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Tax Revenue, Night Lights and Underground Economy: Evidence from China

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ABSTRACT

This objective of this paper is to assess the correlation among economic growth, tax revenues, tax evasion and tax reforms in China. Especially, we explore the usefulness of a special proxy for economic activity: the amount of nightlight that can be observed from outer space as a measure of economic growth to measure its impact on tax revenue. Empirical analyses GDP and taxes were based on the data of National Statistical Yearbook of China from 1991 to 2020. The night-lights data was gathered from the United States Air Force Defense Meteorological Satellite Program (DMSP). Kuznets approach was used to estimate the correlation between China's GDP and taxes. The theoretical model to measure and calculate the sum of night illumination brightness was designed. We used the SUR-OLS method and the sum of night lights data to estimate its impact on China's tax revenues. We have found that the total tax revenue increases with the growth of GDP, revealing that China's GDP has not yet reached the Kuznets inflection point where the elasticity of tax revenue is equal to zero. That is, China's current GDP does not show serious tax evasion. To confirm the correlation between GDP and direct and indirect taxes, we have found that GDP and indirect tax revenue shows a J-shaped curve. However, the relationship between GDP and direct tax holds an N-shaped curve, indicating that indirect tax revenue is less likely to lead to tax evasion than direct tax revenue. The evidence suggests that there is a significant positive correlation between the sum of night lights and GDP, and the impact of sum of night lights on total tax revenue is also positive, but it is insignificant.

KEYWORDS

sum of night light, underground economy, tax evasion, light pollution, defense meteorological satellite program

JEL D43, D69, H26

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Налоговые поступления, ночные огни и теневая экономика: данные из Китая

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АННОТАЦИЯ

Целью данной работы является оценка корреляции между экономическим ростом, налоговыми доходами, уклонением от уплаты налогов и налоговыми реформами в Китае. Изучена возможность использования показателя количества ночного освещения, которое можно наблюдать из космоса, для измерения экономического роста и оценки его влияния на налоговые поступления. Эмпирический анализ ВВП и налогов проводился на основе данных Национального статистического ежегодника Китая за 1991–2020 гг. Данные о ночном освещении были получены из Оборонной метеорологической спутниковой программы. Для оценки корреляции между ВВП и налогами в Китае использовался подход Кузнеца. Для измерения и расчета суммы яркости ночного освещения была разработана теоретическая модель. Для оценки влияния суммарной яркости ночного освещения на налоговые поступления в Китае использован метод SUR-OLS. Выявлено, что общий объем налоговых поступлений увеличивается с ростом ВВП, что свидетельствует о том, что ВВП Китая еще не достиг точки перегиба Кузнеца, когда эластичность налоговых поступлений равна нулю. Это свидетельствует о том, что в текущем ВВП Китая отсутствует серьезное уклонение от уплаты налогов. Исследование корреляции между ВВП и прямыми и косвенными налогами продемонстрировало, что ВВП и доходы от косвенных налогов показывают J-образную кривую. Однако связь между ВВП и прямыми налогами имеет N-образную форму, что указывает на то, что доходы от косвенных налогов с меньшей вероятностью могут привести к уклонению от уплаты налогов, чем доходы от прямых налогов. Исследование показало, что существует значительная положительная корреляция между суммой ночного освещения и ВВП. Влияние суммы ночного освещения на налоговые доходы также положительное, но оно не значительно.

КЛЮЧЕВЫЕ СЛОВА
сумма ночных огней; теневая экономика; уклонение от уплаты налогов; световое загрязнение; оборонная метеорологическая спутниковая программа

1. Introduction

Economic growth is the basis of tax growth, but there are many factors that affect tax growth, including the adjustment of tax policies, tax base erosion caused by the underground economy, etc. In practice, there are some factors that affect tax that are not related to GDP. It can be seen that tax growth is the common result of many factors, and there is no direct comparative relationship between GDP and tax growth.

The most commonly used definition seeks to relate the underground economy to officially measured national income: including all presently not recorded productive (i.e. value-adding) activities which should be in the national product. Underground economy can be measured both directly and indirectly. Indirect methods are measured based on the comparison of macroeconomic aggregates (such as national accounts, cash transactions). However, indirect methods (especially monetary) often overestimate the level of undeclared work and say little about its socio-economic characteristics. Direct methods, on the contrary, are measured based on statistical surveys and have advantages in terms of comparability and detail but tend to underreport the extent of undeclared income [1].

In fact, there are several challenges to the collection of GDP data in many countries, including the absence of standardized national income accounting methods, lack of consistent methodology in data collection, the subjective response of the responders in ground surveys. But more importantly, in many countries, a greater percentage of economic activity is conducted within the underground sector than the ground sectors, and underground sector productivity is often excluded from the formal statistics [2]. Hence, estimation of underground economic activity from the nighttime lights may help to solve many of the difficulties associated with data which gathered through surveys.

This objective of this paper is to assess research on the correlation among economic growth, tax revenues, tax evasion and critical tax reforms of China's tax sharing system since 1994, and the implementation of replacing business tax with value-added tax (VAT) since 2012. Based on the previous arguments, so the following hypothesis can be proposed:

Hypothesis 1. In this research we use satellite images of night lights to measure and testify the correlation between the total amount of night lighting and GDP, and discusses whether the sum of night lights are positively correlated with GDP and reaches a significant level, If so, the sum of night lights is an effective proxy indicator of GDP, further, estimating tax revenue under the sum of night lights.

Hypothesis 2. In this research we use the data base of China's National Statistical Yearbook to measure the relationship between GDP and indirect tax revenue, and the relationship between GDP and direct tax revenue from 1991 to 2020, respectively. Thus, we discuss the empirical analysis results of the tax base erosion caused by the increase and decrease of GDP on direct tax and indirect tax, and compare them.

In sum, this paper is organized as follows. Section 2 is literature review. Section 3 denotes the methodology, research design and research model for estimating the correlation of GDP and the sum of night lights, measure empirical data and the empirical analyses and results are presented in section 4. Finally, in section 5 we summarize and draw some valuable conclusions.

2. Literature Review

The approach forecasts the relationship between GDP growth and aggregate tax revenues. IFS adopts this approach to forecast revenue from minor taxes after adjusting for tax changes announced in previous Budgets. (Giles and Hall [3]).

According to Schneider and Enste's [4] survey, during the last decades the underground economy was nearly three-quarters of the officially recorded GDP in Nigeria and Thailand, but it amounted to a noteworthy 15% in the OECD countries as well.

Milorad and Williams [5] indicate that 22.6% of all employees in Montenegro are unregistered employees. In addition, 17.5% of regular employees receive understated wages from their employers, mainly for the purpose of reducing the tax payment on the total salary payable.

Schneider [4] and Frey [6] focused on the research of tax losses caused by tax evasion of underground activities and interpret the underground economy as an indicator of an unhealthy state between citizens and government.

In recent studies, Zhou [7] shows the hidden income of the urban household in China is not less than 4 trillion and 800 billion yuan and the underground economy scale accounts for as much as 25–49% of the GDP.

In a recent paper, Henderson et al. [8] denotes that the growth rate of night lights intensities is a useful proxy for the growth rate of GDP as well. They show that this estimate is not obviously biased by changes of measurement errors of observed GDP.

Gonzalez and Lrving [9] adopt satellite nightlights to weigh economic activity in México and discrepancies between estimated an official GDP for the purpose of identifying the underground economy.

In addition, several research findings show that the sum of night lights reflect human economic activity (e.g., Sutton & Costanza [10], Christopher et al. [11] and Tilottama et al. [12]). It is worth noting that the night light data released by NOAA came from the defense meteorological satellite program of the United States (DMSP) equipped with operational line scan system (OLS) sensor. DMSP / OLS sensors have been used in the 1970s.When it is applied, it can work at night and detect urban lights and even low-intensity lights from small-scale residential areas and traffic flow. This data reports every "30 seconds" on earth × light intensity ranging from 0-63 on the grid unit of "30 seconds", with a digital archive beginning in 1992. That is, the night light images were taken by the operational line scan system (OLS) carried by DMSP from 1992 to 2013.

Likewise, Elvidge et al. [13] propose that there is a strong correlation between night light, population, GDP and electricity consumption data. Other related research, such as measuring points at different heights and sky azimuths and drawing sky glow distribution maps (Garstang [14]).

Chalkias et al. [15] use DMSP-OLS to analyze space and build urban light damage models. In other research, Li et al. [16] show that the night sky brightness of Shanghai city is four times that of Tokyo city. Henderson et al. [8] believe that for low-income and middle-income countries, it seems reasonable and necessary to analyze the elasticity between real income and real light growth.

While Henderson et al. [8] denote that the correlation between GDP and SNL is stable at the country level, however, Bickenbach et al. [17] demonstrate that it is rather unstable at the regional level within countries. Hence, this paper only discusses the impact of China's overall night lighting on GDP and taxes, and does not separately discuss the impact of night lighting on GDP and taxes of cities and towns.

3. Research Design

3.1. Data

Thinking about the source of the data for this article, our empirical analyses are estimated according to the data base of National Statistical Yearbook of China. In addition, as mentioned earlier, the sum of night lights data is gathered from the United States Air Force Defense Meteorological Satellite Program (DMSP). The night-lights data are gathered from Air Force satellites that have been circling the earth 14 times a day since the 1970s, which measure the light intensity emanating from specific geographic pixels.

3.2. Methodology

Our methodology involves using the SUR-OLS method and Night Light Sum (SNL) data to estimate its impact on China's tax revenues. In research design, this paper discusses three underground economic evaluation methods (Gutmann_UE[18] / Feige_UE[19] / Tanzi_UE[20]), PMI, government expenditure in the previous period, tax reform in 1994 and 2012, night lighting, and the impact of the above variables on tax revenue (TTR/ DTR/ ITR). In empirical analyses, the time series data covered the time period from 1991 to 2020. The tax revenues are the independent variable, whereas the nine selected variables which are classified as components of economic growth are independent variables (GDP, SNL, PMI, Dummy 1994, Dummy 2012, prior period government expenditure, Gutmann_UE,Feige_UE, Tanzi_UE).

3.3. The Model

The International Astronomical Union (IAU) sets the international standard for dark sky in 1997, which is defined as the brightness of the night sky without moon without the influence of man-made light damage (light pollution). The standard is that the sky glow is 21.6mag/arcsec, and the natural brightness of the night sky at the full moon is 16mag/arcsec.

In this paper, we utilize several crucial variables to observe the usefulness of economic activity indicators and their impact on taxation. Especially, we explore the usefulness of a different proxy for economic activity: the amount of light that can be observed from outer space as a measure of economic growth to measure its impact on tax revenue.

By observing the total number of lighting sources at night through the satellite system, we propose a hypothesis that people can only see part of the whole sky when they watch the night sky through the satellite. In the beginning, we suppose the original night sky brightness (area) is A_0, the night sky brightness (area) visible through the satellite is A, then: satellite observation of light depth caused by night illumination on the earth's surface τ can be expressed as:

$$A = A_0 e^{-\tau}, \quad (1)$$

where $A < A_0$ indicates that the night illumination seen from the satellite is lower than the actual night illumination visibility on the earth's surface due to the influence of clouds and air pollution.

Nevertheless, we can calculate the light depth τ via absorption coefficient k and s meters of DMPS satellite system from the earth's surface. Further, we demonstrate that DMPS data is adopted a spherical coordinate system, measured in degrees, 30 seconds which is approximately equal to 0.0083 degrees, and it is about 0.86 square kilometers near the equator. Such that:

$$\tau = \int k ds = \int 1397 ds, \quad (2)$$

where absorption coefficient k can be measured through light source density $\chi = 1.27$ mcd/m^2 and the area of each light spot υ is equal to one thousand and one hundred μ CD/m^2. Hence, the above is represented as follows:

$$k = x\upsilon = 1397. \quad (3)$$

Next, optical density (OD) is defined as an indication of the shading ability of a material. which is measured with a light transmitting mirror. The optical density has no dimensional unit and is a logarithmic value. In reality, the optical density is measured only for aluminized film and pearlescent film. Optical density is the logarithm of the ratio of incident light to transmitted light, or the logarithm of the reciprocal of light transmittance. In addition, the calculation formula is OD = log10 (incident light / transmitted light) or OD = log10 (1 / transmittance), where the area of each light spot υ and its diameter m can be expressed as:

$$\upsilon = \pi\left(\frac{m}{2}\right)^2 \sin\omega, \quad (4)$$

where ω is the average inclination of the light spot, which is 45 degrees. Therefore, the light depth can be expressed as:

$$\tau = \int x\upsilon ds = H\upsilon, \quad (5)$$

where

$$H = \int xds = \left(=\frac{\tau}{\upsilon}\right)$$

variable *H* is the column density, the assumption of column density *H* is multiplied by the total area illuminated at night by the region/country where the satellite is going to observe the earth (the surface area of the hemisphere multiplied by 2).

Thus, we can further calculate the total amount of nighttime illumination in the region or country of the earth to be observed on the satellite, such as *Z*, so that:

$$Z \sim 2\pi\gamma^2 H = \frac{2\pi\tau\gamma^2}{\upsilon} = \frac{2\pi\gamma^2}{\upsilon}\left(-\ln\frac{A}{A_0}\right). \quad (6)$$

Notice that from 1992 to 2013, NOAA took luminous images using the operating line scanning system (OLS) carried by "DMSP". Its value is equivalent to the *Z* derived from equation (6), which is used in this article.

Therefore, through empirical analysis, the relationship between the sum of night lights and GDP is estimated as follows:

$$\widehat{GDP}_t = aZ_t^2 + bZ_t + c. \quad (7)$$

According to the analytic results of SUR-OLS regression, we get:

$$\widehat{GDP}_t = -2.22E - 49Z_t^2 + +4.23E - 07Z_t - 1.714034. \quad (8)$$

Eq. (8) mainly focuses on testing the correlation between the sum of night lights and GDP. In Eq. (8), we depict the correlation coefficient between the sum of night lights (SNL) and GDP is 4.23E-07, reaching 1% significance level, denoting the increment of the sum of night lights is positively correlated with GDP. The empirical study confirms that changes of night lights intensities are a useful proxy of changes of true GDP as well (Henderson et al. [8]).

4. Research results

4.1. Empirical analysis

In this section, our methodology involves assessing the relationship among independent variables UE, GDP, China's major tax reform in 1994 and 2012 and explore their impact on total tax revenue (TTR) covering 1991–2020. This analysis is based on the data base of "National Statistical Yearbook of the People's Republic of China" and uses RMB as the unit measurement. Before the study of co-integration analysis, a unit root test should be carried out for individual variables to determine whether the integration order of variables is the same, and then the multivariate model was further analyzed.

At first, we adopt BDS Test- Serial Independence to check whether the time series variables are i.i.d. (see Brock et al. [21]; Willian et al. [22]). Table 1 depicts the p-values of all variables are 0.0000, Hence, we reject the null hypothesis that the variables are i.i.d.

Then, we use the overlapping variation ratio test of Lo and Craig [23], the null hypothesis denotes the parameter is a martingale. Table 2 shows that TTR and GDP are not a "martingale process" which demonstrates that variables GDP and TTR in this model are not random walking process.

Before conducting empirical research on time series analysis, it is essential to tackle with unit root problems and discuss the cointegration approach between the GDP, Gutmann_UE, Tanzi_UE and Feige_UE for China over a time period ranging from 1991 to 2020 as follow. The results of unit root tests are presented in Table 3, which demonstrates that independent variables Gutmann_UE, Tanzi_UE and Feige_UE present stationary at the first order cointegration under 1% significant

Table 1

BDS independence test (time period: from 1991 to 2020)

Variable	Dimension	BDS statistic	Std. error	Z-Statistic	Prob
GDP	2	0.166377	0.012125	13.72213	0.0000
	6	0.265933	0.024577	10.82042	0.0000
TTR	2	0.166632	0.010993	15.15781	0.0000
	6	0.282599	0.023348	12.10402	0.0000
Gutmann	2	0.194879	0.010608	18.37087	0.0000
	6	0.543515	0.022509	12.10402	0.0000
Feige	2	0.142208	0.024968	5.695507	0.0000
	6	0.392875	0.054869	7.160298	0.0000
Tanzi	2	0.193853	0.009370	20.68861	0.0000
	6	0530556	0019822	26.76583	0.0000

Note: The original data source are derived from National Bureau of Statistics, China

Table 2

Variance ratio test (time period: from 1991 to 2020)

Variable	Period	Variance ratio	Std. error	z-Statistic	Prob
GDP	2	1.766613	0.196148	3.908350	0.0060
	4	3.093528	0.347332	6.027460	0.0060
	8	6.290816	0.516929	10.23509	0.0030
	16	6.831789	0.731531	7.972037	0.0030
	Joint Tests		Value	df	Prob
	Max |z| (at period 8)		10.23509	29	0.0030
TTR	**Period**	**Variance ratio**	**Std. error**	**z-Statistic**	**Prob**
	2	1.700574	0.212401	3.298357	0.0130
	4	2.842488	0.369588	4.985246	0.0140
	8	5.834021	0.535155	9.032938	0.0100
	16	6.838145	0.743883	7.848205	0.0050
	Joint Tests		Value	df	Prob
	Max |z| (at period 8)		9.032938	29	0.0100

Note: we set the null hypothesis: variable GDP is not a martingale, variable TTR is not a martingale. The Variance ratio is $VR_t(q) = \frac{\delta_t^2(q)}{\delta_t^2(1)}$.

Table 3

Performance of unit root test: time series 1991–2020

Variable	N-st difference	(C, T, K)	DW	ADF	5%	1%	Result
GDP	1	(C,n,9)	2.07	–3.65	–3.67	–4.53	I(1)*
Gutmann_UE	1	(C,n,7)	2.06	–5.50	–3.58	–4.32	I(1)***
Tanzi_ UE	1	(C,n,7)	2.05	–5.30	–3.58	–4.32	I(1)***
Feige_UE	1	(C,n,7)	2.23	–5.21	–3.59	–4.35	I(1)***

Note: (C, T, K) indicates whether the test formula contains constant term, time trend and number of lag periods using AIC. Standard errors in parentheses: *** denotes the 1st-differenced form passes the stability test at 1% significance level, ** denotes the 1st-differenced form passes the stability test at 5% significance level.

level, and GDP presents stationary at the first order cointegration under 10% significant level, respectively. Our research reveals the variables are I(1).

Next, we adopt Pairwise Granger Causality method [24, 25] to test whether there exists a correlation between GDP and TTR. In Table 4, the result demonstrates that there does not exist any causality under the 5% significance level.

Table 4

Performance of Pairwise Granger Causality

Null Hypothesis	OBs	F-Statistic	Prob
GDP does not Granger Cause TTR	26	5.3877	0.0055
TTR does not Granger Cause GDP	26	18.6645	5.E-06

We then adopt VAR Residual Serial Correlation LM test. The result depicts that the correlation between GDP and TTR as following:

$$\begin{bmatrix} GDP_t \\ TTR_t \end{bmatrix} = \begin{bmatrix} 0.1449 \\ 2874.563 \end{bmatrix} + \\ + \begin{bmatrix} -0.2966 & 0.0001 \\ -19629.64 & 2.8983 \end{bmatrix} \begin{bmatrix} GDP_{t-1} \\ TTR_{t-1} \end{bmatrix} + \\ + \begin{bmatrix} 0.5063 & -7.29E-05 \\ 8301.89 & -0.879 \end{bmatrix} \begin{bmatrix} GDP_{t-2} \\ TTR_{t-2} \end{bmatrix}. \quad (9)$$

As can be seen from Table 5, the *p*-value of the previous four periods is greater than 0.05, indicating it falls within the acceptance domain. That is, the random error term of the model is a white noise process, and there is no autocorrelation. Clearly, the residual sequence passes the test.

Table 5

VAR Residual Serial Correlation LM test

Lags	LM-stat	Prob
1	7.717263	0.1025
2	7.356669	0.1182
3	6.343649	0.1749
4	6.777367	0.1481

Note: Probs from chi-square with 4 df.

We then utilize CUSUM (cumulative sum) and CUSUM-sq (CUSUM squared) tests to inspect the stability and constancy for SUR-OLS result. Figure 1 shows the CUSUM curve fall within two critical straight lines and does not exceed the range. Hence, it is proved that the parameter TTR, GDP, GDP^2, GDP^3 of the model are stationary.

Next, we use a generalized variance decomposition method (Koop et al. [26]). Through the VAR model, Table 6 shows the unexpected impact variation of GDP and the sum of night lights (SNL) on TTR, respectively.

At the beginning, the percentage of TTR explained by GDP and the sum of night lights (SNL) is extremely small, however, when we observe the next 9 periods. The sum of night lights (SNL) can explain only 0.53% of the variation for TTR

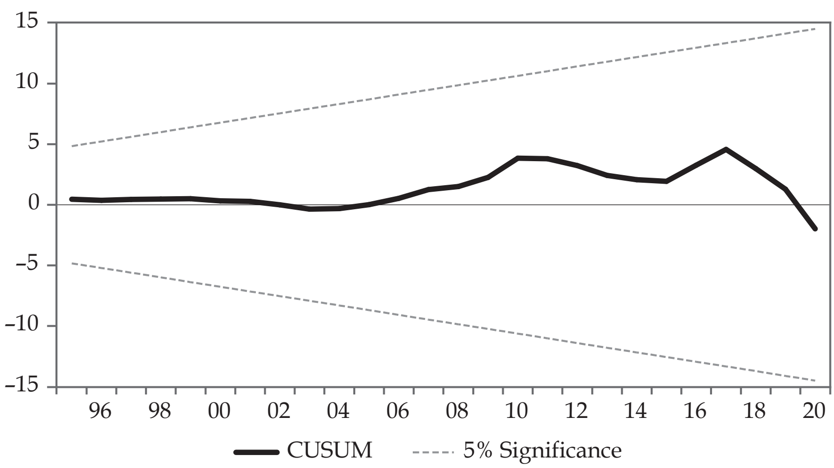

Figure 1. **CUSUM test result**

prediction errors. Comparatively, GDP can explain 40.80% of the variation for TTR prediction error, indicating that variable GDP has a higher correlation with TTR than that of sum of night lights (SNL).

4.2. Estimation of tax revenue under the sum of night lights

To illustrate this point, Eq. (10) discusses the influence of independent variables including economic growth, the sum of night lights (SNL), purchasing manager index (PMI) and Dummy variables (tax reform in 1994 and 2012 respectively) upon the total tax revenue (TTR) as following:

$$TTR_{it} = \alpha_t + \gamma_1 GDP_t + \gamma_2 (GDP_t)^2 + \gamma_3 (GDP_t)^3 + \gamma_4 SNL_t + \gamma_5 PMI_t + \gamma_6 Dmmy1994 + \gamma_7 Dummy2012 + \varepsilon_{itg}, \quad (10)$$

$$\varepsilon_{itg} = \mu_{ig} + v_{itg},$$

where i is tax item, t stands for time, and g is the scope of government auditing.

As mentioned earlier in Eq. (8), the estimated relationship between GDP and SNL is:

$$\widehat{GDP}_t = -2.22E-49SNL_t^2 + 4.23E-07SNL_t - 1.714034.$$

To precisely demonstrate the correlation among tax revenue and relevant variables, the empirical research and results can be stated formally as follows.

Case 1. As is indicated in model 1 of Table 6, we show there is an inverted U-shaped relationship between TTR and GDP, prob (J statistic) is 0.3916, which does not pass the 5% significant level, indicating that we can not reject the null hypothesis that instrumental variables are effective. On the other hand, the empirical result of model 1 indicates that with the growth of GDP, total tax revenue also increases, revealing that China's GDP has not yet reached the Kuznets inflection point where the elasticity of tax revenue is equal to 0. That is, China's current GDP does not exist serious tax evasion.

Case 2. On the basis of Model 1 in Table 6, we add variable PMI, the regression coefficient of PMI is 41.5174, which does not pass the 10% significance test, indicating that the tax increase caused by the PMI price index is not statistically significant.

Case 3. As shown in model 3 of Table 6, we use the night lighting index to detect the possible error of tax originally estimated by GDP (see Henderson et al. [8]). As we add variable SNL into model 1, the results depict the corresponding regression coefficient is 0.0002, which does not pass the 10% significance test, denoting the increase of sum of night lights (SNL), to some extent, may not result in the increment of total tax revenue.

Next, we discuss the impact of economic growth on direct tax as follows.

Case 4. As is indicated in Model 4 of Table 6, we show the economic growth has positive impact on raising direct tax revenue (DTR). The corresponding regression coefficient is 6.284, passing the 1% significance test, showing there is an N-shaped correlation between the DTR

Table 6

Variance decomposition of TTR/GDP/SNL

Period	S.E.	TTR	GDP	Sum of Night Lights
1	1562.443	100.0000	0.000000	0.000000
2	2460.682	81.38599	18.57044	0.043569
3	2942.398	68.62177	29.77517	1.603059
4	3623.122	76.70528	22.23705	1.057667
5	4708.615	70.75343	28.58951	0.657059
6	5505.776	62.59401	36.47445	0.931545
7	6427.284	66.00394	33.30227	0.693787
8	7892.810	63.92787	35.60076	0.471374
9	9245.824	58.66108	40.80301	0.535910

and GDP, revealing that except in the interval of negative slope, GDP has a significantly positive impact on direct tax revenue (DTR). Moreover, we depict the prob (J-statistic) is 0.6224, which does not pass the 5% significant level, revealing it is impossible to reject the null hypothesis that the instrumental variable is effective:

$$DTR_{it} = \alpha_t + \gamma_1 GDP_t + \\ + \gamma_2 (GDP_t)^2 + \gamma_3 (GDP_t)^3 + \varepsilon_{itg}. \quad (11)$$

Case 5. Likewise, in Model 5 of Table 6, we show the GDP has positive impact on raising indirect tax revenue (ITR), the corresponding regression coefficient of GDP is 12,990.35, passing the 1% significance test, revealing there is a J-shaped relationship between the ITR and GDP. These results indicated that, according to model 4 and model 5 of Table 7, the relationship between GDP and indirect tax revenue (ITR) presents a J-shaped curve, however, the relationship between GDP and direct tax revenue (DTR) presents an N-shaped curve, indicating that indirect tax is relatively less likely to lead to tax evasion:

$$ITR_{it} = \alpha_t + \gamma_1 GDP_t + \\ + \gamma_2 (GDP_t)^2 + \gamma_3 (GDP_t)^3 + \varepsilon_{itg}. \quad (12)$$

Case 6. On the basis of Model 1 of Table 7, in Model 6, we add two important tax reform in China in 1994 and 2012 as independent variables, the corresponding regression coefficient is 12,990.35, passing the 1% significance test, depicting the higher the GDP, the larger the total tax revenue.

Further, we show the regression coefficients of dummy variables in 1994 and 2012 are 483.6615 and –1,764.304, respectively. Our empirical research denotes that the dummy variable 1994 is positively correlated with TTR. However, the dummy variable 2012 shows a negative correlation with TTR, but neither of these two dummy variables pass the 10% significance test.

4.3. Underground economy versus tax revenue

There are many methods to measure the size of underground economy. Each approach has its own strengths and weaknesses [5]. In general, the currency demand variable approaches [20; 27] are the most widely used (Johnson et al. [28]).

In estimating the results of underground economy upon tax revenue we incorporate three kinds of underground economic approach methods, including Gutmann_UE, Tanzi_UE and Feige_UE, into Eq. (10) in pursuit of measuring underground economy's influence on total tax revenue (TTR). It can be observed that research conducted by Tanzi [27] calculates only those underground activities that are solely the result of taxes. In general, the estimates are obviously higher for the Gutmann approach than for the Tanzi approach (see Cebula & Feige [29]).

Table 7

SUR-OLS Regression analysis of TTR/DTR/ITR- GDP

Dependent Variable	GDP	$(GDP)^2$	$(GDP)^3$	PMI	Sum of Night Light	Dummy 1994	Dummy 2012	TSLS-(Prob J-statistic)	DW	Curve style
Model 1 (TTR)	13514.21*** (15.5071)	–136.0141 (–0.9437)	–2.0010 (–0.3115)					0.3916	0.9370	∩
Model 2 (TTR)	8372.107** (2.8865)	496.6146 (1.3468)	–25.1322 (–1.7868)	47.5174 (0.2418)				0.3678	1.0807	∫
Model 3 (TTR)	16375.53*** (16.0220)	–1054.171*** (–3.1370)	63.9263*** (2.9542)		0.0002 (1.6110)			0.3678	1.3485	N
Model 4 (DTR)	3514.348*** (6.2840)	–50.8446 (–0.5497)	3.4828 (0.8450)					0.3916	0.6224	N
Model 5 (ITR)	8896.618*** (9.9189)	97.9074 (0.6600)	–13.1680* (–1.9920)					0.3916	2.2567	∫
Model 6 (TTR)	12990.35*** (10.5355)	–27.3618 (–0.1197)	–6.6097 (–0.6685)			483.6615 (0.3094)	–1764.304 (–0.5773)		0.9268	∩

Based on the empirical research as indicated in Table 8, we draw the valuable results as follows.

Case 7. In Model 1 of Table 8, we add variable Gutmann_UE into model 1 of Table 7. We demonstrate that the variable Gutmann_UE is negatively correlated with TTR, passing the 10% significant level. Clearly, the cash deposit ratio (CDR) method depicts that the higher the proportion of currency to current deposit, the more underground economic activities it exists, leading to the decline of TTR.

Case 8. Likewise, in Model 2 of Table 8, we add variable Feige_UE into model 1 of Table 7, the result reveals that the Feige_UE has a negative correlation with TTR, and its coefficient value is –0.6991 which does not pass the 10% significance test.

Case 9. In Model 3 of Table 8, we add variable Tanzi_UE into model 1 of Table 7, the coefficient is –2.5852, indicating that the influence of Tanzi_UE on TTR is negative, passing the 5% significance. Clearly, the result depicts the increase of those underground economy activities that are solely the result of cash transaction will lead to the decrease of taxpayer's willingness to declare total tax revenue. Likewise, the result of Model 6 in Table 8 declares variable Tanzi_UE has a negative correlation with DTR, its coefficient value –1.8667, passing 10% significance, revealing the increase of cash transaction eventually leads to the decrease of DTR:

$$TTR_{it} = \alpha_t + \gamma_1 GDP_t + \gamma_2 (GDP_t)^2 + \\ + \gamma_3 (GDP_t)^3 + \gamma_4 G_{t-1} + \varepsilon_{itg}. \quad (13)$$

Case 10. In Model 10 of Table 8, we show variable "government expenditure" occurred in the previous year has a positive correlation with current TTR, and its coefficient value is –0.1067, however it does not pass the 10% significance test (see Eq. (13)).

Our empirical results are in line with Kelton [30] who considers the government is self-financing and do not necessarily need to collect taxes or borrow. In addition, in our previous article, we have denoted that China's fiscal revenue has a one-way and positive impact on public expenditure, but public expenditure does not appear one-way positive/negative im-

Table 8

Result for Gutmann/Feige/Tanzi and TTR/DTR/ITR

Dependent Variable	GDP	$(GDP)^2$	$(GDP)^3$	G Gutmann -UE	Feige -UE	Tanzi -UE	Prior Period expenditure	TSLS- (Prob J-statistic)	DW	Curve style
Model 1 (TTR)	10816.48*** (6.7189)	192.5907 (0.8894)	–14.3740 (–1.6385)	–18865.92* (–1.6385)				0.0005	0.9405	∫
Model 2 (TTR)	13145.63*** (12.9826)	–90.2730 (–0.5741)	–3.7291 (–0.5456)		–14904.18 (–0.6991)			0.0012	0.9345	∩
Model 3 (TTR)	9817.3*** (6.0126)	302.9156 (1.4152)	–18.5181** (–2.1446)			–46186.32** (–2.5852)		0.0004	0.9625	∫
Model 4 (DTR)	2426.752** (2.2639)	81.6332 (0.5661)	–1.5053 (–0.2577)	–7605.848 (–1.1796)				0.0000	0.6188	∫
Model 5 (DTR)	3506.022*** (5.3524)	–49.8113 (–0.4897)	3.4438 (0.7789)		–336.6822 (–0.0244)			0.0001	0.6221	N
Model 6 (DTR)	1721.41 (1.5696)	162.029 (1.127)	–4.5276 (–0.7806)			–22399.61* (–1.8667)		0.0001	0.6176	∫
Model 7 (ITR)	7493.589*** (4.3236)	268.8075 (1.1530)	–19.6029** (–2.0756)	–9811.748 (–0.9411)				0.4227	2.2961	∫
Model 8 (ITR)	8473.13*** (8.1470)	150.4627 (0.9316)	–15.1535** (–2.1588)		–17124.54 (–0.7820)			0.4061	2.2938	∫
Model 9 (ITR)	7251.472*** (3.9705)	293.2338 (1.2248)	–20.5182** (–2.1244)			–20553.2 (–1.0285)		0.4596	2.3021	∫
Model 10 (TTR)	12255.87*** (9.8024)	–137.0595 (–0.9800)	–3.9937 (–0.6239)				0.1067 (1.3662)	–0.0671	1.0379	∩

pact on fiscal revenue. That is, if the fiscal revenue has a positive one-way impact on expenditure (tax spend hypothesis), it represents that increasing revenue will lead to the increment of public expenditure, but reducing expenditure will not lead to the reduction of fiscal revenue [31].

5. Conclusion

In this paper, our research design differs from the traditional measurement of underground economy and tax revenue.

First, we attempt to design a theoretical model to measure and calculate the sum of night illumination brightness according. Through empirical research, we correspond to the "hypothesis 1" that the sum of night lights has a positive significant correlation with GDP, revealing the correlation between the sum of night lights (SNL) and GDP reaching 1% significance level, denoting the increment of the sum of night lights is positively correlated with GDP. However, when we add the variable SNL to the model, according to the "hypothesis 1", it is found that the corresponding regression coefficient does not pass the 10% significance test, indicating that the increase of total night lighting (SNL) does not necessarily lead to the increase of total tax. In spite of the shortcomings, the methodology developed here to estimate economic activity using a combination of nighttime satellite data, official measures of GDP, and underground economy estimates is a useful and innovative initiative.

Second, with regard to "hypothesis 2", after the previous empirical analysis, we show that during the period from 1991 to 2020, the relationship between GDP and indirect tax revenue (ITR) presents a J-shaped curve, however, the relationship between GDP and direct tax revenue (DTR) shows an N-shaped curve, indicating that indirect tax is relatively less likely to lead to tax evasion.

Third, our research denotes that PMI has a positive correlation with TTR, but the effect is insignificant.

Finally, the underground economy is present in both the developed and developing countries. Almost no official national GDP statistics take into account the contribution of underground economy, however, we demonstrate that with the growth of GDP, TTR also increases, revealing that China's current GDP does not exist serious tax evasion.

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