Energy transition; bridge fuel; assets stranded; green finance tools; natural gas substitution; NK-E-DSGE model

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Overview

Bridge fuels play a crucial role in facilitating assets stranded risks associated with rapid transition from traditional fossil fuels to clean energy. To explore the specific contributions of bridge fuels in achieving orderly energy transition, this study develops a New Keynesian Enhanced Dynamic Stochastic General Equilibrium (NK-E-DSGE) model, incorporating the substitution effect of natural gas—a representative transitional energy source—into the analysis of transition pathways. The results show that while Green Bonds, the strong stimulation instrument for clean energy development, generate economic benefits and carbon reductions effects, they also cause severe assets stranded risks to traditional energy industry. The simulation results of NK-E-DSGE indicate that substitution of natural gas can effectively alleviate the asset shrinkage. Besides, as the asset phase-out of fossil fuel sector is found to derive from the technological iteration to improve competitiveness in endogenous progress-driven market, technological advances of clean energy sector can be one good option for orderly energy transition.

Methods

We introduce environmental externality, financial frictions, and green bonds policy into a standard new Keynesian model to develop a new-keynesian-environmental-dynamic stochastic general equilibrium model (NK-E-DSGE). The model includes seven sectors, namely the households, the intermediate goods sector, the final goods sector, bank, capital producer, government and central bank (Annicchiarico and Di Dio, 2015; Busato et al., 2023; Xiao et al., 2024).

Additionally, In the model, it is assumed that both private banks and the central bank can purchase bonds issued by clean energy firms (green bonds) and fossil energy firms (brown bonds). However, a leverage constraint limits the ability of private banks to fully exploit arbitrage opportunities between bonds and household deposits, resulting in an equilibrium spread between bond yields and deposit interest rates. In practice, China's green bond market is still in its early stages of development, and incentive policies such as financial interest discounts, guarantees, and subsidies for commercial banks require further refinement. Consequently, commercial banks are more inclined to provide green financing channels to environmentally friendly enterprises without altering loan interest rates. Based on this, we define green bonds as a policy instrument that tilts the central bank's balance sheet toward the clean energy sector.

Energy intermediate-good firms are divided in fossil and clean firms.

（1）Fossil energy intermediate-good firms

Fossil energy intermediate-good firms use capital k_t^U、labor h_t^U、fossil fuel M_t to produce fossil energy goods y_t^U according to the following Cobb-Douglas production function:

$$y_t^U = A_t^U\left(k_{t-1}^U\right)^{\alpha}\left(h_t^U\right)^{\Delta}(M_t)^{1-\alpha-\Delta} \tag{11}$$

where fossil capital k_t^U refers to any capital that is specialized to use fossil fuel (Fried et al., 2022). A_t is TFP. To finance capital expenditure, fossil energy firms issue bonds b_t^U, as expressed in Eq. (12).:

$$b_t^U = q_t {k_t}^U \tag{12}$$

where q_t is the price of the capital good. The bond is expressed in real terms and pay a real interest rate. Fossil energy firms buy capital from capital producers, which in turn buy back non-depreciated capital from fossil energy firms. In period t, profits ${\Gamma_t}^U$ of fossil energy firms are given by Eq. (11), where J_t is the price of fossil fuel M_t;

$${\Gamma_t}^U = \left\{p_t^U y_t^U - w_t h_t^U - r_{k,t}^U k_{t-1}^U - M_t J_t\right\} \tag{13}$$

where $r_{k,t}^U$ is the rental rate of capital for fossil energy firms.

$$r_{k,t}^U = \left[r_t^U q_{t-1} - (1-\delta) q_t\right] \tag{14}$$

First order conditions for fossil energy firms read:

$$w_t h_t^U = (1-\alpha)p_t^U y_t^U \tag{15}$$

$$r_{k,t}^U k_{t-1}^U = \alpha p_t^U y_t^U \tag{16}$$

$$J_t M_t = (1-\alpha-\Delta)p_t^U y_t^U \tag{17}$$

Moreover, for studying the important role of natural gas as an alternative energy source in promoting the orderly energy transition, we set the natural gas substitution rate of vv_t. This parameter specifically represents the share vv_t, which determines the absolute amount of natural gas M_t^G in all the fossil energy fuels (M_t) invested by the fossil energy sector. Where, vv_t satisfies $M_t^G = vv_t \cdot M_t$, and $0 < vv_t < 1$. The natural gas substitution rate vv_t meets the following Eq. (18), where $\overline{vv}_t$ represents its steady-state value, $v_{vv,t}$ represents its exogenous impact. Considering that fossil fuels consumption will have a negative impact on the operation of the economic system, the external loss function L_t is added to the original fossil energy production function, as shown in Eq. (19) below. Where $f\ (0 < f < 1)$ represents the loss coefficient of output decline caused by the fossil energy sector. As an alternative energy source in the transition from fossil energy to clean energy, natural gas has relatively low carbon emission per unit and less negative external impact on production. Therefore, L_t is a monotonically increasing function of its argument. Combined with the above setting of natural gas substitution rate, the production function of the fossil energy sector is as follows Eq. (20). By solving the profit maximization of the fossil energy sector, the equilibrium equation of the fossil energy sector is obtained.

$$vv_t = \rho_v vv_{t-1} + (1-\rho_v)\overline{vv}_t \tag{18}$$

$$L_t(vv_t) = 1 - f(1-vv_t) \tag{19}$$

$$y_t^U = A_t(k_{t-1}^U)^{\alpha}(h_t^U)^{\Delta}(M_t)^{1-\alpha-\Delta}L_t J_t M_t = (1-\alpha-\Delta)p_t^U y_t^U \tag{20}$$

Results

The improved DSGE model enables policy simulation and scenario analysis with the parameters. The model is first maintained at the steady-state level in the following sections, after which an exogenous policy shock is introduced, and the impulse response curves of each variable to the shock are analyzed. we explore the dynamic effects of key energy transition policies on the economy, focusing on green bond and climate policies, as well as technological progress in energy sectors. Through simulations, we analyze the impacts of green bond policies on capital flows toward clean energy and the reallocation away from fossil energy. We also investigate two climate policy scenarios—sudden and orderly transitions—examining how changes in energy mix influence macroeconomic variables, energy production, and emissions. Additionally, we consider the role of technological advancements in both fossil and clean energy sectors, assessing their effects on sectoral output, capital accumulation, and environmental outcomes. The results show that while Green Bonds, the strong stimulation instrument for clean energy development, generate economic benefits and carbon reductions effects, they also cause severe assets stranded risks to traditional energy industry. The simulation results of NK-E-DSGE indicate that substitution of natural gas can effectively alleviate the asset shrinkage. Besides, as the asset phase-out of fossil fuel sector is found to derive from the technological iteration to improve competitiveness in endogenous progress-driven market, technological advances of clean energy sector can be one good option for orderly energy transition.

Conclusions

Key findings highlight natural gas as a crucial bridge fuel for a balanced transition. Rapid shifts driven by green bonds lead to significant asset stranding in the fossil sector, while gradual increases in natural gas mitigate these risks, maintaining economic stability. Technological progress in both energy sectors influences transition dynamics, reducing emissions in the clean sector and increasing output in the fossil sector, albeit with higher emissions.

Our results suggest that orderly transitions and technological advancements effectively reduce asset stranding and idle capacity risks. In contrast, rapid and sudden transitions risk economic instability due to sharp declines in fossil capital and output. A balanced approach, incorporating natural gas and technological innovation, emerges as the most viable strategy for achieving energy transition and economic stability.

Additionally, the simulations indicate varying carbon emission outcomes across scenarios. Green bond policies quickly reduce emissions, while sudden transitions offer deeper cuts but jeopardize economic stability. Orderly transitions achieve moderate emission reductions without severe economic disruptions.