Supplementary Data

This is a supplementary data for article :

Multiple pathways to a low-carbon future: Examining evidence from the BRICS+

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Derivation of Theoretical Framework

Industry Sector

Pokrovski (2003) proposed an extension of the conventional neoclassical growth model to include consumed energy, referred to as productive energy (ET). The way productive energy enters the production function is not only by adding to the cost of production but also by enhancing the value generated during the production process (Lee et al., 2008; Lee & Chang, 2007).

We illustrate the industry's output with a basic Cobb-Douglas production function at a constant returns to scale (CRS) while introducing productive energy, in this case, which is the share of RE consumption to non-RE consumption into the function given by:

$$Y_t^I = F(A_t, K_t, L_t, ET_t) = A_t\left(K_t^{\alpha} L_t^{\beta} (ET_t^I)^{1-\alpha-\beta}\right), 0 < \alpha < 1, 0 < \beta < 1 \quad (1)$$

Where Y^I is the total output of industry, A represents exogenous total factor productivity, K denotes the capital input, L denotes the labor input, ET^I denotes energy inputs used in industrial production, which depicts the energy transition (share of renewables to non-renewables) in the industrial sector, α is the elasticity of production of capital, β is the elasticity of production of labor, and the elasticity of production of energy inputs is equal to $1-\alpha-\beta$. is the total output of industry.

Furthermore, following Edenhofer et al.'s (2012) definition of energy transition, the economy's energy transition is given by:

$$ET_t = \frac{REC_t}{NREC_t} \quad (2)$$

Where REC_t is the renewable energy consumption and $NREC_t$ is the non-renewable energy consumption in the industry.

The industry sector faces a cost function as follows:

$$C_t = r_t K_t + w_t L_t + e_t(P_t^E + T_t)ET_t^I \quad (3)$$

Where C_t is the industry's cost of production, r denotes the interest rate of capital, K denotes the capital input, w denotes the wage rate, L denotes the labor input, e denotes the exchange rate, P^E denotes energy price and T denotes the environmental costs associated with transporting energy resources (we use CO_2 emissions as a proxy).

Accordingly, firms maximize their profits as follows:

$$Max\ \pi_t = P_t^Y Y_t - r_t K_t - w_t L_t - e_t(P_t^E + T_t)ET_t^I \quad (4)$$

Where π is the industry sector's profit, P^Y is the price of the final products, r denotes the interest rate of capital, w denotes the wage rate, e denotes the exchange rate, P^E denotes energy price and T denotes the transportation environmental cost of energy resources.

By substituting Eq.1 into Eq.4 and solving the first differential with respect to ET, the resulting equation becomes:

$$\frac{\partial \pi_t}{\partial ET_t^I} = (1 - \alpha - \beta)\frac{P_t^Y Y_t^I}{ET_t^I} - e_t(P_t^E + T_t) = 0 \quad (5)$$

Making ET^I the subject in Eq.5, the industry's energy transition becomes:

$$ET_t^I = (1 - \alpha - \beta)\frac{P_t^Y Y_t^I}{e_t(P_t^E + T_t)} \quad (6)$$

From Eq.6, it is evident that the industry's energy transition is a function of the elasticities of production of labour and capital, the price of final industry products, real output of industry, energy price, exchange rate and energy transportation environmental costs.

Household Sector

Let C_t and ET_t^H be the time-varying indices of household consumption of non-energy goods and energy goods respectively. Generally, household derives utility from the consumption of both non-energy and energy goods. The household energy demand is represented by the following utility function:

$$U_t = (C_t, ET_t^H) = \frac{1}{1-\rho}(C_t)^{1-\rho} + \frac{1}{1-\tau}(ET_t^H)^{1-\tau} \tag{7}$$

Households maximize their utility subject to a budget constraint given by:

$$Y_t^H = P_t^C C_t + e_t(P_t^e + T_t)ET_t^H \tag{8}$$

Where Y^H is the total income of households, P^Crepresents the price of non-energy goods, P^Erepresents the price of energy goods, which is determined by energy price, e represents the exchange rate and T represents the transportation environmental cost of energy goods.

To maximize the utility of households, the household's Lagrange function is set up as follows:

$$L = U(C_t, ET_t^H) - \varphi\{P_t^C C_t + e_t(P_t^E + T_t)ET_t^H - Y_t^H\} \tag{9}$$

The first-order differential with respect to ET^H, C, and φ are given as follows:

$$\frac{\partial L}{\partial ET_t^H} = U^I(ET_t^H) - \varphi\{e_t(P_t^E + T_t)\} = 0 \tag{10}$$

$$\frac{\partial L}{\partial C_t} = U^I(C_t) - \varphi(P_t^C) = 0 \Rightarrow \ \varphi = \frac{U^I(C_t)}{P_t^C} \tag{11}$$

$$\frac{\partial L}{\partial \varphi} = Y_t^H = P_t^C + e_t(P_t^E + T_t)ET_t^H \tag{12}$$

Substituting φ from Eq. 11 into Eq. 10 and solving for ET_t^H, the household's energy transition becomes a function of electricity tariff, exchange rate, transportation environmental costs of energy and the income level of households as expressed in eq. 13 below.

$$ET_t^H = f(P_t^E, e_t, T_t, Y_t^H) \tag{13}$$

The total energy demand of the economy is given by:

$$ET_t = ET_t^I + ET_t^H \tag{14}$$

From Eq.14, the total energy demand of the economy is expressed below

$$ET_t = f(P_t^E, P_t^Y, e_t, T_t, Y_t) \tag{15}$$

Where P^E denotes electricity tariff, P^Y denotes the price of final industry products, e denotes the exchange rate, T represents environmental costs associated with transportation of energy, and Y is the total GDP of the economy which constitutes the total industrial output, (Y^I) and the income level of households (Y^H).