Pollution and Informal Economy*

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Abstract:

In this study we investigate the relationship between the size of the informal economy and the level of environmental pollution/energy use. To this end, first we use different indicators of environmental pollution along with a measure of energy use intensity in a panel data set consisting of 152 countries over the period 1999 - 2009 and empirically examine the relationship between pollution and the shadow economy. The estimation results show that there is an inverse-U relationship between the size of the informal economy and environmental pollution, that is small and large sizes of the informal economy are associated with little environmental pollution and medium levels of informality are associated with higher levels of environmental pollution. Next, we build a two-sector dynamic general equilibrium model to suggest an economic mechanism for this observation. Our model identifies two channels through which informality might affect environmental pollution: The scale effect with which larger (smaller) informal economy size is associated with lower (higher) level of environmental pollution and the deregulation effect with which larger (smaller) informal economy is associated with higher (lower) pollution levels. As these two effects work in opposite directions, the changing relative strength of one with respect to the informal sector size creates the inverted-U relationship between pollution indicators and informality.

Keywords: informal sector; environmental Kuznets curve; pollution; two-sector dynamic general equilibrium models; panel data

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1 Introduction and Related Literature

Informal economy (sector), sometimes also titled as the shadow, hidden or underground economy is generally defined by as a set of economic activities that take place outside the framework of bureaucratic public and private sector establishments. (Hart, 2008). A similar definition is made by Ihrig and Moe (2004) who define it as a sector which produces legal goods, but does not comply with government regulations. Yet another definition is given by Tanzi (1999) as the production and distribution of goods and services that are unaccounted for in the official national income accounts of a country. All these definitions share the common feature in defining the informal sector that as opposed to formal sector that it is imperfectly (if any) regulated and is not subject to government scrutiny. (Also see Thomas, 1992, and Schneider and Enste, 2000 and Elgin and Oztunali, 2012.)

It is a well established fact in the environmental economics literature that environmental pollution highly depends on the intensity of government regulations, overseeing and enforcement of environmental standards. As argued by Baksi and Bose (2010), the presence of a large informal sector in developing countries indicates a serious challenge for the implementation of environmental regulations in these countries. Therefore, it is crucial to understand the links between informality and environmental performance and it would be a mistake to overlook the presence of a shadow economy when analyzing environmental policy outcomes.

To fill in the gap in the literature, in this paper we investigate the relationship between informal economy and environmental pollution/energy use. To this end, in the empirical part of the paper we employ three different pollution indicators: CO_2, SO_2 emission per-capita and energy use intensity (EUI) index which are among mostly widely used pollution variables in the literature. We use annual data from 1999 to 2009 for 152 countries. The cross-country panel data analysis we conduct shows strong evidence towards the existence of an inverted-U relationship between informal sector size (relative to official GDP) and environmental pollution, i.e. the presence of an environmental Kuznets curve relationship for the informal economy. Specifically, small and large sizes of the informal economy are associated with little environmental pollution and medium levels of the size of the informal economy are associated with higher levels of environmental pollution. To account for this non-linear relationship, we identify two channels through which the presence informality might affect environmental pollution: We name the first channel as the *scale effect* through which larger (smaller) informal sector size is associated with lower (higher) level of environmental pollution. This effect is motivated from the fact that informal economy operates on a small scale (especially compared to the formal sector) with a highly labor intensive and less capital-intensive production technology. The low level of capital intensity and the small scale of production make the informal sector less prone to environmental pollution. However, on the other hand there is also the *deregulation effect* of informality through which larger (smaller) informal sector size is associated with higher (lower) level of environmental pollution. This effect is motivated through an intrinsic factor of informality that is absence of regulation in the informal economy. As these two effects work in opposite directions the changing relative strength of one builds the inverted-U relationship between pollution indicators and informal sector size. We then build a two-sector dynamic general equilibrium model to formally account for the observed relationship in the data. Our model provides a strong theoretical account for the empirical observation we make in the empirical part of the paper.

Except a number of notable exceptions, papers in literature on the environmental impacts of informal sector are rare. In one study, Blackman and Bannister (1998a) claim that in various developing countries the informal sector, which they argue that is comprised of low-technology unlicensed micro-enterprises, "...is a major source of pollution" and that "...environmental management in this sector is exceptionally challenging." In line with this study Blackman and Bannister (1998b) argues that is is virtually impossible to regulate the informal sector with conventional tools. Furthermore, Blackman et al. (2006) makes a similar argument and focuses on the estimation of benefits of controlling informal sector emissions. In a theoretical work, Chaudhuri (2005) build a three-sector general equilibrium model with an informal sector and then use this model to analyze the effects of different policies on the environmental standard and welfare of the economy. In a somewhat related work Baksi and Bose (2010) analyze the effects of environmental regulation in the presence of an informal sector and find that stricter regulation can increase or reduce pollution(or have a non-linear relationship with it). Chattopadhyay, Banerjee and Millock (2010) is investigating a similar research question. Finally, in a more recent paper in Elgin and Oztunali (2013), we investigate the relationship between several pollution indicators and informal sector size using annual time-series data from Turkish economy. The findings presented in this paper show strong support for the existence of the two effects outlined above. In the current paper, we aim to generalize this result to a cross-country panel setting and to provide a theoretical account for this observation.

While revealing a new non-linear inverse-U shaped relationship among per capita pollutant emissions and the informal sector size based on the two opposite effects described above, we also check the robustness of our findings by controlling for the possibility of another non-linear relationship related to per capita environmental pollution, namely the Environmental Kuznets Curve (EKC). The EKC hypothesis suggests the existence of an inverse-U shaped relationship per capita pollution and per capita income (see Grossman and Krueger, 1991 and Holtz-Eakin and Selden, 1995). In order to check whether our findings are only due to a potential relationship between per capita formal output and informal sector size, and thus only serve to support the EKC hypothesis, we also introduce per capita formal output into our empirical analysis. However, our results show that this new relationship between informality and pollution is robust even when we control for the EKC.

The rest of the paper is organized as follows: In the next section, we describe the data and provide empirical evidence about the relationship between informality and environmental performance through panel data analysis and system estimations. Next, in the third section we build a theoretical framework in accordance with our empirical findings and test the performance of our theoretical framework. Finally, in the last section we provide concluding remarks.

2 Empirical Analysis

2.1 Methodology

2.1.1 Static Panel Regressions

In order to check the existence of a potential inverse-U relationship between pollution and informal sector size, we estimate the following panel equation using the fixed-effects estimator:

$$E_{i,t} = \beta_0 + \beta_1 IS_{i,t} + \beta_2 IS^2_{i,t} + \sum_{k=3}^{n} \beta_k, X_{k_{i,t}} + \theta_i + \gamma_t + \epsilon_{i,t}$$

where for country i in year t, $\mathrm{IS}_{i,t}$ stands for the informal sector size as % of GDP, $\mathrm{E}_{i,t}$ for the environmental pollution indicator we use as the dependent variable, $X_{k_{i,t}}$ are various control variables included in the regression. Moreover, θ_i represents the country fixed-effects, γ_t the year dummies, and $\epsilon_{i,t}$ is the error term. In all of our static panel data regressions Hausman test points us in favor of a fixed-effect regression and Wooldridge test rejects absence of autocorrelation. Therefore, we allow for AR (1) disturbance in our regressions. In order for the inverse-U relationship to be supported by the data, we expect the signs of estimated coefficients of β_1 and β_2 to be positive and negative, respectively.[1]

2.1.2 System Estimations

Once the inverse-U relationship is established our next task will be to empirically identify how the data give rise to such a a relationship in the first place. As evident from descriptive and empirical literature on informality, informal sector mainly operates on a small scale (especially compared to the formal sector) with a highly labor intensive and less capital-intensive production technology. (See Celestin, 1989, and Ihrig and Moe, 2004.) The low

[1]Suspecting that informal sector size as well as several of our control variables might be endogenous to pollution we have also run regressions using the two-stage least squares estimator with lagged values of the independent variables as instruments. The inverse-U relationship still holds in these cases as well. These results are available upon request from the corresponding author.

level of capital intensity and the small scale of production make the informal sector less prone to environmental pollution as also mentioned by Antweiler, Copeland and Taylor (2001). Following this reasoning, a larger (smaller) informal sector is expected to be associated with a better (worse) environmental performance or smaller (larger) amount of environmental pollution. Notice that this is an indirect effect of informality on pollution through its effect on the intensity of capital. By the generally accepted and widely used definition of the informal sector, it does not comply with most, if not all, of the government regulations. Surely, these regulations include environmental laws, rules, regulations and restrictions as well. Therefore, following this reasoning, a larger (smaller) informal sector is expected to be associated with a worse (better) environmental performance or larger (smaller) amount of environmental pollution. This can be interpreted as a direct effect of informality on pollution through an intrinsic factor of informal sector, absence of governmental regulation. Also, notice that the deregulation effect works in the opposite direction of the scale effect. These two distinct effects of informality, working in opposite directions carry the potential to create a non-linear U or inverse-U relationship between informality and environmental pollution or performance if one effect is stronger than the other at some levels of the informal sector size and vice versa at other levels. Specifically, a hypothesized inverse-U relationship suggests that at lower levels of informal sector size, a marginal increase (reduction) in informal sector size is associated with an increase (reduction) in pollution. However, after a threshold level of informal sector size this relation is reversed. In order for such a nonlinearity to hold, we need to understand whether the relative strength of deregulation and scale effects depend on the size of the informal sector.

To account for a possible non-linear relationship one should first seek factors that create variation in the informal sector size. Level of taxes, tax enforcement and institutional quality indices are among these factors. To this end we use tax enforcement, tax burden, bureaucratic quality and corruption control indices as factors accounting for variation in informal sector size.[2] If these factors create a variation in informal sector size and therefore capital intensity, then they might provide an account of a possible non-linear relationship in a multivariate framework.

The system we estimate is the following:

$$
\begin{aligned}
E_{i,t} &= \beta_{1_0} + \beta_{1_1} IS_{i,t} + \beta_{1_2} K_{i,t} + \sum_{k=3}^{n} \beta_{1_k} X_{k_{i,t}} + \epsilon_{1_{i,t}} \\
K_{i,t} &= \beta_{2_0} + \beta_{2_1} IS_{i,t} + \beta_{2_2} IS_{i,t}^2 + \sum_{k=3}^{n} \beta_{2_k} Z_{k_{i,t}} + \epsilon_{2_{i,t}} \\
IS_{i,t} &= \beta_{3_0} + \sum_{k=1}^{n} \beta_{3_k} V_{k_{i,t}} + \epsilon_{3_{i,t}}
\end{aligned}
$$

where for country i in year t, E stands for the environmental pollution indicator, IS for the informal sector size as % GDP, K for capital-output ratio, $Z_{k_{i,t}}$ for exogenous variables that potentially affect capital, and $V_{k_{i,t}}$ for exogenous variables that create a variation in informal sector size.

The hypothesized deregulation and scale effects will manifest themselves in the estimated coefficients of the first two equations. Specifically, keeping the deregulation effect in mind, we expect the estimated coefficient of β_{1_1} to be positive. Also, notice that this effect, if it exists, is linear. On the other hand, the scale effect will be observed in the estimated coefficients of β_{1_2}, β_{2_1}, and β_{2_1} which we expect to be positive, negative and negative, respectively. Through the scale effect, the informal sector size is expected to reduce capital-output ratio and therefore also pollution at an increasing rate. Joint with the deregulation effect the systems has the potential to create the inverse-U relationship between informality and pollution.

[2] Both Schneider and Enste (2000) and Buehn and Schneider (2012) suggest that these factors indeed matter for informality.

2.2 Data

We use three different indicators of environmental pollution. First two of these are, CO_2 and SO_2 emissions per-capita which are widely used in the pollution literature. Moreover, we also use a third measure, namely the Energy Use Intensity (EUI) Index as well. As control variables, we use GDP per-capita and its square (to control for the EKC hypothesis) and its growth rate (denoted by growth), government spending to GDP ratio (denoted by government exp.), trade openness (defined as the ratio of the sum of exports and imports to GDP), capital-output ratio (denoted by capital), total factor productivity (denoted by productivity) and four institutional measures, namely corruption control, bureaucratic quality, law and order and democratic accountability indices.

Data for CO_2[3] and SO_2[4] is obtained from United Nations Statistic Division (UNSD) Environmental Indicators whereas data for EUI[5] is obtained from the World Bank's World Development Indicators databases. Informal sector size data is obtained from Buehn and Schneider (2012). Data for law and order, corruption control (shortly corruption), bureaucratic quality (shortly bureaucracy) and democratic accountability (shortly democracy) indexes is obtained from ICRG Political Risk Services Database.[6] Data for openness, government spending and GDP per-capita is obtained from Penn World Table. Capital-output ratio is estimated with perpetual inventory method by using Penn World Table. Finally, (total factor) productivity is estimated assuming a Cobb-Douglas production function and using Penn World Table.[7] Summary statistics for all the variables used in the regressions are given in Table 1.

Table 1 about here

[3] CO_2 emissions consiss of emissions from energy industry, from transport, from fuel combustion in industry, services, households, etc. and industrial processes, such as the production of cement.

[4] SO_2 emissions are calculated by using fuel combustion data and sulphur content of fossil fuels used in each country.

[5] EUI refers to use of primary energy before transformation to other end-use fuels, which is equal to indigenous production plus imports and stock changes, minus exports and fuels supplied to ships and aircraft engaged in international transport.

[6] See www.prsgroup.com

[7] More details about data construction is available upon request.

2.3 Estimation Results

2.3.1 Static Panel Analysis

Using data from 1999 to 2009 for 152 countries, we conduct panel regressions for the three pollution variables CO_2, SO_2 emission per-capita and energy use intensity (EUI) as the relevant dependent variable. Tables 2, 3, and 4 present outputs of these estimations.

Table 2 about here

According to Table 2, we observe that the estimated coefficients of informal sector size and squared informal sector size are significantly positive and negative, respectively. This result suggests that there is an inverted-U shaped relationship between the informal sector size and CO_2, while CO_2 is positively and significantly correlated with productivity, capital-output ratio and government expenditure. Furthermore, CO_2 is negatively and significantly correlated with law.

Table 3 about here

The relationship between SO_2 and the informal sector size has also the shape of an inverted-U. Moreover, SO_2 is positively and significantly correlated with productivity. SO_2 is also negatively and significantly correlated with democracy and GDP growth.

Table 4 about here

The relationship between energy use intensity (EUI) and the informal sector size is similar to the cases of CO_2 and SO_2. Furthermore, EUI is positively and significantly correlated with capital, GDP and openness. EUI is also negatively and significantly correlated with law.

Overall, the positive and significant coefficient for $informal$, together with the negative and significant coefficient for informal^2, indicate the existence of an inverse-U shaped relationship between informality and environmental pollution/energy use. High and low levels of informality correspond to low levels of pollution while middle levels of informality correspond to high levels of pollution. Moreover, law and order reduces pollution, and capital increases it. We should also notice that in addition to the clearly identified inverted-U relationships, we can also observe from the estimation results that the peaks of the inverted-U curves occur at around 40-55 percent of shadow economy size, depending on the specific regression and the dependent variable. These are the points at which the pollution and energy use are maximized with respect to the size of the informal sector.

2.3.2 System Estimations

The results of the systems estimations in Tables 5 and 6 show that both the informal sector size and capital-output ratio (shortly capital) are positively correlated with environmental pollution while capital is negatively correlated with the informal sector size, and the informal sector size is negatively correlated with the level and enforcement of tax. When other variables are held constant, a decrease (increase) in the tax enforcement variable affects environmental pollution through two channels. First, it induces an increase (decrease) in the informal sector size and puts upward (downward) pressure on pollution levels directly, and we call this as the *deregulation effect* . Secondly, the induced increase (decrease) in the informal sector size reduces (boosts) capital, and that decreases (increases) pollution indirectly. We call this effect as the *scale effect*. Because of those two opposite direct and indirect effects of a change in the informal sector size, a non-linear and inverted-U shaped relationship between informality and environmental pollution arises.[8]

Tables 5 and 6 about here

[8]Some variables (such as enforcement or taxes) might not only affect informal sector but also have an impact on the size of the formal sector or formal sector variables. However, notice that our measure of the informal economy is not the absolute size of the informal sector; instead we use informal sector size as % of official GDP (i.e. formal economy) as the measure of the extent of informality in a country. Therefore, when a variable (e.g. enforcement) changes and impacts informal sector size (as % of GDP) it means that the size of the informal economy changes relative (e.g. above and beyond) the formal economy; and any potential effect of that variable (enforcement) on formal economy is also accounted for.

3 Model

In this section, to account for the observations we made in the previous section, we present a two-sector dynamic general equilibrium model with the presence of informal sector and environmental pollution.

3.1 Representative Household's Problem

The representative household has the following utility function:

$$\max_{\{C_t, K_{t+1}, l_{ft}, l_{it}\}} \sum_{t=0}^{\infty} \beta^t U(C_t, E_t) \tag{1}$$

with $U_C(C_t, E_t) > 0$ and $U_E(C_t, E_t) < 0$, where E_t is the environmental pollution at time t. The representative household faces the following resource constraint:

$$C_t + K_{t+1} = (1-\tau)\theta_f F(K_t, l_{ft}) + (1-\rho\tau)\theta_i I(l_{it}) + T_t \tag{2}$$

where l_{ft} and l_{it} are the amounts of labor that are devoted to formal and informal sector, respectively. $F(K_t, l_{ft})$ is the constant-returns-to-scale production technology of the formal sector, employing physical capital K_t and labor given the productivity parameter θ_F. $I(l_{it})$ is the production technology of informal sector which exhibits diminishing returns to scale.[9] T_t is lump-sum transfer.[10] τ is the tax rate and $\rho \in [0, 1])$ is the level of the tax enforcement. Notice that in this setup, the income from the informal sector (i.e. $\theta_i I(l_{it})$) is partially taxes by the government, depending on the value of the tax enforcement parameter ρ.

[9] See Ihrig and Moe (2004) or Elgin (2012) for a discussion of these production functions to represent formal and informal sectors.

[10] We simply assume that the taxes collected by the government are rebated back to the consumer.

3.2 Modelling Pollution

We define environmental pollution E_t as an outcome of the production process. As we have two sectors producing output, E_t is defined as follows:

$$E_t = \mu_f \theta_f F(K_t, l_{ft}) + \mu_i \theta_i I(l_{it}) \tag{3}$$

where E_t is a linear combination of formal and informal outputs. μ_f is the pollution coefficient of the formal sector and μ_i is the pollution coefficient of the informal sector.

3.3 Social Planner's Problem

Given$\{K_0, \theta_f, \theta_i, \mu_f, \mu_i, \tau, \rho\}$, an equilibrium for this economy is an allocation $\{{C_t}^e, {K_{t+1}}^e, {l_{ft}}^e, {l_{it}}^e, {E_t}^e\}_{t=0}^{\infty}$ such that the social planner chooses $\{{C_t}^e, {K_{t+1}}^e, {l_{ft}}^e, {l_{it}}^e, {E_t}^e\}_{t=0}^{\infty}$ to solve the following problem:

$$\begin{aligned}
\max_{\{C_t, K_{t+1}, l_{ft}, l_{it}\}} \quad & \sum_{t=0}^{\infty} \beta^t U(C_t, E_t) \\
\text{subject to} \quad & C_t + K_{t+1} = (1-\tau)\theta_f F(K_t, l_{ft}) + (1-\rho\tau)\theta_i I(l_{it}) + T_t \\
& E_t = \mu_f \theta_f F(K_t, l_{ft}) + \mu_i \theta_i I(l_{it}) \\
& l_{ft} + l_{it} = 1 \\
& \text{given } K_0, \mu_f, \mu_i \\
& C_t > 0
\end{aligned} \tag{4}$$

The social planner in this economy maximizes the utility function by choosing optimal consumption and capital levels, and allocating labor optimally to formal and informal sectors while taking into consideration the disutility from environmental pollution, as well as each sector's marginal pollution propensities.

3.4 Characterization of Social Planner's Problem

The first order conditions of the social planner's problem with respect to $C_t, C_{t+1}, K_{t+1}, l_{it}$ and the multiplier λ_t on the resource constraint are as follows:

$$C_t : \beta^t U_C(C_t, E_t) - \lambda_t = 0 \tag{5}$$

$$C_{t+1} : \beta^{t+1} U_C(C_{t+1}, E_{t+1}) - \lambda_{t+1} = 0 \tag{6}$$

$$K_{t+1} : \beta^{t+1} U_E(C_{t+1}, E_{t+1}) \mu_f \theta_f F_K(K_{t+1}, 1 - l_{it+1}) - \lambda_t + \lambda_{t+1}[(1-\tau)\theta_f F_K(K_{t+1}, 1 - l_{it+1})] = 0 \tag{7}$$

$$\begin{aligned} l_{it} : & \beta^t U_E(C_t, E_t)[-\mu_f \theta_f F_{l_i}(K_t, 1 - l_{it}) + \mu_i \theta_i I_{l_i}(l_{it})] \\ & + \lambda_t[-(1-\tau)\theta_f F_{l_i}(K_t, 1 - l_{it}) + (1 - \rho\tau)\theta_i I_{l_i}(l_{it})] = 0 \end{aligned} \tag{8}$$

$$\lambda_t : (1-\tau)\theta_f F(K_t, l_{ft}) + (1 - \rho\tau)\theta_i I(l_{it}) - C_t - K_{t+1} = 0 \tag{9}$$

For further characterization of the equilibrium, functional forms for utility and production functions have to be specified. This is what we do in the next subsection.

3.5 A Simplified Case

An analytical solution to the social planner's problem can only be obtained if the problem is specified in the following form with a linear utility function:

$$\begin{aligned} \max_{\{C_t, K_{t+1}, l_{ft}, l_{it}\}} \quad & \sum_{t=0}^{\infty} \beta^t [C_t - \eta E_t] \\ \text{subject to} \quad & C_t + K_{t+1} = (1-\tau)\theta_f {K_t}^{\alpha}(1 - l_{it})^{1-\alpha} + (1 - \rho\tau)\theta_i l_{it}^{\gamma} + T_t \\ & E_t = \mu_f \theta_f {K_t}^{\alpha}(1 - l_{it})^{1-\alpha} + \mu_i \theta_i l_{it}^{\gamma} \\ & \text{given } K_0, \mu_f, \mu_i \\ & C_t > 0 \end{aligned} \tag{10}$$

The first order conditions to this simplified problem are as follows:

$$C_t : \beta^t - \lambda_t = 0 \tag{11}$$

$$C_{t+1} : \beta^{t+1} - \lambda_{t+1} = 0 \tag{12}$$

$$K_{t+1} : -\beta^{t+1}\eta\mu_f\alpha\theta_f {K_{t+1}}^{\alpha-1}(1-l_{t+1})^{1-\alpha} - \lambda_t + \lambda_{t+1}[(1-\tau)\alpha\theta_f {K_{t+1}}^{\alpha-1}(1-l_{t+1})^{1-\alpha}] = 0 \tag{13}$$

$$\begin{aligned} l_{it} : &-\beta^t\eta[\gamma\mu_i\theta_i {l_{it}}^{\gamma-1} - (1-\alpha)\mu_f\theta_f {K_t}^{\alpha}(1-l_{it})^{-\alpha}] \\ &+ \lambda_t[\gamma(1-\rho\tau)\theta_i {l_{it}}^{\gamma-1} - (1-\alpha)(1-\tau)\theta_f {K_t}^{\alpha}(1-l_{it})^{-\alpha}] = 0 \end{aligned} \tag{14}$$

$$\lambda_t : (1-\tau)\theta_f {K_t}^{\alpha}(1-l_{it})^{1-\alpha} + (1-\rho\tau)\theta_i l_{it}^{\gamma} - C_t - K_{t+1} = 0 \tag{15}$$

Imposition of steady state and combination of (11), (12) and (13) yields the following:

$$K^* = (1-{l_i}^*)\left[\beta\alpha\theta_f[(1-\tau)-\eta\mu_f]\right]^{\frac{1}{1-\alpha}} \tag{16}$$

According to (16), the steady state capital level is negatively related to the steady state informal labor level.

Plugging (16) into (14) yields:

$${l_i}^* = \left[\frac{\gamma\theta_i[(1-\rho\tau)-\eta\mu_i]}{[(1-\tau)-\eta\mu_f](1-\alpha)\theta_f(\beta\alpha\theta_f[(1-\tau)-\eta\mu_f])^{\frac{\alpha}{1-\alpha}}}\right]^{\frac{1}{1-\gamma}} \tag{17}$$

The steady state informal labor level is negatively related to the coefficient of tax enforcement on informal sector ρ, the coefficient of disutility from pollution η and informal sector's marginal pollution propensity μ_i; while it is positively related to informal sector's TFP and the decreasing return to scale parameter γ.

Combination of (16) and (17) gives:

$$E^* = \mu_f \theta_f \left[\beta \alpha \theta_f [(1-\tau) - \eta \mu_f] \right]^{\frac{\alpha}{1-\alpha}} (1 - l_i{}^*) + \mu_i \theta_i l_i{}^{*\gamma} \tag{18}$$

where the steady state environmental pollution level depends on the steady state informal labor level, both sectors' total factor productivities and marginal pollution propensities. Equation (18) also clearly illustrates the deregulation and scale effects of informality on pollution. Keeping the equation (16) in mind, the first term in (18) simply a linear function capital stock (which given equation 16 is a linear function of informal labor thereby a convex function of informal output) and the second term is simply a linear function of informal output. Therefore, we observe the deregulation effect in the second term and the scale effect in the first term.

The derivative of the steady state environmental pollution with respect to steady state informal labor is the following:

$$\frac{dE^*}{dl_i{}^*} = -\mu_f \theta_f \left[\beta \alpha \theta_f [(1-\tau) - \eta \mu_f] \right]^{\frac{\alpha}{1-\alpha}} + \mu_i \theta_i \gamma \left[\frac{[(1-\tau) - \eta \mu_f](1-\alpha)\theta_f (\beta \alpha \theta_f [(1-\tau) - \eta \mu_f])^{\frac{\alpha}{1-\alpha}}}{\gamma \theta_i [(1-\rho\tau) - \eta \mu_i]} \right] \tag{19}$$

As it can be observed from equation (19) and Figure 1, the sign of $dE^*/dl_i{}^*$ depends on the parameter for tax enforcement ρ since the positive term in equation (19) is positively related to ρ. As a result, in a setting where $dE^*/dl_i{}^*$ is initially positive, a decrease in ρ decreases $dE^*/dl_i{}^*$. After a threshold level of ρ, $dE^*/dl_i{}^*$ becomes negative and this creates an inverse-U shaped relationship between E^* and $l_i{}^*$ that is displayed in Figure 1.

3.6 General Case: Numerical Simulations

In the above-presented simplified case with linear utility could obtain analytical results which helped us to associate pollution to informal sector size. Now, in this subsection we are after obtaining similar results after dropping the linear utility assumption. Then, we use a more general utility function which is strictly concave in both of its arguments.

Specifically, the social planners problem now becomes the following:

$$\max_{\{C_t,K_{t+1},l_{ft},l_{it}\}} \quad \sum_{t=0}^{\infty}\beta^t[log(C_t)-\eta\frac{{E_t}^{\phi}}{\phi}] \tag{20}$$

$$\text{subject to} \quad C_t+K_{t+1}-(1-\delta)K_t=(1-\tau)\theta_f {K_t}^{\alpha}(1-l_{it})^{1-\alpha}+(1-\rho\tau)\theta_i l_{it}^{\gamma}+T_t$$

$$E_t=\mu_f\theta_f {K_t}^{\alpha}(1-l_{it})^{1-\alpha}+\mu_i\theta_i l_{it}^{\gamma}$$

$$\text{given } K_0,\mu_f,\mu_i$$

$$C_t>0,\eta>0,\phi>1$$

Unfortunately, without further simplification we cannot obtain an analytical solution to this problem. This is why we rely on numerical simulations in this case.

To evaluate the performance of the model we normalize μ_f to unity and experiment a set of values for μ_i. The simulation below uses the value $\mu_i = 2$ as we try to match the average informal sector size in in the dataset we use in the empirical section, i.e. we try to match $\frac{\theta_i I(l_{it})}{\theta_f F(K_t,l_{ft})}$=34.60%. The values for η and ϕ are 1 and 2, respectively. For other parameters, we used the values specified in Ihrig and Moe (2004). These are $\alpha = 0.33$, $\gamma = 0.495$, $\beta = 0.96$, $\theta_F = 2.10$, $\theta_i = 55.30$, $\tau = 0.093$ and $\delta = 0.08$.

Once we decide on these values for the parameters, we start to vary ρ from 1 to 0, i.e. reduce the tax enforcement parameter to create a variation in informal labor and hence informal sector size. The result of the simulation given in Figure 2 shows that there is an inverse-U relationship between steady state pollution and informal labor in the general case. Notice that this is in line with our empirical analysis in the previous section of the paper.

The suggested nonlinear relationship between the informal sector size and pollution has important policy consequences. In this section we focus on two specific policy tools which can be easily used within theoretical model presented in the previous section. These are varying the tax burden (τ) and the level of tax enforcement (ρ). Specifically, we study the behavior of steady state environmental pollution with respect to changes in tax levels and the level of tax enforcement with the parameters set above. Other than the fixed parameters as specified in the previous subsection, we vary τ and ρ and note the behavior of various endogenous variables in percentage deviations from their steady state levels. The results of policy changes with respect to the level and enforcement of taxes are presented in tables 7 and 8, respectively.

Tables 7 and 8 about here

In Table 7, as opposed to keeping it constant at $\tau = 0.093$ as in the previous subsetion, we vary the tax rate between 0 and 40% and present how various variables differ from their steady state value with $\tau = 0.093$. Increasing τ not surprisingly reduces the capital stock and formal GDP and increases the size of the informal sector. The effect on pollution however is nonlinear. A similar result is obtained in Table 8 when we vary ρ.[11]

When the two policy tools are compared, we observe that increasing the level of tax enforcement is more effective than varying taxes. However, one should definitely take into account the presence of nonlinearities when using this policy agains pollution. For example, an insufficient increase in tax enforcement can actually aggravate pollution instead of reducing it. Nevertheless, compared to increasing the level of taxes, increasing the level of tax enforcement does not reduce real GDP and boost informal economy. Moreover, we should also notice that from a policy point of view, varying enforcement is much more easier than varying taxes as the latter requires a lengthier political process compared to the former.

4 Conclusion

In this paper, drawing motivation from the environmental Kuznets curve literature, we explore the relationship between informality and environmental pollution. First, we run

[11] The biggest effect occurs when we also allow ρ to take a value bigger than 1. Similar to Ihrig and Moe (2004), in this case ρ can be interpreted as a large penalty imposed on the informal sector when caught evading taxes.

cross-country panel regressions for different environmental pollution variables with informality and various other explanatory variables, and observe an inverse-U shaped relationship between pollution and informality. We also conduct systems estimations among pollution variables and key explanatory variables in order to understand the mechanism of this nonlinear relationship between the informal sector size and environmental pollution, specifically to investigate the two possible effects related to the informal sector, namely the scale effect and the deregulation effect, that may give rise to an inverse-U shaped relationship between pollutant emissions and the informal sector size. The results which indicate a positive correlation between pollutant emissions and the informal sector size validate our identification of deregulation effect, while the negative correlation between capital intensity (which is positively correlated with emissions) and informal sector size confirms the existence of the scale effect.[12] Building upon these empirical results, we also build a two sector dynamic general equilibrium model with a variable degree of tax enforcement on informal sector. Our analytical and numerical results show that the enforcement of taxes is the key policy tool to reduce pollution when taking this nonlinearity into account.

We yield that our empirical findings and theoretical construct are highly aggregate and further and deeper investigation is very much needed, especially in microeconomic (firm or household) level. These we intend to leave to future research.

[12] Throughout the paper we implicitly assume that the pollution emissions statistics represent both formal and informal economies. However, even if the emissions only measure pollution of the formal sector (and not of the informal sector), the mechanism we propose would work. When the size of the informal sector gets larger, the economy wide capital-output ratio would fall and this would simply imply less pollution (scale effect at work). Moreover, considering that a large informal sector is usually a product of policy deficiencies (such as insufficient enforcement, bad governance etc.) these would imply that the environmental regulations on the informal sector are also insufficiently enforced, which would then create incentive even for formal producers to pollute more. (deregulation effect at work.) So, even in this extreme case, where pollutions statistics only represent formal economy, we believe that the mechanism we propose will work.

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Appendix: Figures and Tabels

Figure 1

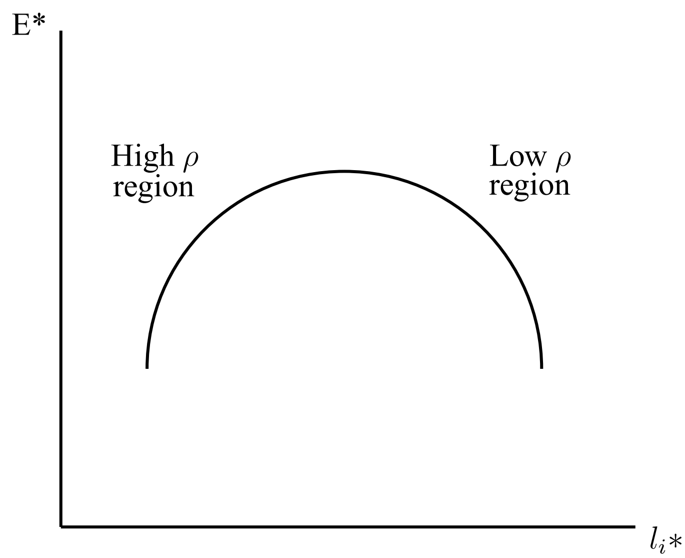

Figure 2

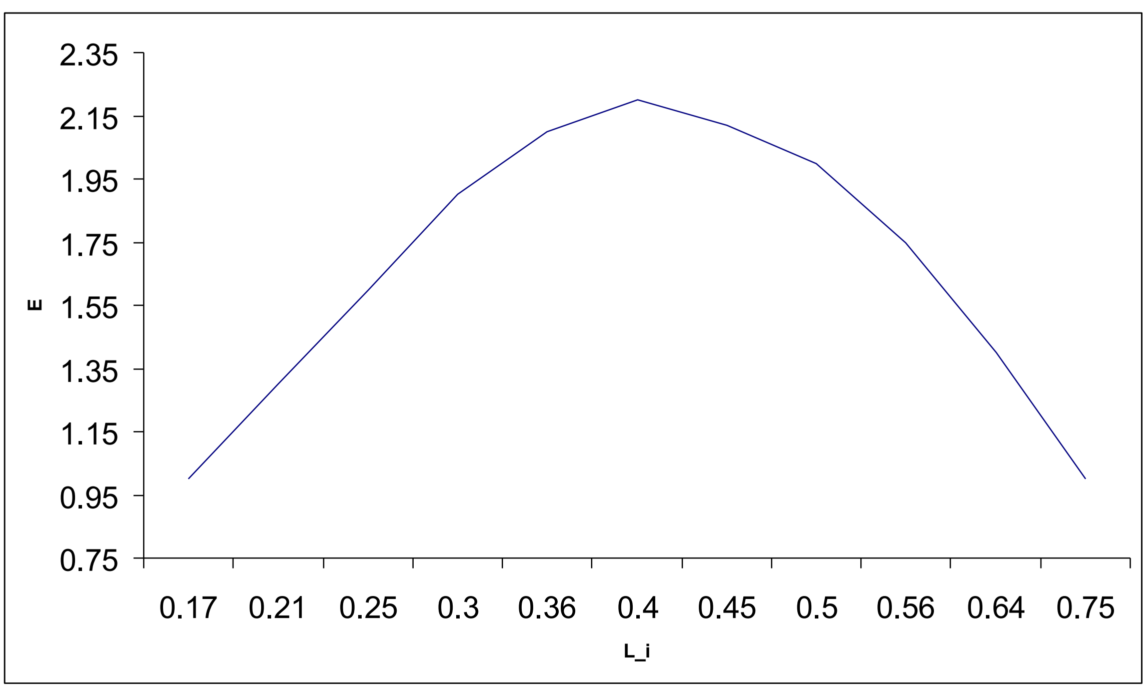

Table 1: Complete Dataset Summary Statistics

	Mean	Std. Deviation	Minimum	Maximum
CO_2	5.21459	7.07	0.01	64.17
SO_2	0.02	0.03	0.00	0.20
EUI	2483.97	2934.34	127.64	22336.45
Informal Sector Size (in %)	34.60	13.54	8.4	72.5
Law and Order Index	3.88	1.34	.5	6
Democracy Index	3.99	1.68	0	6
Bureaucracy	2.22	1.10	0	4
Corruption	2.77	1.22	0	6
Openness	89.54	52.52	4.83	453.44
Capital-Output Ratio	2.33	1.96	-18.37	10.90
Productivity	492.97	313.49	52.11	1849.26
Government exp.	15.21	5.68	2.28	42.95
GDP per-capita	7133.87	10400.38	80.62	56624.73
Growth in GDP per-capita	3.10	5.50	-32.33	56.40

Table 2: CO_2 Emissions and Shadow Economy

(Dependent Variable: CO_2)

	Panel	Panel	Panel	Panel	Panel	Panel	Panel
Constant	-6.577***	-5.595***	-5.369***	-4.964***	-6.340***	-6.230***	-6.473***
	(0.000)	(0.000)	(0.000)	(0.004)	(0.000)	(0.000)	(0.000)
Informal	0.511***	0.538***	0.526***	0.280*	0.287*	0.268*	0.283*
	(0.000)	(0.000)	(0.000)	(0.096)	(0.093)	(0.098)	(0.077)
$Informal^2$	-0.0045***	-0.0047***	-0.0045***	-0.0030*	-0.0030*	-0.0030*	-0.0030*
	(0.003)	(0.004)	(0.004)	(0.074)	(0.077)	(0.085)	(0.081)
Law		-0.188*	-0.197*	-0.215*	-0.217*	-0.218*	-0.197*
		(0.071)	(0.062)	(0.052)	(0.059)	(0.054)	(0.077)
Democracy			0.0385	0.0657	0.0796	0.0802	
			(0.615)	(0.395)	(0.317)	(0.311)	
Productivity				0.0089***	0.0087***	0.0084***	0.0080***
				(0.000)	(0.000)	(0.000)	(0.000)
Capital				0.791***	0.745***	0.725***	0.839***
				(0.007)	(0.020)	(0.021)	(0.006)
Growth				-0.0057	-0.0087	-0.008	
				(0.408)	(0.241)	(0.245)	
Corruption				-0.0171	-0.0264		
				(0.838)	(0.762)		
Bureaucracy				-0.0273	-0.0052		
				(0.927)	(0.986)		
Gdp				-0.0001	-0.00007		
				(0.462)	(0.679)		
Gdp^2				1.30e-09	7.60e-10		
				(0.593)	(0.759)		
Government exp.					0.0702***	0.0718***	0.0656***
					(0.007)	(0.005)	(0.010)
Openness							
Overall R-sq	0.322	0.3127	0.3146	0.3234	0.3882	0.4573	0.3991
Observations	1475	1324	1321	1307	1267	1267	1270
F-test	10.35	7.45	5.52	5.02	5.20	7.78	10.29

Robust standard errors are reported in parentheses. ***, **, * denote 1, 5, and 10% confidence levels, respectively.

Table 3: SO_2 Emissions and Shadow Economy

(Dependent Variable: SO_2)

	Panel	Panel	Panel	Panel	Panel	Panel	Panel
Constant	-0.0381***	-0.0360***	-0.0356***	-0.0495***	-0.0535***	-0.0559***	-0.0381***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Informal	0.0028***	0.0027**	0.0029***	0.0029**	0.0030**	0.0030**	0.0028**
	(0.009)	(0.013)	(0.010)	(0.032)	(0.033)	(0.033)	(0.037)
$Informal^2$	-0.000025**	-0.000025**	-0.000026**	-0.000026**	-0.000026**	-0.000026**	-0.000026**
	(0.033)	(0.047)	(0.036)	(0.067)	(0.073)	(0.073)	(0.066)
Law		-0.0001	-0.00002	-0.00009	-0.0001	-0.00009	
		(0.843)	(0.974)	(0.881)	(0.872)	(0.882)	
Democracy			-0.00064	-0.00075	-0.00077	-0.00087*	-0.00077*
			(0.160)	(0.103)	(0.104)	(0.069)	(0.094)
Productivity				0.000027**	0.000028**	0.00003**	0.000024**
				(0.029)	(0.027)	(0.024)	(0.045)
Capital				0.0025	0.0029	0.0030	
				(0.288)	(0.230)	(0.225)	
Growth				-0.000065*	-0.00007*	-0.000077*	-0.00008**
				(0.092)	(0.079)	(0.062)	(0.029)
Corruption				-0.000045	1.31e-07	1.86e-06	
				(0.922)	(1.000)	(0.995)	
Bureaucracy				0.0016	0.0017	0.0018	
				(0.295)	(0.292)	(0.270)	
Gdp				-1.83e-06	-1.75e-06	-1.86e-06	-1.23e-06*
				(0.295)	(0.289)	(0.257)	(0.074)
Gdp^2				1.23e-11	1.13e-11	9.86e-12	
				(0.624)	(0.659)	(0.697)	
Government exp.					0.00009	0.00010	
					(0.525)	(0.451)	
Openness						0.000038	0.000032
						(0.111)	(0.165)
Overall R-sq	0.0500	0.0421	0.0422	0.0071	0.0061	0.0035	0.0037
Observations	1039	992	988	982	982	982	982
F-test	4.09	2.57	2.33	1.69	1.63	1.72	2.61

Robust standard errors are reported in parentheses. ***, **, * denote 1, 5, and 10% confidence levels, respectively.

Table 4: EUI Emissions and Shadow Economy

(Dependent Variable:Energy Use Intensity)

	Panel	Panel	Panel	Panel	Panel	Panel	Panel	Panel
Constant	-4197.1***	-4147.8***	-4128.8***	-4124.1***	-3251.6***	-3455.5***	-3534.7***	-4391.5***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Informal	302.82***	326.30***	325.28***	260.54***	190.67***	192.64***	185.41***	325.47***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.001)	(0.001)	(0.002)	(0.000)
$Informal^2$	-2.645***	-2.876***	-2.871***	-2.402***	-1.829***	-1.831***	-1.768***	-2.886***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.002)	(0.002)	(0.003)	(0.000)
Law		-79.28*	-80.00*	-87.75***	-82.37**	-85.53**	-85.9**6	-80.84***
		(0.010)	(0.010)	(0.009)	(0.013)	(0.014)	(0.013)	(0.009)
Democracy			4.007	3.157	3.807	4.503	-1.073	
			(0.862)	(0.894)	((0.872)	(0.853)	(0.965)	
Productivity				1.702***	0.576	0.530	0.611	
				(0.002)	(0.342)	(0.399)	(0.330)	
Capital				242.95**	213.49*	199.25*	182.82	184.99
				(0.037)	(0.065)	(0.087)	(0.129)	(0.132)
Growth				0.396	1..055	0.816	0.476	
				(0.842)	(0.594)	((0.707)	(0.826)	
Corruption				10.44	8.98	8.64	5.86	
				(0.655)	(0.699)	(0.722)	(0.808)	
Bureaucracy				-0.137	7.665	9.061	12.787	
				(0.999)	(0.928)	(0.916)	(0.881)	
Gdp					0.192***	0.201***	0.195***	
					(0.003)	(0.003)	(0.004)	
Gdp^2					-1.24e-06	-1.31e-06	-1.40e-06	
					(0.173)	(0.156)	(0.130)	
Government exp.						11.66	12.01	
						(0.139)	(0.126)	
Openness							2.801**	2.066**
							(0.015)	(0.024)
Overall R-sq	0.3068	0.2978	0.2979	0.1171	0.0773	0.0786	0.0968	0.2895
Observations	1283	1217	1214	1200	1200	1166	1166	1211
F-test	25.06	18.54	13.81	8.59	8.00	7.31	7.22	12.26

Robust standard errors are reported in parentheses. ***, **, * denote 1, 5, and 10% confidence levels, respectively.

Table 5: CO2, Capital and Informal Sector: Systems Estimations

	OLS			GMM		
Dependent Variable	CO2	Capital	Informal	CO2	Capital	Informal
Informal	0.72***	-0.27**		0.93***	-0.26**	
	(0.23)	(0.13)		(0.29)	(0.12)	
$Informal^2$		-0.03***			-0.02**	
		(0.01)			(0.01)	
Capital	1.11***			1.31***		
	(0.29)			(0.33)		
Democracy	-0.44*			-0.40		
	(0.11)			(0.40)		
GDP	0.35***			0.20***		
	(0.04)			(0.03)		
Openness	0.02**			0.02		
	(0.01)			(0.02)		
GDP^2	-0.0007**			-0.0005**		
	(0.0003)			(0.0002)		
Pop. Density	-0.01			-0.01		
	(0.04)			(0.01)		
Growth		0.20***			0.30**	
		(0.05)			(0.14)	
Gov. Exp.		-0.18			-0.17**	
		(0.15)			(0.09)	
Enforcement			-1.18***			-1.04***
			(0.38)			(0.30)
Corruption			0.34			-0.34
			(0.47)			(0.27)
Bureaucracy			-5.99***			-2.99***
			(0.75)			(0.41)
Tax			0.06			-0.04
			(0.06)			(0.05)
R-squared	0.51	0.32	0.50	0.59	0.74	0.55
Observations	1440	1588	982	1287	1438	832

Standard errors are in parentheses. ***, **, * denote 1, 5, and 10% confidence levels, respectively. In all regressions, a constant is also included but not reported.

Table 6: SO2, Capital and Informal Sector: Systems Estimations

	OLS			GMM		
Dependent Variable	SO2	Capital	Informal	SO2	Capital	Informal
Informal	0.25**	-0.25***		0.31***	-0.26***	
	(0.11)	(0.05)		(0.07)	(0.06)	
Informal^2		-0.03***			-0.02**	
		(0.01)			(0.01)	
Capital	0.78***			0.31***		
	(0.19)			(0.04)		
Democracy	-0.04**			-0.04		
	(0.02)			(0.04)		
GDP	0.01***			0.02***		
	(0.003)			(0.004)		
Openness	0.01			0.003***		
	(0.01)			(0.001)		
GDP^2	-0.00007*			-0.0005***		
	(0.00001)			(0.0001)		
Pop. Density	-0.001			-0.01		
	(0.001)			(0.007)		
Growth		0.21***			0.31***	
		(0.06)			(0.12)	
Gov. Exp.		-0.16			-0.17	
		(0.16)			(0.11)	
Enforcement			-1.18***			-1.05***
			(0.39)			(0.29)
Corruption			0.35			-0.34
			(0.48)			(0.29)
Bureaucracy			-5.98***			-2.99***
			(0.75)			(0.40)
Tax			0.05			-0.04
			(0.06)			(0.04)
R-squared	0.13	0.24	0.55	0.19	0.28	0.49
Observations	1104	1588	982	953	1438	832

Standard errors are in parentheses. ***, **, * denote 1, 5, and 10% confidence levels, respectively. In all regressions, a constant is also included but not reported.

Table 7

Varying taxes while holding enforcement constant (ρ=0)

Tax rate (τ)	0.00	0.10	0.20	0.30	0.40
%Δ in Capital (K)	0.17	-0.05	-0.30	-0.52	-0.75
%Δ in Real GDP (Y)	0.10	-0.04	-0.19	-0.42	-0.80
%Δ in Informal Output (Y_i/Y)	-0.20	0.01	0.27	0.55	2.10
%Δ in Pollution (E)	-0.04	0.02	0.10	-0.16	-0.23

Percentage deviation from the initial steady state value

Table 8

Varying enforcement while holding taxes constant (τ=0.093)

Enforcement (ρ)	0.05	0.10	0.25	0.5	0.75	2
%Δ in Capital (K)	0.01	0.02	0.04	0.10	0.47	0.79
%Δ in Real GDP (Y)	0.01	0.02	0.04	0.06	0.08	0.11
%Δ in Informal Output (Y_i/Y)	-0.02	-0.06	-0.14	-0.27	-0.39	-0.57
%Δ in Pollution (E)	0.01	0.03	0.06	0.02	-0.01	-0.29

Percentage deviation from the initial steady state value