}$$

$$y_t = Z_t x_t + \varepsilon_t \tag{4}$$

Equation (3) is the state equation and Equation (4) is the observation equation, where $E\left(\varepsilon_t \varepsilon_t'\right) = H_t$ and $E\left(\eta_t \eta_t'\right) = \Theta_t$. Here x_t is an $m \times 1$ unobserved state vector and y_t an $n \times 1$ vector of observation. It is assumed that A_t, Θ_t, Z_t, and H_t are known matrices of dimensions $m \times m$, $m \times m$, $n \times m$, and $n \times n$, respectively. Furthermore, it is assumed that $E\left(\varepsilon_s \eta_t'\right) = 0$ for all t and s.

The observed diesel consumption and the estimate of true diesel consumption are plotted in Figure 1. Here, it is assumed that there is no consumption of informal diesel fuel at the beginning of the sample. The difference between the true and observed (official) diesel consumption gives us the amount of informal diesel consumption. Figure 1 suggests that in mid-2008, the level of informal diesel consumption begins to increase rapidly. This increase prevails until mid-2012. Afterward, the level of informal consumption shows a tendency to decrease until 2018. After 2018, the size of the informal sector starts to increase again. Yalta and Yalta (2016), who specifically study the period of 2007–2012, provide similar estimates. Moreover, the general trends in the estimates of both this paper and their work are also in line for the period of 2007–2012 that they study. The general trends of their estimates and ours are mostly parallel. For the common sample, both studies observe that the size of the informal sector reaches its peak in 2010.

The pattern of the informal diesel sector measured in Figure 1 is parallel to the diesel market developments in Turkey. In 2008, the financial crisis adversely affected the Turkish economy. This financial crisis depreciated the local currency and decreased output growth, which in turn triggered an increase in the informal sector. This trend continued until 2012, when the Syrian civil war accelerated and the Turkish-Syrian border began to be controlled more strictly. Stricter control on Turkish

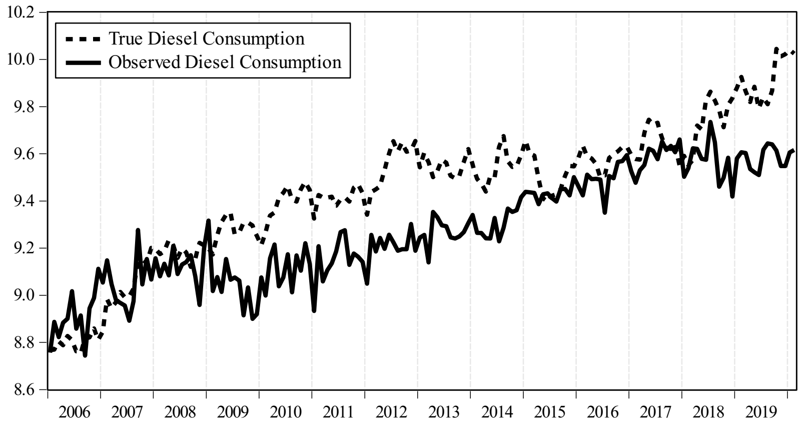

Figure 1. Levels of true and official observed diesel consumption.

borders with Syria and Iraq caused a decline in illegal diesel smuggling (DGS 2017). Moreover, the anti-smuggling legislation adopted by the parliament in 2014[2] also helped decrease the size of the informal diesel sector. Until 2018, this decreasing trend continued. However, another period of economic recession starting in 2018 brought about an increase in the informal diesel sector in Turkey.

The diesel consumption of diesel vehicles is differentiated across different vehicle groups. In order to conduct a robustness analysis for our estimates, a new series that captures the number of vehicles using diesel fuel is generated by utilizing the mean of the monthly change in vehicle types. The new series is captured with factor analysis where a single factor is gathered from these seven diesel-using vehicle variables. The relevant statistics and figures for this specification and the others are reported in the Appendix.[3]

Next, the diesel consumptions of trucks and buses are quite high; thus, we repeat the exercise considering truck and bus diesel consumption only. The GDP is a better measure of economic activity but those data are only available on a quarterly basis, so we use interpolated GDP data in the benchmark analysis. We also use the monthly industrial production index rather than the interpolated GDP in the third robustness analysis. Transportation is not the only sector that uses diesel; we repeat the exercises with sub-components of the industrial sector and the transportation sector. We generate a factor that captures all industrial activity from the sub-components of the industrial production index and repeat the exercise as the fourth and final robustness analysis. Our estimates are all parallel to our benchmark specification. Thus, the estimates of our basic model are robust.

4. Conclusion

The level of informal diesel fuel consumption in Turkey has been estimated using the Kalman filter method with monthly time-series data for the period of 2005–2020. Our estimates reveal that the consumption of informal diesel fuel began increasing after 2008. The size of the informal sector was stable between 2012 and 2014 and then began to decrease in 2014. As of 2018, it is on the rise again.

The results obtained are consistent with legislative, economic, and political developments in Turkey. Regarding the statutory changes made in 2014, and due to increased security measures along the country's borders, fuel smuggling activities have declined since 2014 (DGS 2017). The official reports and robustness test results support the level of informal diesel fuel consumption captured by our model.

[2]Revisions on Anti-Smuggling Law No. 5607 on 06.14.2014.
[3]Unit root and stationary tests of all the variables used in the remaining part of the paper can be found in Table 1.

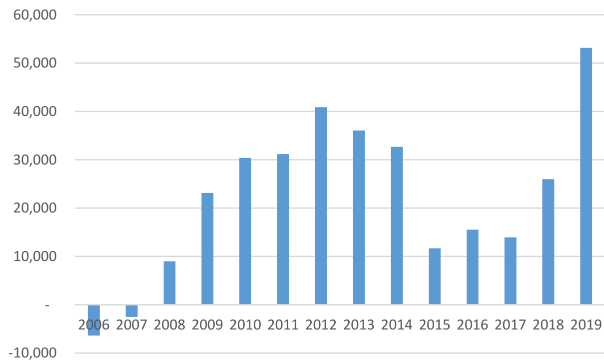

Figure 2. Size of Informal Diesel Market (Thousand Barrels).

Figure 2 reports the size of the informal diesel sector compared with 2005. Our estimates suggest that the increase in the informal sector in 2019 compared to what it had been in 2005 is 54 million barrels at the cost of 2.6 billion USD in tax revenue losses. Although 2.6 billion USD may appear to be a large figure for the size of the informal sector, the latest police operations suggest that this estimate is reasonable. For example, on January 16, 2021, the authorities uncovered a tax evasion scheme in a single operation that cost Turkey 15 billion Turkish lira between 2016 and 2020, and 3.6 billion Turkish lira (314 million USD) in 2020 alone (Aydın 2021).

Informal oil product consumption is important for countries due to tax revenue losses, inefficiencies in tax policies, and black-market activities. Thus, understanding the dynamics of the informal sector is important for the effectiveness of prevention policies. Eliminating the informal sector will benefit Turkey in various dimensions. The main source of smuggling and the informal sector's size is the difference between pre- and post-diesel prices. Any policy to eliminate this difference will eliminate the informal sector. Moreover, it should be noted that the size of the black market will not be the same across different sectors or markets. Carefully crafted micro policies will help eliminate the black market in those sectors or markets. Forcing the use of markers to identify diesel or giving tax rebates in differentiated markets might also be fruitful.

Acknowlegements

We thank for Anita Akkaş, Leslie Demir and anonymous referees for their valuable comments and suggestions, and Fatih Karanfil for providing us with the MATLAB program codes for the Kalman filter estimates.

ORCID

H. Fatih Yaz http://orcid.org/0000-0002-3729-2196
Nukhet Dogan http://orcid.org/0000-0002-2115-1807
M. Hakan Berument http://orcid.org/0000-0003-2276-4741

References

Abid, M., and O. B. Salha. 2013. The informal economy in Tunisia: Measurement and linkage with the formal economy. *International Journal of Economics and Business Research* 6 (2):194–209. doi:10.1504/IJEBR.2013.055539.

Aydın, C. 2021. Silici 2′de 120 kişiye gözaltı. *Hürriyet*. Feburary 27. Accessed April 01,2021. https://www.hurriyet.com.tr/ekonomi/silici-2de-120-kisiye-gozalti-41750639 .

Davutyan, N. 2008. Estimating the size of Turkey's informal sector: An expenditure-based approach. *Journal of Economic Policy Reform* 11 (4):261–71. doi:10.1080/17487870802598393.

Dell'Anno, R., and F. Schneider. 2004. The shadow economy of Italy and other OECD countries: What do we know? *Journal of Public Finance and Public Choice* 21 (2–3):97–120. doi:10.1332/251569203X15668905422009.

Derdiyok, T. 1993. Türkiye'nin Kayıtdışı Ekonomisinin Tahmini. *Türkiye İktisat Dergisi* 14:54–63.
DGS. 2017. *Kaçakçılık ve organize suçlarla mücadele 2016 raporu*. Ankara: Directorate General of Security (DGS) in Turkey.
Dickey, D. A., and W. A. Fuller. 1979. Distribution of the estimators for autoregressive time series with a unit root. *Journal of the American Statistical Association* 74 (366):427–31.
Feige, E. 1996. Overseas holdings of U.S. currency and the underground economy. In *Exploring the Underground Economy*, 5-62, ed. S. Pozo, 5–62. Kalamazoo: MI: W.E. Upjohn Institute for Employment Research.
Ghosh, T., S. Anderson, R. L. Powell, P. C. Sutton, and C. D. Elvidge. 2009. Estimation of Mexico's informal economy and remittances using nighttime imagery. *Remote Sensing* 1 (3):418–44. doi:10.3390/rs1030418.
IEA. 2018. Total Final Consumption (TFC) by source. from IEA https://www.iea.org/statistics
Ilgın, Y. 2002. Kayıtdışı ekonomiyi tahmin yöntemleri ve Türkiye'de durum. In *DPT Planlama Dergisi*, 145–55.
Johansen, S., and K. Juselius. 1990. Maximum likelihood estimation and inference on cointegration--with applications to the demand for money. *Oxford Bulletin of Economics and Statistics* 52 (2):169–210. doi:10.1111/j.1468-0084.1990.mp52002003.x.
Karanfil, F., and A. Özkaya. 2007. Estimation of real GDP and unrecorded economy in Turkey based on environmental data. *Energy Policy* 35 (10):4902–08. doi:10.1016/j.enpol.2007.04.012.
Kasnakoglu, Z. 1993. Monetary approach to the measurement of unrecorded economy in Turkey. *METU Studies in Development 20*(1-2):87–111.
Kaufmann, D., and A. Kaliberda. 1996. *Integrating the unofficial economy into the dynamics of post-socialist economies: A framework of analysis and evidence*. B. Kaminsky (Ed.), Economic Transition in Russia and the New States of Eurasia, M.E., Sharpe Press, London: 81-120. doi:10.1596/1813-9450-1691.
Korkmaz, E., and A. P. Akgüngör. 2018. Flower pollination algorithm approach for the transportation energy demand estimation in Turkey: Model development and application. *Energy Sources, Part B: Economics, Planning, and Policy* 13 (11–12):429–47. doi:10.1080/15567249.2019.1572835.
Kwiatkowski, D., P. C. Phillips, P. Schmidt, and Y. Shin. 1992. Testing the null hypothesis of stationarity against the alternative of a unit root: How sure are we that economic time series have a unit root. *Journal of Econometrics* 54 (1–3):159–78.
Lackó, M. 1999. Electricity intensity and the unrecorded economy in post-socialist countries. In *Underground Economies in Transition*, ed. K. Ott and E. L. Feige, 102–42. Aldershot: Ashgate Publishing Company.
Medina, L., and F. Schneider. 2018. Shadow economies around the world: what did we learn over the last 20 years? *IMF Working Paper* 18/17: 1–76.
Mogensen, G. V. 1995. *The shadow economy in Denmark 1994: Measurement and results*. Copenhagen: Rockwool Foundation Research Unit: Distributed by Danmarks Statistics.
Ng, S., and P. Perron. 2001. Lag Length selection and the construction of unit root tests with good size and power. *Econometrica* 69 (6):1519–54. doi:10.1111/1468-0262.00256.
OECD. 2018. *Consumption tax trends 2018: VAT/GST and excise rate*. Paris: OECD Publishing.
Ogunc, F., and G. Yilmaz 2000. Estimating the underground economy in Turkey: CBRT Research Department Discussion Paper.
Paglin, M. 1994. The underground economy: New estimates from household income and expenditure surveys. *The Yale Law Journal* 103 (8):2239–57. doi:10.2307/797046.
. Renzi-Ricci, G. 2016. Estimating equity betas: What can a time-varying approach add? A comparison of ordinary least squares and the Kalman filter. Insights in Economics, 1–9, NERA Economic Consulting, New York, NY.
Savaşan, F. 2003. Modeling the underground economy in Turkey: Randomized response and MIMIC models. *Journal of Economic Insight (Formerly the Journal of Economics (MVEA))* 29 (1):49–76.
Schneider, F. 1997. The shadow economies of Western Europe. *Economic Affairs* 17 (3):42–48. doi:10.1111/1468-0270.00041.
Schneider, F., and F. Savasan. 2007. Dynamic estimates of the size of shadow economies of Turkey and of her neighbouring countries. *International Research Journal of Finance and Economics* 9 (5):126–43.
Sen, S., and M. Uzunoz. 2017. Is Economic growth sensitive to oil consumption shocks in Turkey? *Energy Sources, Part B: Economics, Planning, and Policy* 12 (1):70–76. doi:10.1080/15567249.2016.1170907.
Smith, P. 1994. Assessing the size of the underground economy: The statistics Canada perspective. *Canadian Economic Observer* 11-010 (3):16–33.
Stock, J. H. 1987. Asymptotic properties of least squares estimators of cointegrating vectors. *Econometrica* 55 (5):1035–56. doi:10.2307/1911260.
Tanaka, K., and S. Keola. 2017. Shedding light on the shadow economy: A nighttime light approach. *The Journal of Development Studies* 53 (1):32–48. doi:10.1080/00220388.2016.1171845.
Temel, A., A. Şimşek, and K. Yazıcı. 1994. *Kayıtdışı ekonomi tanımı, tespit yöntemleri ve Türk ekonomisindeki büyüklüğü*. Ankara: DPT.
Us, V. 2004. Kayıtdışı ekonomi tahmini yöntem önerisi: Türkiye örneği. In: Discussion Paper, Turkish Economic Association.

Williams, C., and F. Schneider. 2016. *Measuring the global shadow economy: The prevalence of informal work and labour*. UK: Edward Elgar Publishing.
Williams, C., and M. A. Lansky. 2013. Informal employment in developed and developing economies: Perspectives and policy responses. *International Labour Review* 152 (3–4):355–80. doi:10.1111/j.1564-913X.2013.00196.x.
Witte, A. D. 1987. The nature and extend of unreported activity: A survey concentrating on a recent US-research. *The Unofficial Economy: Consequences and perspectives in different economic systems*. Gower: Aldershot.
Yalta, A. T., and A. Y. Yalta. 2016. the Dynamics of Fuel Demand and Illegal Fuel Activity in Turkey. *Energy Economics* 54 :144–58. doi:10.1016/j.eneco.2015.11.026.

APPENDIX

Here we give alternative analyses for robustness.

Alternative 1: Tables A1,A2, and A3 and Figure A1: The$DVEHICLE_t^{01}$ series are captured with a factor analysis where a single factor is gathered from seven diesel vehicle variables.

Table A1. . Johansen Test Statistics for the Number of Cointegration Relationships..

				Critical Values at 95%	
Eigenvalue	H_0:r[1]=	*L* Trace	*L* Max	*L* trace	*L* Max
0.290***	0	85.191	60.356	29.797	21.132
0.095***	1	24.836	17.641	15.495	14.265
0.040***	2	7.194	7.194	3.841	3.841

[1]: r indicates the number of cointegration relationships.
*** indicates rejection of the hypothesis at 1%.

Table A2. Estimate of the Diesel Vehicle Specification: $DVEHICLE_t^{01} = \alpha_0 + \alpha_1 DIESELC_t^{01} + \alpha_2 GDP_t + \mu_t$..

Independent Variables	Coefficients	Standard Error	*t*-value	*p*-value
Constant	−4.375***	0.658	−6.652	0.000
$DIESELC_t^{01}$	0.462***	0.128	3.614	0.000
GDP_t	1.193***	0.155	7.670	0.000

*** indicates the level of significance at 1%.

Table A3. Estimate of the Diesel Vehicle Specification Residual: $\omega_t = \delta + \varphi t + \vartheta\omega_{t-1} + u_t$.

Independent Variables	Coefficients	Standard Errors	*t*-value	*p*-value
Constant	0.021*	0.012	1.736	0.084
trend	−0.0001	0.0001	−1.268	0.206
ω_{t-1}	0.862***	0.024	35.845	0.000

*** indicates the level of significance at 1%, ** at 5%, * at 10%.

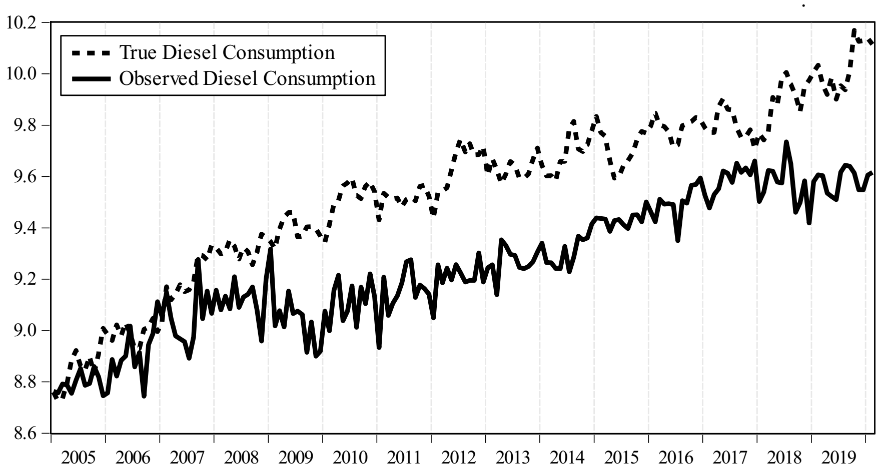

Figure A1. Levels of True and Official Observed Diesel Consumption Where True Diesel Consumption Moves with the Alternative Diesel Consumption Vehicle Measure.

Alternative 2: B1, B2, and B3 and Figure B1 use DVEHICLE_t^{02} as a measure (number of trucks and buses) of diesel motor vehicles.

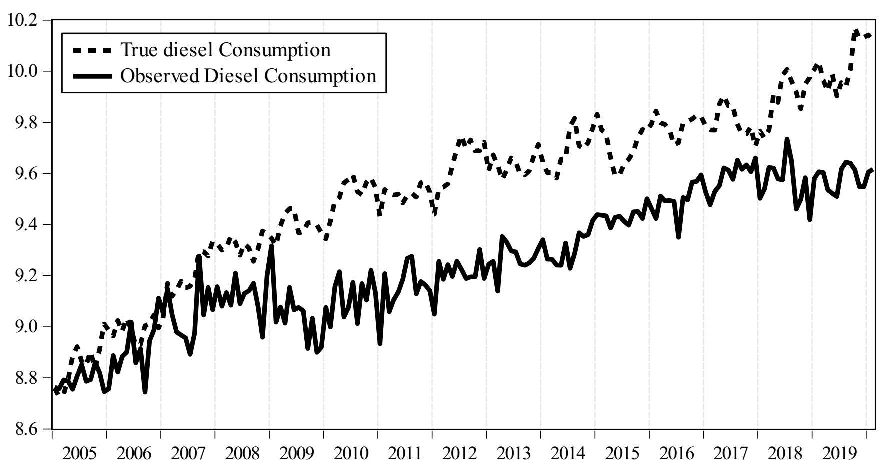

Figure B1. Level of True and Official Observed Diesel Consumption Where True Diesel Consumption Moves with Truck and Bus Vehicles.

Table B1. Johansen Test Statistics for the Number of Cointegration Relationships.

				Critical Values at 95%	
Eigenvalue	H_0: $r^1 =$	L Trace	L Max	L Trace	L Max
0.317***	0	91.156	67.132	29.797	21.132
0.099***	1	24.023	18.477	15.494	14.165
0.031***	2	5.547	5.547	3.841	3.841

[1]: r indicates the number of cointegration relationships.
*** indicates rejection of the hypothesis at 1%.

Table B2. Estimates of Diesel Vehicle Specification: $DVEHICLE_t^{02} = \theta_0 + \theta_1 DIESELC_t^c + \theta_2 GDP_t + \omega_t$.

Independent Variables	Coefficients	Standard Error	*t*-value	*p*-value
Constant	−2.841***	0.636	−4.467	0.000
$DIESELC_t^c$	0.436***	0.124	3.524	0.0005
GDP_t	0.918***	0.150	6.106	0.000

*** indicates the level of significance at 1%.

Table B3. Estimate of the Diesel Vehicle Specification Residual: $\omega_t = \delta + \varphi t + \vartheta\omega_{t-1} + u_t$..

Independent Variables	Coefficients	Standard Error	*t*-value	*p*-value
Constant	0.022**	0.010	2.108	0.036
trend	−0.0001	0.0001	−1.616	0.108
ω_{t-1}	0.863***	0.022	38.925	0.000

*** indicates the level of significance at 1%, ** at 5%.

Alternative 3: Tables C1,C2, and C3 and Figure C1: In the observation equation, the industrial production index is used instead of monthly interpolated GDP.

Table C1. Johansen Test Statistics for the Number of Cointegration Relationships.

				Critical Values at 95%	
Eigenvalue	H_0:r^a =	*L* Trace	*L* Max	*L* Trace	*L* Max
0.293***	0	78.110	61.496	29.797	21.132
0.065	1	16.614	11.966	15.494	14.265
0.026**	2	4.647	4.647	3.841	3.841

[a]: r indicates the number of cointegration relationships.
*** indicates rejection of the hypothesis at 1%, ** at 5%.

Table C2. Estimates of the Diesel Vehicle Specification: $DVEHICLE_t = \beta_0 + \beta_1 DIESELC_t^c + \beta_2 IP_t + \omega_t$.

Independent Variables	Coefficients	Standard Error	*t*-value	*p*-value
Constant	8.194***	0.396	20.698	0.000
$DIESELC_t^c$	0.284***	0.073719	3.856	0.000
IP_t	1.119***	0.086	12.973	0.000

*** indicates the level of significance at 1%.

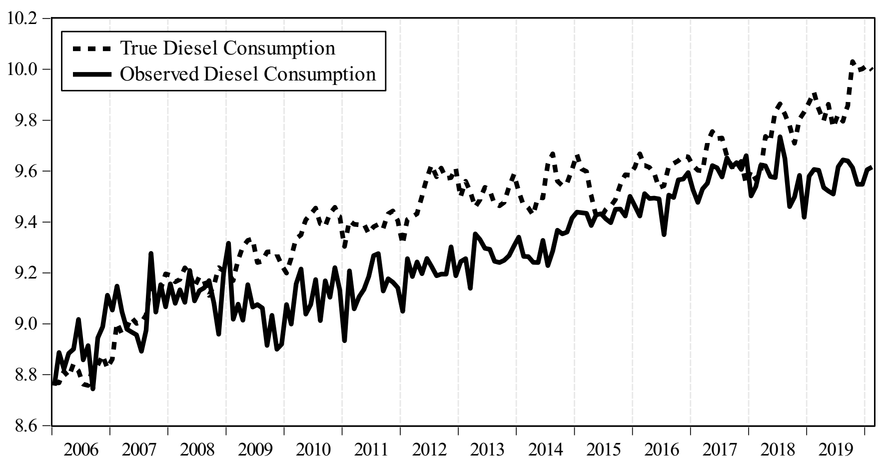

Figure C1. Level of True and Official Observed Diesel Consumption Where Industrial Production Index Is Used Instead of GDP in the Observation Equation.

Alternative 4: Tables D1 and D2 and Figure D1: In the observation equation, a single factor gathered from all subcomponents of the industrial production index is used instead of interpolated GDP.

Table C3. Estimate of the Diesel Vehicle Specification Residual: $\omega_t = \delta + \vartheta_1\omega_{t-1} + \vartheta_{12}\omega_{t-12} + u_t$.

Independent Variables	Coefficients	Standard Error	*t*-value	*p*-value
Constant	0.012*	0.007	1.727	0.086
ω_{t-1}	0.253***	0.057	4.465	0.000
ω_{t-12}	0.562***	0.054	10.460	0.000

*** indicates the level of significance at 1%, * at 10%.

Table D1. Estimates of the Diesel Vehicle Specification: $DVEHICLE_t = \gamma_0 + \gamma_1 DIESELC_t^c + \gamma_2 TIPF_t + \omega_t$..

Independent Variables	Coefficients	Standard Error	*t*-value	*p*-value
Constant	10.017***	0.852	11.753	0.000
$DIESELC_t^c$	0.623***	0.092	6.750	0.000
$TIPF1_t$	0.165***	0.027	6.174	0.000

*** indicates the level of significance at 1%.

Table D2. Estimate of the Diesel Vehicle Specification Residual: $\omega_t = \delta + \vartheta_1\omega_{t-1} + \vartheta_{12}\omega_{t-12} + u_t$.

Independent Variables	Coefficients	Standard Error	*t*-value	*p*-value
Constant	0.017**	0.008	2.125	0.035
ω_{t-1}	0.304***	0.055	5.497	0.000
ω_{t-12}	0.593***	0.054	10.933	0.000

*** indicates the level of significance at 1%, ** at 5%.

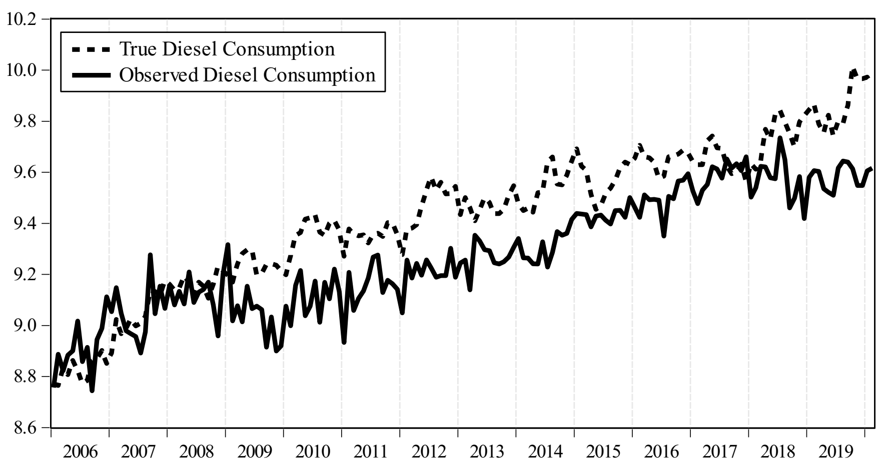

Figure D1. Level of true and official observed diesel consumption where true diesel consumption moves with total industrial production factor.