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Is Environmentally Sustainable Growth Being Achieved in China? An Analysis of Pollution Emission as a Production Input

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Abstract: It is argued that China's economic growth in the recent decades has been relying too much on environmental inputs. In this paper, we study the contribution of pollution emission as an environmental input to the growth of China's output. We base our empirical analysis on a relevant theoretical framework of environmentally sustainable growth. Our regression exercise produces a relatively high value of the elasticity of output with respect to pollution emission. Given our estimation results, we are quite concerned that environmentally friendly economic growth is not being sustained in China. Relevant policy measures regarding pollution emissions and pollution abatement are therefore urgently called for.
Keywords: sustainable growth; environment; pollution emission; production input
JEL Classifications: O13; O47; O53.

1. Introduction

There have been prevailing concerns over the negative environmental consequences of the rapid economic growth in China. It is argued that China's economic growth in the recent decades has been relying too heavily on environmental inputs. The excessive use of environmental inputs is seemingly posing serious threats to China's water, air, forests, bio-system, and energy supplies [1], leading to bad consequences such as environmental deterioration and resource degradation. Total annual direct losses from such environmental damages were estimated to take up to ten percent of total annual income of China (see, for example, [2], [3] and [4]).

In this paper, we empirically study the contribution of pollution (carbon) emission as an environmental input to the growth of China's output. We base our empirical analysis on a theoretical framework of environmentally sustainable growth.

2. The Theoretical Framework

We follow [5] and consider an augmented version of the Solow growth model that regards the flow of pollution emissions as a production input. The aggregate production function takes the form

$$Y = K^{\alpha}(AL)^{\beta}(BZ)^{\gamma} \tag{1}$$

where Y is output, K is capital, L is labor input, and A is the level of labor-augmenting technology. We assume constant returns to scale with respect to K, AL and BZ, that is, $\alpha+\beta+\gamma=1$. The production function (1) conveniently takes pollution emissions as a factor of production, where Z stands for a flow of pollution emissions that can be kept constant at different levels, which are dependent on policy considerations and technological conditions. B is the level of technology that augments the efficiency of pollution emissions as a production input. We further model that L, A and B grow exogenously at rates n, g and b, that is, $g_L \equiv \dot{L}/L = n$, $g_A \equiv \dot{A}/A = g$ and $g_B \equiv \dot{B}/B = b$, where a dot overhead denotes the time derivative.[1]

[1] In this study, we use g_X ($\equiv \dot{X}/X$) to denote the growth rate of variable X over time.

Taking advantage of the constant-returns-to-scale structure of (1), we can rewrite the production function compactly in per worker (per unit of labor) terms as[2]

$$y = k^{\alpha} A^{\beta} (Bz)^{\gamma} \tag{2}$$

where we define $y \equiv Y/L$, $k \equiv K/L$ and $z \equiv Z/L$. Equation (2) in turn implies

$$g_y = \alpha g_k + \beta g + \gamma(b-n) \tag{3}$$

where we (temporarily) hold the level of the flow of pollution emissions Z constant. We can show that the economy converges to a steady state (balanced growth path). Define the capital-output ratio as $\psi \equiv K/Y = k/y$. Equation (2) gives

$$\psi = k^{1-\alpha} A^{-\beta} (Bz)^{-\gamma} \tag{4}$$

which in turn implies

$$g_{\psi} = (1-\alpha) g_k - \beta g - \gamma(b-n) \tag{5}$$

where $g_k = g_K - n$ by construction.

As the dynamics of K follows $\dot{K} = sY - \delta K$, where s and δ are the investment rate and depreciation rate respectively, we must have

$$g_k = g_K - n = \frac{s}{\psi} - \delta - n \tag{6}$$

which we insert back into (5) to get the following

$$\dot{\psi} = (1-\alpha)s - \lambda \psi \tag{7}$$

with $\lambda \equiv (1-\alpha)\delta + \beta(n+g) + \gamma b > 0$. It then can be seen that ψ converges to a steady state value of

$$\psi^* = \frac{(1-\alpha)s}{\lambda} \tag{8}$$

which in turn implies that on the balanced growth path, per worker capital k and per worker output y grow at the same rate. Resorting back to equation (3), we obtain this steady state growth rate of per worker capital and per worker output

$$g_k^* = g_y^* = \frac{\beta g + \gamma(b-n)}{1-\alpha} \equiv \xi \tag{9}$$

where the value of the growth rate is denoted by ξ. Similarly, the growth rates of K and Y (where $g_K = g_k + n$ and $g_Y = g_y + n$ by construction) also take the same value on the balanced growth path, which is

$$g_K^* = g_Y^* = \frac{\beta(n+g) + \gamma b}{1-\alpha} = \xi + n \tag{10}$$

With a bit of rearrangement, the production function in (1) can be rewritten as

$$Y = \psi^{\alpha/(1-\alpha)} (AL)^{\beta/(1-\alpha)} (BZ)^{\gamma/(1-\alpha)} \tag{11}$$

If we further define

$$\tilde{y} \equiv Y / [(AL)^{\beta/(1-\alpha)} (BZ)^{\gamma/(1-\alpha)}] \tag{12}$$

$$\tilde{k} \equiv K / [(AL)^{\beta/(1-\alpha)} (BZ)^{\gamma/(1-\alpha)}] \tag{13}$$

Then according to (1), we have

[2] For simplicity, we can assume that each worker owns one unit of labor.

$$\tilde{y} = \tilde{k}^{\alpha} \tag{14}$$

The dynamics of K, that is, $\dot{K} = sY - \delta K$, implies that the steady state in terms of $\tilde{k}$ and $\tilde{y}$ can be expressed as

$$\tilde{k}^{*} = \left[\frac{(1-\alpha)s}{\lambda}\right]^{1/(1-\alpha)} \tag{15}$$

$$\tilde{y}^{*} = \left[\frac{(1-\alpha)s}{\lambda}\right]^{\alpha/(1-\alpha)} \tag{16}$$

where we note that $\lambda/(1-\alpha) = \delta + \xi + n$.

Therefore, for any specific level of Z, it is easily shown that on the balanced growth path, aggregate output grows according to

$$Y^{*}(t;Z) = \left[\frac{(1-\alpha)s}{\lambda}\right]^{\alpha/(1-\alpha)} (A_0 L_0)^{\beta/(1-\alpha)} (B_0 Z)^{\gamma/(1-\alpha)} e^{(\xi+n)t} \tag{17}$$

where the initial values of A, L and B are denoted A_0, L_0 and B_0. By the same reasoning, on the balanced growth path, per worker output grows according to

$$y^{*}(t;Z) = \left[\frac{(1-\alpha)s}{\lambda}\right]^{\alpha/(1-\alpha)} A_0^{\beta/(1-\alpha)} (B_0 Z / L_0)^{\gamma/(1-\alpha)} e^{\xi t} \tag{18}$$

where we can see that $\partial y^{*}/\partial Z > 0$ and $\partial^2 y^{*}/\partial Z^2 < 0$. Thus, ceteris paribus, an increase in the pollution emissions input raises the steady state level of (per worker) output at a decreasing rate. As the variable Z can be understood as a policy variable, the level of Z can thus be chosen based on considerations on the tradeoff between economic growth and the environmental quality.

We further assume that the stock of pollution, denoted D, accumulates according to

$$\dot{D} = Z - \rho D \tag{19}$$

where $\rho > 0$ is the natural rate of regeneration and $D = 0$ represents a pristine environment with a zero pollution stock. For the environmental quality to improve, the level of the policy variable Z should be chosen (at each point in time) so that $\dot{D} < 0$. If we assume that on the balanced growth path discussed above, the stock of environmental pollution should decrease, say, at a constant rate, then the level of Z should be chosen so that Z decreases at the same rate as D.[3] Suppose that on the balanced growth path, $g_D^{*} = g_Z^{*} = -m$, and the level of Z is chosen so that $Z(t) = Z_0 e^{-mt}$, where $0 < m < \rho$, then equation (18) can be rewritten as

$$y^{*}(t) = \left[\frac{(1-\alpha)s}{\lambda}\right]^{\alpha/(1-\alpha)} A_0^{\beta/(1-\alpha)} (B_0 Z_0 / L_0)^{\gamma/(1-\alpha)} e^{\vartheta t} \tag{20}$$

where $\vartheta \equiv [\beta g + \gamma(b - n - m)]/(1-\alpha)$, and Z_0 denotes the level of Z at time zero. Given (19) and (20), we can see that long-run green growth requires

$$\beta g + \gamma(b - n - m) > 0 \tag{21}$$

which implies that in the long run, sufficiently large values of g and b are necessary for environmentally sustainable economic growth.

3. Econometric Modeling

[3] This is because according to (19), $g_D = Z/D - \rho$. Then Z/D must be a constant on the balanced growth path if g_D is assumed to be a constant on the balanced growth path.

We can now move from the theoretical setup to our econometric modeling. Approximating around the steady state $\tilde{y}^*$, the speed of convergence of $\tilde{y}$ is given by

$$\frac{d\ln\tilde{y}(t)}{dt} = \lambda[\ln\tilde{y}^* - \ln\tilde{y}(t)] \quad (19)$$

in which $\lambda = (1-\alpha)\delta + \beta(n+g) + \gamma b > 0$, as given earlier. Equation (19) implies

$$\ln\tilde{y}(t_2) = (1-e^{-\lambda\tau})\ln\tilde{y}^* + e^{-\lambda\tau}\ln\tilde{y}(t_1) \quad (20)$$

where $\tilde{y}(t_1)$ and $\tilde{y}(t_2)$ are values of $\tilde{y}(t)$ at time t_1 and t_2 ($t_1 < t_2$), and $\tau = (t_2 - t_1)$. Equation (20) can then be rewritten in per worker terms as

$$\begin{aligned}\ln y(t_2) &= e^{-\lambda\tau}\ln y(t_1) + (1-e^{-\lambda\tau})\frac{\alpha}{1-\alpha}\ln s - (1-e^{-\lambda\tau})\frac{\alpha}{1-\alpha}\ln(n+\xi+\delta) \\ &+ (1-e^{-\lambda\tau})\frac{\gamma}{1-\alpha}\ln Z + (1-e^{-\lambda\tau})\ln V_0 + \xi(t_2 - e^{-\lambda\tau}t_1)\end{aligned} \quad (21)$$

where $V_0 \equiv A_0^{\beta/(1-\alpha)}(B_0/L_0)^{\gamma/(1-\alpha)}$. Another version of equation (21) can be written as

$$\begin{aligned}\ln y(t_2) &= e^{-\lambda\tau}\ln y(t_1) + (1-e^{-\lambda\tau})\frac{\alpha}{1-\alpha}\ln s - (1-e^{-\lambda\tau})\frac{\alpha}{1-\alpha}\ln(n+\xi+\delta) \\ &+ (1-e^{-\lambda\tau})\frac{\gamma}{1-\alpha}\ln z + (1-e^{-\lambda\tau})\ln W_0 + \chi(t_2 - e^{-\lambda\tau}t_1)\end{aligned} \quad (22)$$

where we substitute the per worker term $z \equiv Z/L$ for the aggregate-level variable Z in (21), and define $W_0 \equiv A_0^{\beta/(1-\alpha)}B_0^{\gamma/(1-\alpha)}$ and $\chi \equiv (\beta g + \gamma b)/(1-\alpha)$. Equation (21) or (22) forms the basis for our subsequent empirical analysis. The final choice between the two models (i.e. (21) and (22)) will hinge on whether the aggregate-level, Z, or the per worker level, z, represents a better policy variable concerning the emission standard that is assumed to remain relatively stable over the interval $\tau = (t_2 - t_1)$.

A regression model of a panel data structure that is directly based on (22) (or otherwise on (21)) can be expressed as

$$\bar{y}_{it} = \pi\bar{y}_{i,t-1} + \sum_{j=1}^{3}\varphi_j x_{it}^j + \eta_t + c_i + \varepsilon_{it} \quad (23)$$

where the first subscript i indexes the province and the second subscript t indexes the time period defined. $\bar{y}_{it}$ and $\bar{y}_{i,t-1}$ correspond to $\ln y(t_2)$ and $\ln y(t_1)$ in (22), with $\pi \equiv e^{-\lambda\tau}$. The x_{it}^j's are respectively $\ln s$, $\ln(n+\xi+\delta)$ and $\ln z$ in (22). The term c_i is the time-constant province heterogeneity that captures $(1-e^{-\lambda\tau})\ln W_0$ in (22), η_t is the time-variant intercept taking account of the $\chi(t_2 - e^{-\lambda\tau}t_1)$ term in (22), and finally ε_{it} is a zero-mean idiosyncratic error that varies across provinces and over time periods.

However, such a regression setup confronts us with several practical issues. First, a circularity exists: one major purpose of our regression analysis is estimating the unknown values of the structural parameters α and β, but the value of ξ in the explanatory variable $\ln(n+\xi+\delta)$ is unknown because it depends on the (unknown) values of α and β. Second, the value of λ is dependent on the level of n, which varies across provinces and over time. This is to say that the coefficients on the three explanatory variables are not fixed, but are variant across provinces and over time. Third, the model in (23) directly follows the Cobb-Douglas form of the production function in (1) and related assumptions (one of which is the assumption of constant returns to scale).

The challenging issues above thus motivate us to modify our model in (23) accordingly to make it econometrically tractable. One central issue is to determine the likely value of the unknown parameter ξ. To carry out our preliminary round of regression exercise, we temporarily assume $\xi = 0.02$. Later we will run more regressions using different assumed values of ξ as a sensitivity analysis and robustness check. As a result, our benchmark regression specification is now written explicitly as

$$\ln y_{i,t+1} = e^{-\lambda\tau} \ln y_{it} + (1-e^{-\lambda\tau}) \frac{\alpha}{1-\alpha} \ln s_{it} - (1-e^{-\lambda\tau}) \frac{\alpha}{1-\alpha} \ln(n_{it} + 0.05) \tag{24}$$
$$+ (1-e^{-\lambda\tau}) \frac{\gamma}{1-\alpha} \ln x_{it} + c_i + \eta_t + \varepsilon_{it}$$

where we have assumed a unified value of the depreciation rate (across provinces and over time) that is $\delta = 0.03$ (see, for example, [6] and [7]). The variable x_{it} is a certain choice of the pollution variable to be specified later, which is either directly related to Z in (21) or z in (22).

4. The Data and Empirical Results

Our sample includes 28 provincial-level regions (provinces for short) in the mainland of China over the period of 1997–2013. Except for the variable x_{it}, data on all the other variables in equation (24) can be straightforwardly obtained from relevant official publications of the National Bureau of Statistics of China. However, exact annual data on provincial (per capita) pollution emission are hard to come by directly. We therefore use carbon emission as a proxy for general pollution emission. A feasible measure of annual per capita carbon emission can be constructed in the following way

$$x_{it} = \sum_j \frac{E_{jit}}{E_{it}} \cdot \frac{x_{jit}}{E_{jit}} \cdot E_{it} = \sum_j S_{jit} \cdot F_{jit} \cdot E_{it} \tag{25}$$

where x_{it} is per capita carbon emission, E_{it} is total energy resource consumption, x_{jit} is per capita carbon emission from the consumption of the *j*-th type of energy resource, and E_{jit} is consumption of the *j*-th type of energy resource. Therefore, S_{jit} denotes the share of consumption of the *j*-th type of energy resource in total energy resource consumption, and F_{jit} denotes the emission coefficient of the *j*-th type of energy resource regarding per capita carbon emission. In this analysis, taking account of data availability and data consistency, we opt to use three types of energy resources, namely, petroleum, coal and natural gas, to construct our measure of carbon emission based on the formula in (25). Relevant data needed for the construction can also be found in relevant official publications of the National Bureau of Statistics of China.

We use an annual data setup in our regression analysis, where each period t in (24) pertains to one calendar year, so that we have 17 calendar years in our sample period 1997–2013. Therefore, we use 16 time (year) dummy variables, along with a common intercept, to take care of the time intercept η_t in (24). One of our ultimate aims is to estimate the structural parameters in the model, which are, namely, α and γ. Besides obtaining the estimated values of the structural parameters α and γ, we also estimate the magnitude of the speed of convergence λ. However, our primary interest is in the magnitude of the coefficient on (partial effect of) the carbon emission term in (24).

Our estimation results show that the estimated coefficients on the explanatory variables are statistically significant (at the 5% level) and have the expected signs.[4] The estimated convergence speed λ is about 0.05, meaning that once the partial effects of the other explanatory variables including the fixed region effects are netted out, per capita output converges to its steady state value at an annual speed of about 5%. The estimated value of α turns out to be about 0.40: the value falls well within the likely range of its theoretically and empirically accepted values. The estimated value of γ, which is the focus of our primary interest, turns out to be about 0.35. These two estimates of α and γ together implies that the parameter β in (1) is about 0.25. Using slightly different presumed values of the unknown parameter ξ to rerun the regression above as a robustness check, we end up with the conclusion that our estimation results are not sensitive to the presumed value of ξ.

[4] To save page space, we omit summarizing the results in a table.

5. Concluding Remarks

It is argued that China's economic growth in the recent decades has been relying too heavily on environmental inputs. In this paper, we have empirically analyzed the contribution of pollution (carbon) emission as an environmental input to the growth of China's output. We have based our empirical analysis on a relevant theoretical framework of environmentally sustainable growth. According to our theoretical modeling, we conclude that for environmentally friendly (green) economic growth to be sustained, we need to have sufficiently large values of g and b in the condition (21). This is also to say that, given the values of g and b, a large ratio of γ to β is evidence against environmentally sustainable growth. Our regression exercise, however, has produced an estimated value of γ as high as 0.35 (compared with an estimated value of β which is about 0.25). Therefore, given our regression results, we are quite concerned that environmentally friendly economic growth is not being sustained in China. Relevant policy measures regarding pollution emissions and pollution abatement are therefore urgently in need.

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