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**Article**

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# Modelling the green transition of the Chinese economy

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*This paper develops a stock–flow consistent (SFC) macroeconomic model with an energy sector for China to investigate the effect of green policies on green transition and the economy. We provide an analytical solution for green transition that illustrates the relative cost of using conventional energy with respect to renewable energy to determine the share of renewable energy and how the development of the energy sector promotes green transition. Our solution also demonstrates the necessity of green policies for a green transition. We calibrate the model to the national determined contributions (NDCs) scenarios from the Network for Greening the Financial System (NGFS) and run simulations from 2019 to 2035. The results show carbon taxes stimulate green transition but have a negative impact on the economy, accompanied by a reduction in economic growth, current account deficit and a rise in inflation. Carbon taxes deteriorate firms' balance sheets. Governments benefit from carbon taxes in the short run but face a higher public debt to GDP ratio in the long run. Carbon taxes reduce carbon intensity and carbon emissions. We also compared the effect of green fiscal policy to conventional fiscal policies financed by carbon taxes (carbon rebate). Green subsidies benefit economic growth more effectively. They reduce inflation caused by carbon taxes and stimulate the green transition further.*

**Keywords:** *Stock-flow consistent modelling, Open economy, Energy pricing, Renewable energy, Climate policy*

**JEL codes:** *E12, F41, Q41, Q42, Q58*

## 1 INTRODUCTION

China, the largest carbon emitter in the world, has recently formulated a series of policy targets aiming at reducing carbon emissions (summarised in Table 1). According to the '14th Five-Year Plan', carbon emissions to GDP in 2025 and 2030 must not surpass 18 per cent of the level in 2020 and 65 per cent of the level in 2005, respectively. Total carbon emissions should peak in 2030 and reach carbon neutrality in 2060. The share of non-fossil energy consumption in total energy consumption should reach around 25 per cent in 2030 and more than 80 per cent by 2060.

China has been planning and implementing a set of economic policies to achieve these goals, promoting green bonds and green loans, providing subsidies and tax cuts in green industrial sectors, establishing the issuance of a carbon emission right market (launched on 16 July 2021), and increasing public green consumption. This paper attempts to model the green transition of the Chinese economy in a stock–flow consistent (SFC) framework, building scenarios and testing the effectiveness of these policies.

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*Table 1 China climate change policy targets*

	2025	2030	2060
Carbon emission to GDP	18% less than the level in 2020	65% less than the level in 2005	
Carbon emission		Peak	Carbon neutrality
Non-fossil energy consumption		25% of total	80%+ of total

*Source:* Responding to Climate Change: China's Policies and Actions.

There are a few studies using different modelling techniques that have addressed some ecological issues in China. Carraro/Massetti (2013) examine future energy and emission scenarios in China using an integrated assessment model (IAM) called WITCH (World Induced Technical Change Hybrid model) under a Ramsey–Cass–Koopmans optimal growth framework with an endogenous technical change in the energy sector. Yang/Teng (2018) evaluate the co-benefit of carbon mitigation in local air pollution reduction by using the China-MAPLE model, a bottom-up optimizing model that solves the linear optimal problem of the energy system. Huang et al. (2021) investigate the effect of tightening environmental regulation on non-green firms' balance sheets and the financial risk in the banking system by building an environmental dynamic stochastic general equilibrium (E-DSGE) model. Su et al. (2022) estimate the macroeconomic cost of a deep decarbonisation pathway for China by integrating the China-MAPLE model with KLEM-CHN, a dynamic recursive Solow–Swan growth type model. However, all of these studies lack attention to aggregate demand and are modelled theoretically.

SFC models are different from the mainstream models in the sense that the economy is demand-driven. The equilibrium of the final goods market is closed by aggregate output, while in mainstream (DSGE) models, the output is predetermined by the production technology, and the equilibrium is closed by private demand, consumption or investment through the inter-temporal consumption behaviour of the agents, that is, the Euler equation.

The demand-driven model of economic growth has the advantage of studying social transformation to achieve sustainable growth, such as sustainable consumption, reduced working time and the rebound effect. Respecting the 2-degree goal, neo-classical models display an instant drop in capital stock that guarantees full employment of capital and labour under output contraction, which is not shown in history, for example, the Great Recession (Rezai et al. 2013). Another advantage of the SFC approach is its explicit attention to macro-financial feedback loops. The balance sheets in the SFC models could reflect society's wealth and debt level, which makes them able to study the financial stability and growth sustainability of the economy (Bezemer 2010). It is not the main goal of this paper to argue which method is superior to the other. A more explicit discussion on this issue could be found in Lavoie (2022).

Studies on ecological SFC models have been flourishing in recent years. A brief summary and classification of the literature can be found in Carnevali et al. (2020). Most of the studies build a theoretical model and calibrate it to a few series of historical data or projections from other models, for example, IPCC scenarios. This paper, different from theirs, attempts to model the system of the economy empirically.<sup>1</sup> The model set-ups are based on the national balance sheet and transaction–flow matrix, which makes it capable

1. More precisely, the methodology of this paper is not fully empirical but hybrid because it does not study the empirical fact of the Chinese economy.

of capturing the specific features of the Chinese economy (Zezza/ Zezza 2019). Behaviour equations are designed based on economic theory but adjusted to the empirical estimation of the data.

The theoretical framework of this paper refers largely to the DEFINE (Dynamic Ecosystem-FINance-Economy) model from Dafermos et al. (2017; 2018). In DEFINE, endogenous ecological efficiency and technology improvement are characterised by the increase in the share of green capital. It reduces energy intensity and raises the share of renewable energy, resulting in less carbon emissions. Our model focuses on the green transition in the energy sector that reduces carbon emissions per energy consumption.

This paper is structured as follows: Section 2 describes the model. Section 3 presents and discusses the scenarios' results. Lastly, Section 4 concludes with remarks.

## 2 THE MODEL

Energy production is driven by aggregate demand. There are two types of capital in the energy sector: capital for conventional energy production ( $k_c$ ) and capital for renewable energy ( $k_r$ ). Technology progress is characterised as an increase in the share of renewable energy production capital that reduces carbon emissions per energy used. The economy comprises five sectors: households, firms, banks, governments and the rest of the world (RoW). Households and governments consume the final good according to their consumption functions. Investments are made by households (mainly real estate acquisition), firms (final good production and energy production) and governments (final good production) through their investment decisions. Banks receive deposits and issue bonds and loans to fulfil money demand, and they adjust the interest rate following an inflation-biased Taylor Rule. The private sector pays carbon taxes to the government according to their emissions, which depend on their value-added and carbon intensity. Accounting equations, such as changes in loans and bonds and the accumulation of assets and liabilities, are modelled to guarantee stock–flow consistency. Behaviour equations, for example, consumption and investment decisions and financial instrument saving/borrowings, follow standard post-Keynesian economic theory and adjust to the econometric regression results. Prices are endogenous and depend on production costs.

### 2.1 Energy sector

Energy consumption depends on aggregate demand,

$$ENER_t = EI_t y_t \quad (1)$$

where  $ENER_t$  denotes energy consumption;  $EI_t$ , energy intensity; and  $y_t$ , real GDP. For simplicity, we set energy intensity as exogenous. We calibrate its growth rate to our baseline scenario discussed in Section 3. This implies that there is an exogenous technical progress in energy efficiency or structural change moving to low energy intensity economic activities,

$$EI_t = EI_{t-1}(1 + g_{ei,t}), g_{ei,t} < 0 \quad (2)$$

where  $g_{ei,t}$  is the energy intensity growth that we are going to calibrate.

Capitals for energy production,  $k_{e,t}$ , are required, giving the level of energy consumption followed by a simple technology,

$$ENER_t = e_0 k_{e,t-1}^{e_1}, e_1 > 0 \quad (3)$$

We assume that energy producers' expectations are static, future energy demand grows as the current growth rate,

$$k_{e,t} = \left( \frac{ENER_{t+1}^{exp}}{e_0} \right)^{\frac{1}{e_1}} = \left( \frac{E_t(1+g_{e,t})(1+g_{y,t})}{e_0} \right)^{\frac{1}{e_1}} \quad (4)$$

where  $g_{y,t} = \frac{\Delta y_t}{y_{t-1}}$  denotes the real GDP growth rate at period  $t$ .

There is an imperfect substitution between conventional energy and renewable energy because energy users/producers need capital, that is, facilities, to consume/produce renewable energy, and these initial capitals demand conventional energy to produce. When the capital for renewable energy production does not exist, conventional energy complements renewable energy. As renewable energy production expands, conventional energy and renewable energy become substitutes. The consumption preference/production technology between conventional energy,  $CE_t$ , and renewable energy,  $RE_t$ , follows a variable elasticity of substitution (VES) function as in Revankar (1971), suggested by Aleti/Hochman (2020):

$$ENER_t = V(CE_t, RE_t) = \gamma CE_t^{\omega(1-\delta\rho)} [RE_t + (\rho-1)CE_t]^{\omega\delta\rho} \quad (5)$$

$$\gamma > 0, \omega > 0, 0 < \delta < 1, 0 \leq \delta\rho \leq 1, \frac{RE_t}{CE_t} > \frac{1-\rho}{1-\delta\rho}$$

The allocation between conventional energy and renewable energy is solved by an expenditure minimisation problem,

$$\min_{CE_t, RE_t} P_{ce,t} CE_t + P_{re,t} RE_t \quad (6)$$

constrained by equation (5). From the first-order condition, we get that the price ratio between conventional energy and renewable energy equals their marginal rate of substitution,

$$\frac{P_{ce,t}}{P_{re,t}} = \frac{\frac{\partial V}{\partial CE_t}}{\frac{\partial V}{\partial RE_t}} = \beta_{re} + \alpha_{re} \frac{RE_t}{CE_t} \quad (7)$$

where  $\alpha_{re} = \frac{1-\delta\rho}{\delta\rho}$  and  $\beta_{re} = \frac{\rho-1}{\delta\rho}$ .<sup>2</sup> We define the share of capital for renewable energy production as  $\Gamma_{k_{re},t} = \frac{k_{re,t}}{k_{e,t}}$ , and assume the same energy production technology

2. Note that the elasticity of substitution of renewable energy with respect to conventional energy is,  $\varepsilon_t = \frac{dRE_t / RE_t}{dCE_t / CE_t} = -\beta_{re} \frac{CE_t}{RE_t} - \alpha_{re}$ . At the early stage, when the share of renewable energy is small, the elasticity of substitution is small, and conventional energy and renewable energy are

(equation (3)) for the two types of energy, then the share of renewable energy,  $\Gamma_{re,t} = \frac{RE_t}{E_t}$ , follows:

$$\Gamma_{re,t} = (\Gamma_{k_{re},t-1})^{e_1} = \left( \frac{k_{re,t-1}}{k_{e,t-1}} \right)^{e_1} \quad (8)$$

Combining equation (7) with equation (8) and using the static expectation assumption that energy suppliers believe the price ratio in the next period will follow the same as in the current period, we, thus, obtain a function that governs the share of capital for renewable energy production,

$$\Gamma_{k_{re},t} = \left[ \frac{\frac{\alpha_{re}}{CT_t} + 1}{\frac{P_{ce,t} + \frac{CT_t}{CE_t}}{P_{re,t}} - \beta_{re}} \right]^{-\frac{1}{e_1}}, \quad \alpha_{re} > 0, \beta_{re} < 0 \quad (9)$$

Here, we have an additional element,  $\frac{CT_t}{CE_t}$ , the unit cost of carbon tax ( $CT$ ) for producing conventional energy. Equation (9) tells us that the share of capital for producing renewable energy depends on the relative cost of using conventional energy to renewable energy,  $\frac{P_{ce,t} + \frac{CT_t}{CE_t}}{P_{re,t}}$ . Since  $e_1$  and  $\alpha_{re}$  are positive when the price of conventional energy or carbon tax per unit of conventional energy increases or the price of renewable energy decreases, firms tend to allocate more capital for producing renewable energy.

We assume perfect competition among firms that produce conventional energy, and they bear a linear variable production cost,  $r_{kce}k_{ce,t}$ .<sup>3</sup> Conventional energy producers face the following profit maximisation problem,

$$\begin{aligned} \max_{k_{ce,t}} & P_{ce,t+1}CE_{t+1} - r_{kce}k_{ce,t} \\ \text{s.t.} & CE_{t+1} = e_0k_{ce,t}^{e_1} \end{aligned} \quad (10)$$

The first-order condition gives us the conventional energy pricing,

$$P_{ce,t+1} = \frac{r_{kce}}{e_0e_1}k_{ce,t}^{1-e_1}, e_1 < 1 \quad (11)$$

complemented (if  $RE_t \rightarrow 0, \varepsilon \rightarrow +\infty$ , perfect complementarity). As the share of renewable energy increases, the elasticity of substitution increases to  $-\alpha_{re}$  when the share of renewable energy approaches 1.

3. This assumption is convenient for solving the solution. Also, Chinese energy companies are state-owned. They try to maximize the market efficiency as if in a perfect competition market, though they have high market power.

For firms producing renewable energy, they bear a fixed cost (that is, fixed operating and management cost),  $F_{re}$ , as in Lorenczik et al. (2020), a significant share of renewable energy has zero short-run marginal cost and the interest payment of borrowing for the construction of the facilities,  $r_{k_{re,t}} K_{re,t}$ . The government can subsidise a proportion of the total cost,  $GS_t = \gamma_{GS,t} (F_{re} + r_{k_{re,t}} K_{re,t})$ . Assuming they earn zero profit, the price of renewable energy equals the unit cost of renewable energy production, that is, the levelised cost (Monnin et al. 2015),

$$P_{re,t+1} = \frac{F_{re} + r_{k_{re,t}} K_{re,t} - GS_t}{e_0 k_{re,t}^{e_1}} \quad (12)$$

where  $r_{k_{re,t}} = \mu r_{pf,t}$  with  $\mu \in [0,1]$  is the interest rate for financing investment in renewable energy production.  $\mu = 1$  is our baseline scenario, which means that the renewable energy producers bear the same loan rate as the other firms,  $r_{pf,t}$ . If commercial banks implement green finance for renewable energy firms, they ask for a lower interest rate for financing

them.<sup>4</sup>  $K_{re,t} = \max \left\{ P_{k,t} k_{re,t}, \frac{P_{k,t} K_{re,t-1}}{P_{k,t-1}} \right\}$  is the existing capital stock in value for renewable energy production.<sup>5</sup>

From equations (11) and (12), it is obvious that the price and quantity for conventional energy production are positively correlated and negatively correlated for renewable energy (in the short run). This is consistent with the data from 2013 to 2018 in China (see Figure 1). The electric price generated by coal co-moves with its quantity, falling before 2016 and rising after 2016. The rise of electric production by wind, nuclear and solar is accompanied by a significant drop in electricity prices generated. A potential interpretation of this phenomenon is that the conventional energy industries are already well established. They do not bear fixed costs but only variable costs, such as buying coals and paying wages and rents. Thus, the marginal cost of production increases as the quantity increases and the price increases. However, in the short run, the renewable energy sectors bear only small variable costs, but they face a major fixed cost for operation and management. As the production expands, the fixed cost is amortised, and renewable energy becomes cheaper.

Based on the above settings, we make the following propositions,

**Proposition 1** *Green transition takes place as the energy sector develops.*

**Proposition 2** *Without any green policy, the green transition itself would stagnate in the long run.*

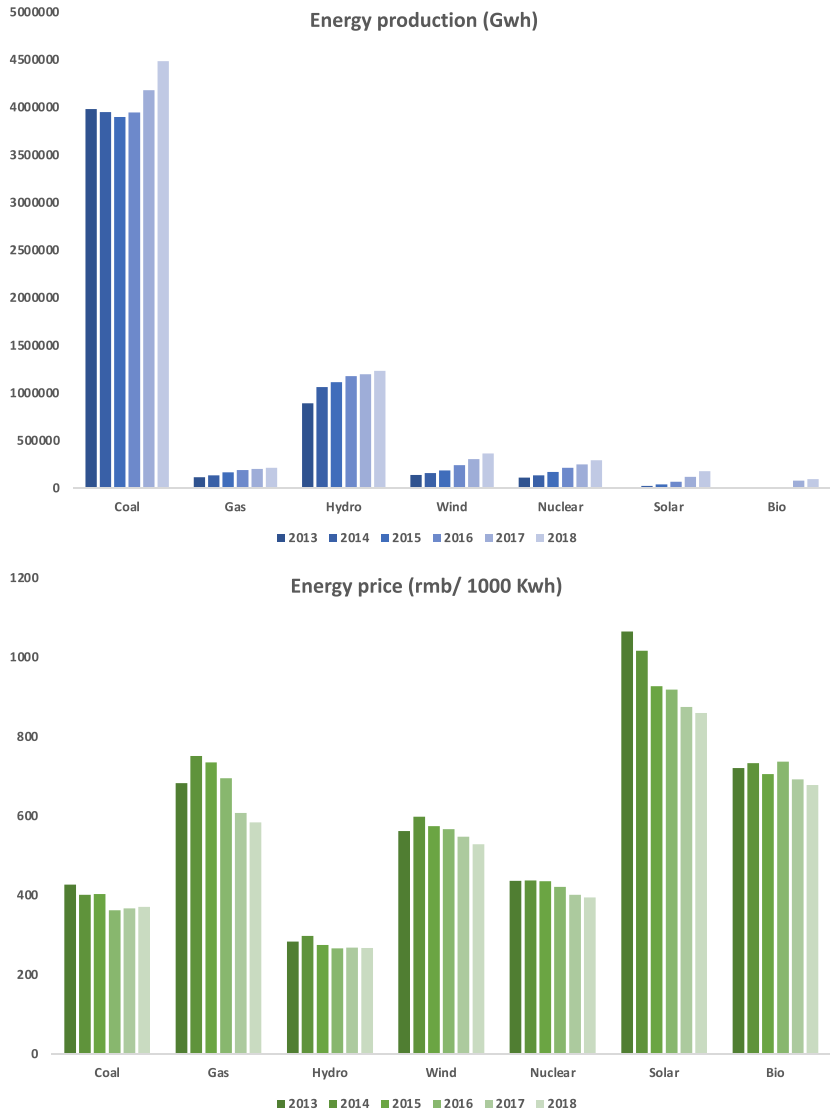
**Proposition 3** *Green policies accelerate green transition at the early stage.*

*Proof:*

For simplicity, we assume that the price of firms' capital is fixed at its steady-state value, that is,  $P_{k,t} = 1$ , and a steady growth regime for the energy sector (that is, a constant growth rate of energy consumption), so that the capital in value equals the capital in volume utilised,  $K_{re,t} = k_{re,t}$ . Dividing equation (11) by (12), we get the price ratio,

4. Unfortunately, we do not find a significant effect of this shock under this set-up when we run our simulations because the financing cost of renewable energy production is negligible within the simulation period. It becomes significant only when there is a sufficiently large scale of renewable energy production.

5.  $k_{re,t}$  is the capital stock in volume utilised, which is determined by the renewable energy demand. However,  $K_{re,t}$  is the total capital stock in value for renewable energy production. It includes both the utilised and non-utilised capital.



Source: China Energy Portal.

Figure 1 Electric production and price by energy type

$$\frac{P_{ce,t+1}}{P_{re,t+1}} = \frac{r_{k_{ce}} k_{e,t} (1 - \Gamma_{k_{re},t})^{1-\epsilon_1} \Gamma_{k_{re},t}^{\epsilon_1}}{e_1 (F_{re} + r_{k_{re},t} k_{e,t} \Gamma_{k_{re},t})} \quad (13)$$

Without considering carbon tax, that is,  $CT_t = 0$ , substituting equation (13) with 1 lag into equation (9) and taking the partial derivative of the share of capital for renewable

energy production,  $\Gamma_{k_{re},t}$ , with respect to the total capital for energy production,  $k_{e,t-1}$ , we get

$$\frac{\partial \Gamma_{k_{re},t}}{\partial k_{e,t-1}} = \frac{\alpha_{re} \Gamma_{k_{re},t}^{1+e_1}}{e_1} \left[ \frac{r_{k_{re}} k_{e,t} (1 - \Gamma_{k_{re},t})^{1-e_1} \Gamma_{k_{re},t}^{e_1}}{e_1 (F_{re} + r_{k_{re},t} k_{e,t} \Gamma_{k_{re},t})} - \beta_{re} \right]^{-2} \frac{r_{k_{re}} F_{re} (1 - \Gamma_{k_{re},t-1})^{1-e_1} \Gamma_{k_{re},t-1}^{e_1}}{(F_{re} + r_{k_{re},t} k_{e,t-1} \Gamma_{k_{re},t-1})^2} > 0 \quad (14)$$

It shows that as the energy sector expands,  $k_{e,t-1}$  increases, and the share of capital for renewable energy production increases. However, in the long run, when the total capital for energy production becomes very large,  $k_{e,t-1} \rightarrow \infty$ , the speed of green transition slows

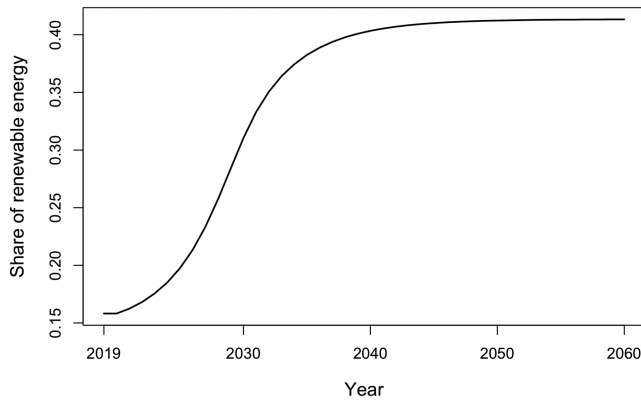
down,  $\frac{\partial \Gamma_{k_{re},t}}{\partial k_{e,t-1}} \rightarrow 0$ . Figure 2 shows the dynamic motion of the share of renewable energy,

$\Gamma_{re,t}$ . It is a simulation under a constant growth rate of energy consumption with a real GDP growth of around 0.06 and an energy intensity growth of around -0.02. As can be observed, the share of capital for renewable energy production increases over time but hits a ceiling in the long run. Without any policy intervention, for example, carbon tax, green subsidies, green regulations or green finance, the green transition stagnates in the long run.

From equation (13), we take the partial derivative of the price ratio with respect to the share of capital for renewable energy production,

$$\frac{\partial \frac{P_{ce,t+1}}{P_{re,t+1}}}{\partial \Gamma_{k_{re},t}} = \left[ \left( e_1 \frac{1 - \Gamma_{k_{re},t}}{\Gamma_{k_{re},t}} + e_1 - 1 \right) (F_{re} + r_{k_{re},t} k_{e,t} \Gamma_{k_{re},t}) - (1 - \Gamma_{k_{re},t} r_{k_{re},t} k_{e,t}) \right] \quad (15)$$

$$\frac{r_{k_{re}} k_{e,t}}{e_1 (F_{re} + r_{k_{re},t} k_{e,t})^2} \left( \frac{\Gamma_{k_{re},t}}{1 - \Gamma_{k_{re},t}} \right)^{e_1}$$



*Note:* Simulation result without a carbon tax and the impact of energy price on CPI, with  $g_{y,t} = 0.05950501$  and  $g_{\sigma,t} = -0.021913503$ .

Figure 2 The dynamic motion of the share of green capital for renewable energy production

One can show that if

$$\Gamma_{k_{re}} \leq \frac{e_1 F_{re}}{F_{re} + (1 - e_1) r_{k_{re},t} k_{e,t}}, \frac{\partial \frac{P_{ce,t+1}}{P_{re,t+1}}}{\partial \Gamma_{k_{re},t}} \geq 0$$

and if

$$\Gamma_{k_{re}} > \frac{e_1 F_{re}}{F_{re} + (1 - e_1) r_{k_{re},t} k_{e,t}}$$

vice versa. The price ratio in the future,  $\frac{P_{ce,t+1}}{P_{re,t+1}}$ , increases as the current share of green capital,  $\Gamma_{k_{re},t}$ , increases when the share of green capital is not greater than this threshold,  $\frac{e_1 F_{re}}{F_{re} + (1 - e_1) r_{k_{re},t} k_{e,t}}$ , which depends on the elasticity of energy production with respect to capital,  $e_1$ , and the relative size of the fixed cost of renewable energy production,  $F_{re}$ , to its financing cost,  $r_{k_{re},t} k_{e,t}$ .

Combining with equation (9), we know that there is a positive feedback loop between the price ratio and the share of capital for renewable energy production when the share of renewable energy production is not fairly large. The larger the elasticity of energy production with respect to capital or the smaller the financing cost of renewable energy production relative to its fixed cost, the more likely a green transition is sustainable.

Ignoring the carbon tax term,  $\frac{CT_t}{CE_t}$ , in equation (9), and taking the second-order derivative of the share of capital for renewable energy production with respect to the price ratio,

$$\frac{\partial^2 \Gamma_{k_{re},t}}{\partial \left( \frac{P_{ce,t}}{P_{re,t}} \right)^2} = \frac{\alpha_{re}}{e_1} (\Gamma_{k_{re},t})^{1+\epsilon_1} \left( \frac{P_{ce,t}}{P_{re,t}} - \beta_{re} \right)^4 \left[ \frac{1+e_1}{e_1} \alpha_{re} (\Gamma_{k_{re},t})^{\epsilon_1} - 2 \left( \frac{P_{ce,t}}{P_{re,t}} - \beta_{re} \right) \right] \quad (16)$$

Note that when the price ratio is small enough, the second-order partial derivative is positive, the share of capital for renewable energy production,  $\Gamma_{k_{re},t}$ , is a convex function with respect to the price ratio,  $\frac{P_{re,t}}{P_{ce,t}}$ , which depends on the lagged share of capital for renewable

energy production,  $\Gamma_{k_{re},t-1}$ . Therefore, when the share of capital for renewable energy production is small enough, it is an increasing convex function of its own lag, and it grows exponentially over time (see Figure 2). Green policies can be seen as a positive shock to green transition, which lets it jump to a higher increasing speed, that is, jumping from the flat part to a steeper part of the curve in Figure 2.

We summarise and interpret all the above. Under a steady growth regime of the energy sector, the price of renewable energy is mainly determined by the fixed O&M cost and decreases because of the scale effect. However, the price of conventional energy increases because of its increasing marginal cost. The cheaper the price of renewable energy to conventional energy, the more demand for renewable energy. The speed of the green transition accelerates. In the long run, as the financing cost of renewable energy production accumulates, the price of renewable energy production stops decreasing and starts increasing over

time. The increasing speed of the price of both types of energy is the same because they depend on their capital for the same power,  $1 - e_1$ . Thus, the price ratio will be fixed in the long run. And green transition stagnates.

One caveat of the proposition is that it does not consider the feedback effect of green policies on economic growth and energy sector development. For example, the negative effect of carbon taxes on economic growth will reduce the speed of capital accumulation for renewable energy production, slowing down the green transition. Nevertheless, this indirect effect would not exceed the direct effect of green policies on green transitions, which we will show in our scenario results.

## 2.2 Carbon emissions

Carbon emission,  $EMIS_t$ , is determined by the ratio of emission per unit of energy consumption,  $\theta_t$ , and the level of energy consumption,

$$EMIS_t = \theta_t ENER_t \quad (17)$$

The ratio of emission per unit of energy consumption decreases as the share of renewable energy increases,

$$\theta_t = ce_0 + ce_1 \Gamma_{re,t}, ce_1 < 0 \quad (18)$$

Carbon intensity,  $CI_t$ , by definition, is carbon emission per real GDP,

$$CI_t = \frac{EMIS_t}{y_t} \quad (19)$$

Carbon tax or carbon price is paid under a uniform tax rate or price,

$$CT_t = \tau_{ct,t} EMIS_t \quad (20)$$

where  $\tau_{ct,t}$  is the carbon price or carbon tax rate, its value depends on the scenario that we will discuss in Section 3.

Since governments pay carbon taxes to themselves, we net out carbon tax paid by governments, then, carbon tax received by governments is the sum of the private sector carbon tax payment,

$$CT_{g,t} = \sum_i CT_{i,t} = \tau_{ct,t} CI_t Y_{i,t}, \quad i = f, b, h \quad (21)$$

where  $f, b, h$  represent firms, banks and households, respectively.

## 2.3 Macroeconomy

The economy comprises five sectors: firms, banks, governments, households and the RoW (see Table 2). Firms, banks, governments and households hold fixed capital,  $K_{1f}, K_{1b}, K_{1g}$  and  $K_b$ , respectively. Within firms, energy industries hold capital for energy production,  $K_e$ , and part of the capital for renewable energy production,  $K_{re}$ . Firms and governments hold inventories,  $K_{2f}$  and  $K_{2g}$ , respectively, which include both output and input inventories. Firms, banks and governments hold other non-financial assets (NFA),  $K_{3f}, K_{3b}$  and  $K_{3g}$ , respectively, which include patents and nationally owned construction land, etc. Banks hold international reserves,  $G$ . Households hold currencies issued by the central

Table 2 The national balance sheet

	Firms	Banks	Governments	Households	RoW	Total
Fixed capitals	$+K_{1f}$	$+K_{1b}$	$+K_{1g}$	$+K_h$		$+K_1$
Capitals for energy production	$+K_e$					
Capitals for renewable energy production	$+K_{re}$					
Inventories	$+K_{2f}$	$+K_{3b}$	$+K_{2g}$			$+K_2$
Other NFA	$+K_{3f}$	$+G$	$+K_{3g}$		$-G$	$+K_3$
International reserves		$-H$				0
Currencies				$+H$		0
Deposits	$+D_f$	$+D_b - D$	$+D_g$	$+D_h$		0
Bonds	$-B_f$	$+B_{ab} - B_{lb}$	$-B_g$	$+B_h$		0
Loans	$-L_f$	$+L_b$		$-L_h$	$+L_{ar} - L_{lr}$	0
Equities	$+E_{df} - E_{ff}$	$+E_{ab} - E_{lb}$	$+E_g$	$+E_h$	$+E_r$	0
Investment funds shares		$+IFS_{ab} - IFS_{lb}$	$IFS_g$	$+IFS_h$		0
FDI	$+FDI_{out} - FDI_{in}$				$+FDI_{in} - FDI_{out}$	0
Insurance	$+A_f$	$-A$		$+A_h$		0
Other accounts payable/ receivable (+/-)	$+Z_f$	$+Z_b$	$+Z_g$	$+Z_h$	$+Z_r$	0
Net worth	0	0	$V_g$	$V_h$	$V_r$	$+K$

Note: + denotes assets, - denotes liabilities.

bank,  $H$ . Banks issue deposits,  $D$ . Sectors borrow money from each other through bonds or loans,  $B$  and  $L$ . Firms' and banks' equity on the liability side account for both equity issued and net assets, so their net worth is 0 (*China's National Balance Sheet 2018*). In this case, the net worth of firms and banks is transferred to their owners (the other sectors) through equities holding,  $E$ . Investing banks issue investment fund shares to investors,  $IFS$ . Firms and households buy insurance from banks,  $A_f$  and  $A_b$ , respectively. Other accounts payable/receivables,  $Z$ , capture the statistic misallocation and net position of all the other instruments by sectors that are not included in the model.<sup>6</sup> Net worth represents the net asset position of the sectors, in other words, wealth. The total wealth of the economy should equal total physical capital, aggregate fixed capitals, inventories and other NFA,  $V_g + V_b + V_r = K = K_1 + K_2 + K_3$ .

The transaction–flow matrix shows the transaction received and paid between sectors (see Table 3). Each column has to sum up to zero to satisfy the vertical consistency, meaning that transactions received and paid have to even out in every sector (for example, household budget constraint). Each row also has to sum up to zero for horizontal consistency. It guarantees that there is no black hole; any transaction received/paid by a sector has to be paid/received by another sector.

Note that firms' and banks' equity on the liability side account for both equity issued and net assets, so their net worth is 0 (*China's National Balance Sheet 2018*, see Table 2). Equity flows reported by the National Bureau of Statistics of China (NBSC) are 0 (see Table 3). Therefore, we have the following treatment for the equity liabilities of firms and banks, (i) the value of firms' and banks' equity on the liability side of the balance sheet satisfied the following conditions to guarantee their net worth is zero,

$$E_{lf,t} = K_{1f,t} + K_{2f,t} + K_{3f,t} + D_{f,t} - B_{f,t} - L_{f,t} + E_{af,t} + FDI_{out,t} - FDI_{in,t} + A_{f,t} + Z_{f,t} (V_{f,t} = 0) \quad (22)$$

$$E_{lb,t} = K_{1b,t} + K_{3b,t} + G_t - H_t + D_{b,t} - D_t + B_{ab,t} - B_{lb,t} + L_{b,t} + E_{ab,t} + IFS_{ab,t} - IFS_{lb,t} - A_t + Z_{b,t} (V_b = 0) \quad (23)$$

(ii) Since there are no equity flows, the revaluation effect accounts for all the changes in value,

$$REV_{ej,t} = E_{lj,t} - E_{lj,t-1}, \quad j = b, f \quad (24)$$

(iii) We derive the implicit equity price indices,<sup>7</sup>

$$P_{ej,t} = P_{ej,t-1} \frac{REV_{ej,t}}{E_{lj,t-1}}, \quad j = b, f \quad (25)$$

The following subsections present the main equations of the sectors. Behaviour equations follow the standard post-Keynesian macroeconomic theory (for example, Godley and

6. For simplicity, we drop net positions of the instruments held by sectors that are negligible in their size, for example, currencies held by sectors other than households and foreign bonds held and issued.

7. We have tried using the stock market price index to estimate equity flows, but it would increase the mismatch of net financial investment between the real account and financial account in the transaction–flow matrix.

Table 3 Transaction-flow matrix

	Production	Firms	Banks	Governments	Households	RoW	Total
GDP	$-Y$	$+Y_f$	$+Y_b$	$+Y_g$	$+Y_h$		0
Consumption	$+C$			$-C_g$	$-C_h$		0
Fixed capital formation	$+I_1$	$-I_{1f}$	$-I_{1b}$	$-I_{1g}$	$-I_{1h}$		0
Change in inventories	$+I_2$	$-I_{2f}$		$-I_{2g}$			0
Acquisition less disposals of other NFA		$-I_3$		$+I_3$			0
Export	$+X$					$-X$	0
Import	$-M$					$+M$	0
Wages		$-W_f$	$-W_b$	$-W_g$	$+W - W_b$	$-W_r$	0
Net taxes on production		$-TL_f$	$-TL_b$	$+TL_g$	$-TL_h$		0
Carbon taxes		$-CT_f$	$-CT_b$	$+CT_g$	$-CT_h$		0
Interest on deposits		$+INT_{df}$	$+INT_{db} - INT_d$	$+INT_{dg}$	$+INT_{dh}$		0
Interest on bonds		$-INT_{bf}$	$+INT_{bb} - INT_{bb}$	$-INT_{bg}$	$+INT_{bh}$		0
Interest on loans		$-INT_{lf}$	$+INT_{lb}$		$-INT_{lh}$	$+INT_{lr} - INT_{pr}$	0
Distributed income of Corporations		$+DIV_{ff}$	$+DIV_{fb} - DIV_{pb}$	$+DIV_g$	$+DIV_h$	$+DIV_r$	0
Other income from properties		$-DIV_{pf}$			$+OIP_h$	$-OIP_r$	0
Taxes on income and wealth		$+OIP_{ff}$	$-OIP_{fb}$	$+OIP_g$	$-I_{fb}$		0
Social contributions		$-T_f$	$-T_b$	$+T_g$	$-SC$		0
Social benefits				$+SC$	$+SB$		0
Other current transfers		$-O_f$	$+O_b$	$-SB$	$-O_h$	$-O_r$	0
Capital transfers		$+TRK$		$+O_g$			0
Green subsidies		$+GS$		$-TRK$			0
International reserves				$-GS$		$+AG$	0
Currencies			$-AG$		$-AH$		0
Deposits		$-AD_f$	$+AH$		$-AD_h$		0
Bonds		$+AD_f$	$-AD_b + AD$	$-AD_g$	$-AD_h$		0
		$+AB_{ff}$	$-AB_{fb} + AB_{pb}$	$+AB_g$	$-AB_h$		0

(continues overleaf)

Table 3 (continued)

	Production	Firms	Banks	Governments	Households	RoW	Total
Loans		$+\Delta L_f$	$-\Delta L_b$		$+\Delta L_h$	$-\Delta L_{ar} + \Delta L_{br}$	0
Investment fund shares			$-\Delta IFS_{ab} + \Delta IFS_{bb}$	$-\Delta IFS_g$	$-\Delta IFS_h$		0
FDI inward		$+\Delta FDI_{in}$				$-\Delta FDI_{in}$	0
FDI outward		$-\Delta FDI_{out}$				$+\Delta FDI_{out}$	0
Insurance		$-\Delta A_f$	$+\Delta A$		$-\Delta A_h$		0
Other account payable / receivables (+/-)		$-\Delta Z_f$	$-\Delta Z_b$	$-\Delta Z_g$	$-\Delta Z_h$	$-\Delta Z_r$	0
Total	0	0	0	0	0	0	0

*Note:* + denotes transactions received, - denotes transactions paid. According to the National Bureau of Statistics of China, acquisition less disposals of other NFA are mainly transfers from firms to governments, and there are no data for banks, which are inconsistent with the balance sheet.

Lavoie, 2006) and are pragmatically verified by econometrics employing historical annual data from 2000 to 2019 (NBSC, China's National Balance Sheet and World Bank).<sup>8</sup> Other simplified behaviour equations and accounting equations are shown in detail in Appendix 1, available online at <https://doi.org/10.4337/ejeep.2024.0141>.

### 2.3.1 Final good equilibrium

Final good production,  $Y_t$ , fulfils the aggregate demand, which consists of households consumption,  $C_{h,t}$ , government consumption,  $C_{g,t}$ , fixed capital formation by firms, banks and governments,  $I_{1f,t}$ ,  $I_{1b,t}$  and  $I_{1g,t}$ , respectively, fixed capital formation by households (mainly dwelling acquisition),  $I_{h,t}$ , change in inventories by firms and governments,  $I_{2f,t}$  and  $I_{2g,t}$ , and net exports,  $X_t - M_t$ ,

$$Y_t = C_{h,t} + C_{g,t} + I_{1f,t} + I_{1b,t} + I_{1g,t} + I_{h,t} + I_{2f,t} + I_{2g,t} + X_t - M_t \quad (26)$$

Aggregate demand in real term (in volume),

$$y_t = c_{h,t} + c_{g,t} + i_{1f,t} + i_{1b,t} + i_{1g,t} + i_{h,t} + i_{2f,t} + i_{2g,t} + x_t - m_t \quad (27)$$

where

$$\begin{aligned} c_{h,t} &= \frac{C_{h,t}}{P_{c,t}}, c_{g,t} = \frac{C_{g,t}}{P_{c,t}}, i_{f,t} = \frac{I_{1f,t}}{P_{k_1,t}}, i_{b,t} = \frac{I_{1b,t}}{P_{k_1,t}}, i_{g,t} = \frac{I_{1g,t}}{P_{k_1,t}}, i_{h,t} = \frac{I_{h,t}}{P_{k_h,t}}, i_{2f,t} \\ &= \frac{I_{2f,t}}{P_{k_{2f,t}}}, i_{2g,t} = \frac{I_{2g,t}}{P_{k_{2g,t}}}, x_t = \frac{X_t}{P_{x,t}} \end{aligned}$$

and  $m_t = \frac{M_t}{P_{m,t}}$  are the aggregate demand components in volume.<sup>9</sup>  $P_{c,t}$  is the consumer price index (CPI).  $P_{k_1,t}$  is the general capital price index.  $P_{k_h,t}$  is the capital price index of households.  $P_{k_{2f,t}}$  and  $P_{k_{2g,t}}$  are the price of inventories held by firms and governments, respectively. Lastly,  $P_{x,t}$  and  $P_{m,t}$  are the export and import price index, respectively. By definition, then, the GDP deflator is  $P_{y,t} = \frac{Y_t}{y_t}$ .

Production technology follows a Leontief production function, which gives us the supply constraint of the economy,

$$y_t \leq \min \left\{ \omega_0 y_{t-1}^{\omega_1} k_{1f,t}^{\omega_2} k_{1f,t-1}^{\omega_3} fdi_{in,t-1}^{\omega_4}, y_{N,t} L F_t \right\} \quad (28)$$

where  $\omega_0 = e^{\frac{\beta_2\beta_3 - \beta_0}{\beta_1}}$ ,  $\omega_1 = 1 + \frac{\beta_2\beta_4}{\beta_1}$ ,  $\omega_2 = \frac{1}{\beta_1}$ ,  $\omega_3 = -\frac{1 + \beta_2}{\beta_1}$  and  $\omega_4 = \frac{\beta_2\beta_5}{\beta_1}$ . The first term on the right-hand side of equation (28) is the potential real GDP produced by capital, where  $k_{1f}$  is firms' fixed capital in volume and  $fdi_{in}$  is the inward FDI stock in volume.  $\beta_0$  denotes autonomous utilised fixed capital growth.  $\beta_1 > 0$  is the short-run elasticity of

8. Our method is pragmatic in the sense that we try to follow economic theories as closely as possible but drop the determinants in the behaviour equations that are not statistically significant.

9. Capital letters denote variables in value (nominal term), and small letters denote variables in volume (real term).

firms' utilised fixed capital to real GDP.  $-1 < \beta_2 < 0$  is the parameter of firms' utilised fixed capital in long-run correction.  $\beta_3$  is the autonomous firms' fixed capital utilised in logarithm.  $\beta_4 > 1$  is the long-run elasticity of firms' utilised fixed capital to real GDP, which shows a decreasing marginal productivity of capital in the long run.  $\beta_5 < 0$  captures the technology spillover effect of inward FDI on capital productivity (Cheung/Ping 2004).<sup>10</sup> The second term is the potential real GDP by labour, where  $y_{N,t}$  denotes labour productivity, measured in real GDP per labour, referring to Reati (2001), and  $LF_t$  denotes labour force. Labour productivity depends on exogenous productivity improvement over time (that is, human capital accumulation) and the technology spillover from inward FDI (Cheung/Ping 2004),

$$\Delta \ln y_{N,t} = y_{n_0} + y_{n_1} \Delta \ln fdi_{in,t} + y_{n_2} [\ln y_{N,t-1} - y_{n_3} - y_{n_4} \ln fdi_{in,t-1} - y_{n_5} (t-1)] \quad (30)$$

where  $y_{n_0}$  is the short-run autonomous labour productivity growth,  $y_{n_1} > 0$  captures the short-run technology spillover effect of inward FDI on labour productivity,  $-1 < y_{n_2} < 0$  is the parameter of labour productivity long-run correction,  $y_{n_3}$  is the initial labour productivity level in logarithm,  $y_{n_4} > 0$  captures the long-run technology spillover effect of inward FDI on labour productivity and  $y_{n_5} > 0$  captures the exogenous labour productivity improvement over time.

If the economy hits the supply constraints, firms' investment would be constrained by residual savings, as in supply-led models (for example, Solow 1956),

$$\dot{i}_{f,t} = y_t - c_{h,t} - c_{g,t} - \dot{i}_{b,t} - \dot{i}_{l,t} - \dot{i}_{h,t} - \dot{i}_{2f,t} - \dot{i}_{2g,t} - x_t + m_t \quad (31)$$

The capacity utilization of the firms' fixed capital,  $U_{k,t}$ , is derived based on the capital productivity from equation (28),

$$U_{k,t} = \frac{1}{k_{1f,t}} \left[ \frac{y_t}{\omega_0 y_{t-1}^{\omega_1} (k_{1f,t-1} U_{k,t-1})^{\omega_3} fdi_{in,t-1}^{\omega_4}} \right]^{\frac{1}{\omega_2}} \quad (32)$$

### 2.3.2 Labour market

Following Keynes (1937), the employment level is determined by aggregate demand. Then, employment in our model,  $N_t$ , is simply real GDP over labour productivity,

$$N_t = \frac{y_t}{y_{N,t}} \quad (33)$$

Real wage,  $w_t$ , is determined by labour productivity,

$$\Delta \ln w_t = w_0 + w_1 \Delta \ln y_{N,t}, \quad w_1 > 0 \quad (34)$$

10. The first term in equation (28) comes from this estimation:

$$\Delta \ln(k_{1f,t} U_{k,t}) = \beta_0 + \beta_1 \Delta \ln y_t + \beta_2 [\ln(k_{1f,t-1} U_{k,t-1})] - \beta_3 - \beta_4 \ln y_{t-1} - \beta_5 \ln fdi_{in,t-1} \quad (29)$$

where  $U_{k,t}$  denotes capacity utilization.

where  $w_0$  is the autonomous real wage growth and  $w_1$  denotes the elasticity of real wage growth to labour productivity growth.<sup>11</sup>

The total wage bill,  $W_t$ , equals the nominal wage times labour,

$$W_t = P_{y,t} w_t N_t \quad (35)$$

where  $P_{y,t} w_t$  is the nominal wage.

Unit labour cost, by definition, is the total wage bill divided by real GDP,

$$ULC_t = \frac{W_t}{y_t} \quad (36)$$

### 2.3.3 Prices

Producers fulfil aggregate demand but set their prices based on their cost of production. The CPI,  $P_{c,t}$ , is determined by unit labour cost,  $ULC_{t-1}$ , and the price of aggregate energy,  $P_{ener,t}$  (see Appendix 1, available online at <https://doi.org/10.4337/ejeep.2024.0141>), which captures the microeconomic rebound effect (Sorrell/Dimitropoulos 2008),

$$\Delta \ln P_{c,t} = p_{c0} + p_{c1} \Delta \ln ULC_{t-1} + p_{c2} (\ln P_{c,t-1} - p_{c3} - p_{c4} \ln ULC_{t-1} - p_{c5} \ln P_{ener,t-1}) \quad (37)$$

where  $p_{c0} > 0$  is the long-run mark-up,  $p_{c1} > 0$  is the short-run elasticity of CPI to unit labour cost,  $-1 < p_{c2} < 0$  is the coefficient of long-run correction,  $p_{c3} > 0$  is the long-run mark-up,  $p_{c4} > 0$  is the long-run elasticity of CPI to unit labour cost and  $p_{c5} > 0$  captures the microeconomic rebound effect.<sup>12</sup>

The price of productive fixed capital depends on unit labour cost, CPI and capacity utilisation (Yoo 1995),

$$\Delta \ln P_{k,t} = \alpha_0 + \alpha_1 \Delta \ln P_{c,t-1} + \alpha_2 (\ln P_{k,t-1} - \alpha_3 \ln ULC_{t-1} - \alpha_4 U_{k,t-1}) \quad (38)$$

where  $\alpha_0$  is the short-run mark-up,  $\alpha_1 > 0$  is the short-run elasticity of the price of fixed capital to CPI,  $0 < \alpha_2 < 1$  is the long-run correction parameter,  $\alpha_3 > 0$  is the long-run elasticity of the price of fixed capital to unit labour cost and  $\alpha_4 > 0$  is the long-run elasticity of the price of fixed capital to capacity utilisation.

The price of housing correlates to CPI,

$$\Delta \ln P_{kh,t} = p_{kb1} \Delta \ln P_{c,t} \quad (39)$$

where  $p_{kb1} > 0$  is the elasticity of housing price growth to inflation.<sup>13</sup>

11. We did not find any statistical evidence of a significant effect of unemployment on real wage from our data. It suggests a flat Philips curve from 2000 to 2021 in China.

12. The lag for  $\Delta \ln ULC_{t-1}$  is to prevent simultaneity in the model, the coefficient are estimated without lag. The same reason for other determinants we show in the other parts of the paper.

13. We have tried a series of regressors for the price of housing, such as housing acquisition, capacity utilization for demand components and unit labour cost and interest rates for supply components. Only inflation is a significant regressor for housing price growth. Equations (37) and (39) build an indirect path for unit labour cost and energy price to the price of housing through CPI.

Exports' price is determined by unit labour cost,

$$\Delta \ln P_{x,t} = p_{x1} \Delta \ln ULC_{t-1} \quad (40)$$

where  $p_{x1} > 0$  denotes the elasticity of exports' price growth to unit labour cost growth. GDP deflator, by definition, is GDP in value over GDP in volume,

$$P_{y,t} = \frac{Y_t}{y_t} \quad (41)$$

For simplicity, we assume the price of inventories, other NFAs and imports equal to GDP deflator in one lag, that is,  $P_{i,t} = P_{y,t-1}$ , where  $i = k_{2f}, k_{2g}, k_3, m$  denote firms' inventories, governments' inventories, other NFAs and imports, respectively.

#### 2.3.4 Households

Households earn revenues, wages, interest from deposits, dividends, other income from properties and social benefits. They pay taxes, interest on loans and social contributions.

Households' consumption depends on their consumption level in the past (habit formation), their disposable income is deflated by consumption price,  $\frac{YD_{t-1}}{P_{c,t-1}}$  (income effect),

$$\Delta \ln c_{h,t} = c_0 + c_1 \Delta \ln \frac{YD_{t-1}}{P_{c,t-1}} + c_2 \left( \ln c_{h,t-1} - c_3 \ln c_{h,t-2} - c_4 \ln \frac{YD_{t-1}}{P_{c,t-1}} \right) \quad (42)$$

where  $c_0$  denotes the short-run autonomous consumption,  $c_1 > 0$  is the short-run income effect,  $-1 < c_2 < 1$  is the long-run correction parameter,  $c_3 > 0$  captures consumption habit formation and  $c_4 > 0$  is the long-run income effect.

Households' fixed capital formation (housing demand) depends on net worth deflated by the price of housing,  $\frac{V_{h,t-1}}{P_{k_h,t-1}}$ ,

$$\Delta \ln i_{h,t} = i_{h0} + i_{h1} \Delta \ln \frac{V_{h,t-1}}{P_{k_h,t-1}} \quad (43)$$

where  $i_{h0}$  is the autonomous housing demand growth and  $i_{h1} > 0$  captures the wealth effect.

Financial assets and liabilities follow Tobin's portfolio theory (Tobin 1982) as in Godley/Lavoie (2006). Households have liquidity preferences on currencies. They keep a proportion of their net worth as cash in hand and hold more when income increases,

$$\frac{H_t}{V_{h,t-1}} = h_0 + h_1 \frac{YD_{t-1}}{V_{h,t-1}} \quad (44)$$

where  $h_0 > 0$  is the liquidity preference for currencies and  $h_1 > 0$  captures the income effect.

Households also have a liquidity preference for deposits. They save proportionally of their net worth as deposits and earn real interest at a rate of  $r_{rh,t} - \pi_{y,t-1}$ , where  $r_{rh,t}$  is the rate of interest received by households and  $\pi_{y,t-1}$  denotes GDP deflator inflation. However,

they bear an opportunity cost of not repaying loans at a rate of  $r_{pb,t} - \pi_{y,t-1}$ , where  $r_{pb,t}$  is the rate of interest paid by households,

$$\frac{D_{h,t}}{V_{h,t-1}} = d_{h0} + d_{h1}(r_{hb,t} - \pi_{y,t-1}) + d_{h2}(r_{pb,t} - \pi_{y,t-1}) \quad (45)$$

where  $d_{h0} > 0$  is the liquidity preference for deposits.  $d_{h1} > 0$  is the sensitivity of household deposits to real interest received and  $d_{h2} < 0$  is the sensitivity of household deposits to real interest received.

Households invest in bonds to earn interest but bear the opportunity cost of not repaying loans and not investing in investment fund shares at a rate of  $\frac{DIV_{h,t} + REV_{e_h,t-1} + REV_{if_h,t}}{E_{h,t-1} + IFS_{h,t-1}} - \pi_{y,t-1}$ , where  $REV_{e_h,t-1}$  is the revaluation effect of households' equity and  $REV_{if_h,t}$  is the revaluation effect of households' investment fund shares.

$$\begin{aligned} \frac{B_{h,t}}{V_{h,t-1}} &= b_{h0} + b_{h1}(r_{hb,t} - \pi_{y,t-1}) + b_{h2}(r_{pb,t} - \pi_{y,t-1}) \\ &+ b_{h3} \left( \frac{DIV_{h,t} + REV_{e_h,t-1} + REV_{if_h,t}}{E_{h,t-1} + IFS_{h,t-1}} - \pi_{y,t-1} \right) \end{aligned} \quad (46)$$

where  $b_{h0}$  is the preference for bonds,  $b_{h1} > 0$  is the sensitivity of households' bonds to real interest received,  $b_{h2} < 0$  is the sensitivity of households' bonds to real interest paid and  $b_{h3} < 0$  is the sensitivity of households' bonds to real equity and investment fund shares return.

Households invest in investment fund shares with a proportion of their net worth. Their behaviour performs auto-correlation, chasing the winner and cutting the loser. They would invest with a higher ratio when they had a lower income-wealth ratio.

$$\frac{IFS_{h,t}}{V_{h,t-1}} = if_{h0} + if_{h1} \frac{IFS_{h,t-1}}{V_{h,t-1}} + if_{h2} \frac{YD_{t-1}}{V_{h,t-1}} \quad (47)$$

where  $if_{h0}$  is the preference for investment fund shares,  $if_{h1} > 0$  is the one-lag auto-correlation coefficient and  $if_{h2} < 0$  is the sensitivity of household investment fund shares to disposable income.

Households buy insurance at a proportion of their net worth but bear the opportunity cost of not buying investment fund shares and less when their income increases (inferior good),

$$\frac{A_{h,t}}{V_{h,t-1}} = a_{h0} + a_{h1} \left( \frac{DIV_{h,t} + REV_{e_h,t-1} + REV_{if_h,t}}{E_{h,t-1} + IFS_{h,t-1}} - \pi_{y,t-1} \right) + a_{h2} \frac{YD_{t-1}}{V_{h,t-1}} \quad (48)$$

where  $a_{h0}$  is the preference for insurance,  $a_{h1} < 0$  is the sensitivity of households' insurance to real equity and investment fund shares return and  $a_{h2} < 0$  is the sensitivity of households' insurance to disposable income.

### 2.3.5 Firms

Firms earn revenue from production, interest from deposits and dividends from equity ownership. They also pay taxes, wages and interest on debt and distribute profit through dividends.

Firms' fixed capital formation rate,  $\frac{\Delta k_{1f,t}}{k_{1f,t-1}}$ , is driven by the gross profit rate,  $\frac{\Pi_{f,t-1} - INT_{pf,t-1}}{P_{k1,t} k_{1f,t-1}}$  (Kaleckian), and capacity utilisation (Sraffian),

$$\frac{\Delta k_{1f,t}}{k_{1f,t-1}} = i_{f0} + i_{f1} \frac{\Pi_{f,t-1} - INT_{pf,t-1}}{P_{k1,t} k_{1f,t-1}} + i_{f2} U_{k,t-1} \quad (49)$$

where  $i_{f0}$  is the autonomous capital formation rate,  $i_{f1} > 0$  is the sensitivity to the net profit rate and  $i_{f2} > 0$  is the sensitivity to capacity utilisation.

Firms hold deposits as a proportion of their net worth, that is,  $E_{lf,t-1}$ , in need of operation expenditure. They increase savings in deposits as the real interest that they receive increases,  $r_{rf,t} - \pi_{y,t-1}$ , and their net cash flow increases,  $\frac{FP_{t-1}}{E_{lf,t-1}}$ .

$$\frac{D_{f,t}}{E_{yf,t-1}} = d_{f0} + d_{f1}(r_{rf,t} - \pi_{y,t-1}) + d_{f2} \frac{FP_{t-1}}{E_{lf,t-1}} \quad (50)$$

where  $d_{f0} > 0$  denotes the liquidity preference of firms,  $d_{f1} > 0$  is the sensitivity of firms' deposits to the real rate of interest received and  $d_{f2} > 0$  is the sensitivity of firms' deposits to net disposable income.

Firms issue bonds to finance and less when they have sufficient cash flow,

$$\frac{B_{f,t}}{E_{yf,t-1}} = b_{f0} + b_{f1} \frac{FP_{t-1}}{E_{lf,t-1}} \quad (51)$$

where  $b_{f0} > 0$  is the preference for issuing bonds and  $b_{f1} < 0$  is the sensitivity of firms' bonds to net disposable income.

Firms hold other firms' equities as parent companies. The price of equities held by firms depends on the price of equities other firms issued,<sup>14</sup>

$$P_{e_{df},t} = P_{e_{yf},t}. \quad (52)$$

Firms would invest abroad in the form of outward foreign direct investment (FDI) when domestic investment is less profitable,

$$\frac{FDI_{out,t}}{E_{yf,t-1}} = fdi_{out0} + fdi_{out1} \frac{\Pi_{f,t-1} - INT_{pf,t-1}}{P_{k1,t} k_{1f,t-1}} \quad (53)$$

where  $fdi_{out0} > 0$  is the preference for outward FDI and  $fdi_{out1} < 0$  is the sensitivity of outward FDI to the net profit rate of domestic investment.

14. It comes from the empirical results, the implicit price growth of firms' equity held can only be statically explained by the price of firms equity issued.

Firms buy insurance but less when they receive sufficient cash flows,

$$\frac{A_{f,t}}{E_{yf,t-1}} = a_{f0} + a_{f1} + \frac{FP_{t-1}}{E_{yf,t-1}} \quad (54)$$

where  $a_{f0} > 0$  is the preference for insurance and  $a_{f1} < 0$  is the sensitivity of firms' insurance to net disposable income.

### 2.3.6 Banks

Banks earn revenue and interest from lending. They also pay wages, taxes, interest on deposits and inter-bank lending, dividends and insurance indemnity. As the closing sector of the model, the vertical consistency of the banks' transaction flows, that is, budget constraint is inherently fulfilled.

The central bank is included in the banking sector and runs an inflation-biased Taylor Rule monetary policy by adjusting the ten-year government bond yield and targeting housing prices, in addition,

$$r_{10,t} = r_0 + (1 - r_1 - r_2)r_{10,t-1} + r_1 \Delta \ln P_{k_b,t} + r_2 \pi_t \quad (55)$$

where  $\pi_t = \frac{\Delta P_{c,t}}{P_{c,t-1}}$  denotes the CPI inflation,  $r_0 > 0$  is the ten-year government bond yield

lower bound,  $r_1 > 0$  is the sensitivity of the ten-year government bond yield to housing price growth and  $r_2 > 0$  is the sensitivity of the ten-year government bond yield to CPI inflation.

The banks' rate of interest received, that is, lending rate, is positively correlated to capacity utilisation (counter-cyclical),

$$\ln r_{rb,t} = r_{rb0} + r_{rb1} U_{k,t-1} \quad (56)$$

where  $r_{rb0}$  is the lower bound in logarithm and  $r_{rb1} > 0$  is the semi-elasticity of banks' rate of interest received to capacity utilisation.

Firms' rate of interest paid co-moves with banks' rate of interest received.<sup>15</sup>

$$r_{pf,t} = r_{pf0} + (1 - r_{pf1})r_{pf,t-1} + r_{pf1} r_{rb,t} \quad (57)$$

where  $r_{pf0} > 0$  is the interest rate premium and  $r_{pf1} > 0$  is the sensitivity of firms' rate of interest paid to banks' rate of interest received.

Other domestic interest rates positively correlate to ten-year government bond yield (see the Appendix 1, available online at <https://doi.org/10.4337/ejep.2024.0141>).

Banks' fixed capital formation rate,  $\frac{\Delta k_{1b,t}}{k_{1b,t-1}}$ , depends on banks' net profit rate,  $\frac{BP_{g,t-1} + DIV_{pb,t-1}}{P_{k_1,t} k_{1b,t-1}}$ ,

15. The largest proportion of interest received by banks is paid by firms in terms of bonds and loan interest.

$$\frac{\Delta k_{1b,t}}{k_{1b,t-1}} = i_{b0} + i_{b1} \frac{BP_{g,t-1} + DIV_{pb,t-1}}{P_{k_1,t} k_{1b,t-1}} \quad (58)$$

where  $i_{b0}$  is banks' autonomous fixed capital formation rate and  $i_{b1} > 0$  is the sensitivity of banks' fixed capital formation rate to net profit rate.

Banks have liquidity preference for holding deposits and increase their holding if the real rate of interest received increases,  $r_{rb,t} - \pi_{y,t-1}$ ,

$$\frac{D_{b,t}}{E_{lb,t-1}} = d_{b0} + d_{b1} (r_{rb,t} - \pi_{y,t-1}) \quad (59)$$

where  $d_{b0} > 0$  is banks' liquidity preference for holding deposits and  $d_{b1} > 0$  is the sensitivity of banks' deposits to the real rate of interest received.

Banks issue bonds in case of a shortage of funds because banks face liquidity risk by holding long-term assets, for example, firm loans, and short-term debts, for example, household deposits, and would issue less if the real rate of interest paid rises,  $r_{pb,t} - \pi_{y,t-1}$ ,

$$\frac{B_{lb,t}}{E_{lb,t-1}} = b_{lb0} + b_{lb1} (r_{pb,t} - \pi_{y,t-1}) \quad (60)$$

where  $B_{lb0} > 0$  is banks' liquidity demand for issuing bonds and  $b_{lb1} < 0$  is the sensitivity of banks' bonds issued to the real rate of interest paid.

Banks, including financial corporations, would invest in investment fund shares for risky profits, and they would invest more if it is more profitable,  $\frac{DIV_{rb,t} + REV_{e_{ab},t} + REV_{if_{ab},t}}{E_{ab,t-1} + IFS_{ab,t-1}} + \pi_{y,t-1}$ , and less when they have sufficient cash flows,  $\frac{BP_{t-1}}{E_{lb,t-1}}$ ,

$$\frac{IFS_{ab,t}}{E_{lb,t-1}} = if_{ab0} + if_{ab1} \left( \frac{DIV_{rb,t} + REV_{e_{ab},t} + REV_{if_{ab},t}}{E_{ab,t-1} + IFS_{ab,t-1}} + \pi_{y,t-1} \right) + if_{ab2} \frac{BP_{t-1}}{E_{lb,t-1}} \quad (61)$$

where  $if_{ab0} > 0$  is the preference for holding investment fund shares,  $if_{ab1} > 0$  is the sensitivity of banks' investment fund shares held to the real rate of investment fund shares return and  $if_{ab2} < 0$  is the sensitivity of banks' investment fund shares held to net disposable income.

### 2.3.7 Governments

Governments receive taxes, including carbon taxes, interest rates from deposits, dividends and social contributions. They pay wages, interest for bonds and social benefits.

Governments' consumption consists of goods and services provided to society. It is pro-cyclical because when economic activity increases, the demand for public goods and services increases. For simplicity, we assume it is proportional to real output,

$$c_{g,t} = c_{g0} y_{t-1} \quad (62)$$

Similarly, we also assume government investments are proportional to real output,

$$i_{g,t} = i_{g0} \mathcal{Y}_{t-1} \quad (63)$$

The Chinese commercial banks are mainly state-owned. The price of government equities held depends largely on the price of banks' equities issued,

$$\Delta \ln P_{e_g,t} = p_{eg0} + p_{eg1} (\ln P_{e_g,t-1} - p_{eg2} - p_{eg3} \ln P_{e_{bb,t-1}}) \quad (64)$$

where  $p_{eg0} > 0$  is the return premium of government equities,  $0 < p_{eg1} < 1$  is the long-term correction of the price of government equities,  $p_{eg2}$  is the price premium of government equities in logarithm and  $p_{eg3} > 0$  is the elasticity of the price of governments' equities held to the price of banks' equities issued.

### 2.3.8 The rest of the world

The RoW demands export goods, supplies import goods and other current transfers and financial transfers between the domestic sectors.

The nominal effective exchange rate (rise= appreciation),  $XR_t$ , follows the uncovered interest parity, which depends on the ten-year government yield,  $r_{10,t}$ , and federal funds rate,  $FFR_t$ ,

$$\Delta \ln XR_t = xr_0 + xr_1 \ln \left( \frac{1 + r_{10,t}}{1 + FFR_t} \right) \quad (65)$$

where  $xr_0 < 0$  is the preference premium for domestic currencies compared to foreign currencies and  $xr_1 > 0$  is the elasticity of nominal effective exchange rate to interest parity.

The federal funds rate,  $ffr_t$ , and foreign GDP (nominated in US dollar),  $Y_{r,t}$ , are exogenous in the model and calibrated for the baseline scenario we discuss in Section 3.

Due to the conversion of currencies, the rate of interest paid by the foreign sector includes the change in exchange rate within the maturity,

$$r_{pr,t} = r_{pr0} + (1 - r_{pr1} - r_{pr2})r_{pr,t-1} + r_{pr1}\Delta \ln XR_t + r_{pr2}FFR_t \quad (66)$$

where  $r_{pr0} > 0$  is the interest rate premium,  $r_{pr1} < 0$  is the sensitivity of the interest rate paid by the foreign sector to nominal effective exchange rate growth and  $r_{pr2} > 0$  is the sensitivity to federal funds rate.

Equivalently, the rate of interest received by the foreign sector also includes the change in exchange rate,

$$r_{rr,t} = r_{rr0} + (1 - r_{rr1})r_{rr,t-1} + r_{rr1}\Delta \ln XR_t \quad (67)$$

where  $r_{rr0} > 0$  is the interest rate lower bound and  $r_{rr1} > 0$  is the sensitivity of the interest rate received by the foreign sector to nominal effective exchange rate growth.

Exports depend on foreign demand converted into domestic currencies and deflated by export price,  $\frac{Y_{r,t}}{P_{x,t}XR_t}$ ,

$$\Delta \ln x_t = x_0 + x_1 \Delta \ln \frac{Y_{r,t}}{P_{x,t} XR_t} + x_2 \left( \ln x_{t-1} - x_3 - x_4 \ln \frac{Y_{r,t-1}}{P_{x,t-1} XR_{t-1}} \right) \quad (68)$$

where  $x_0$  is the short-run autonomous export demand,  $x_1 > 0$  is the short-run elasticity of export to foreign demand,  $-1 < x_2 < 0$  is the export long-run correction parameter,  $x_3 > 0$  is the long-run autonomous export demand in logarithm and  $x_4 > 0$  is the long-run export demand elasticity.

For simplicity, imports are proportional to real GDP,

$$m_t = m_{0,t} y_{t-1} \quad (69)$$

where  $m_{0,t}$  is a moving parameter to calibrate the real GDP of our baseline scenario.

The foreign sectors lend loans to the domestic sectors depending on the rate of interest received, the higher the return, the more they supply,

$$\frac{\Delta L_{ar,t}}{L_{ar,t-1}} = l_{ar0} + l_{ar1} r_{rr,t} \quad (70)$$

where  $l_{ar0}$  is the foreign loan autonomous accumulation rate and  $l_{ar1} > 0$  is the sensitivity of foreign loan lending to the rate of interest received by the foreign sector.

The foreign sectors hold equities in both the real sector and the financial sector. The price of the RoW equity held,  $P_{e_r,t}$ , depends on the price of equities issued by firms and banks,

$$\Delta \ln P_{e_r,t} = p_{er0} + p_{er1} \Delta \ln P_{e_{fb},t-1} + p_{er2} (\ln P_{e_r,t-1} - p_{er3} \ln P_{e_{ff},t-1}) \quad (71)$$

where  $p_{er0}$  is the return premium of the RoW equity held,  $p_{er1} > 0$  is the short-run elasticity of the price of the RoW equities held to the price of banks' equity issued,  $-1 < p_{er2} < 0$  is the long-run correction parameter and  $p_{er3} > 0$  is the long-run elasticity of the price the RoW equities held to the price of firms equities issued.

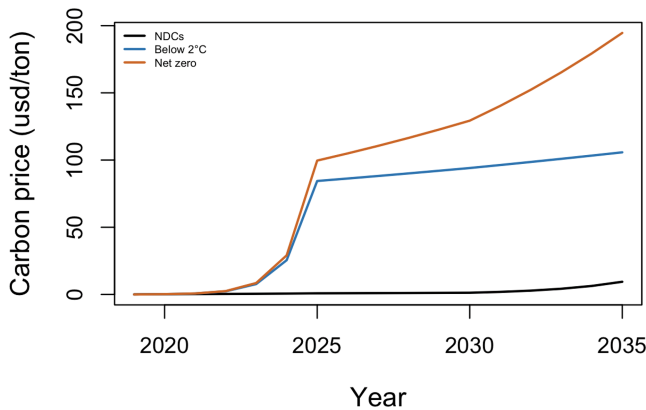
Inward FDI depends on the domestic firms' gross profit,  $\frac{\Pi_{f,t-1}}{P_{k,t} k_{1f,t-1}}$ , with more domestic economic growth, cheaper labour, lower taxes and cheaper fixed asset prices, the domestic sector will attract more inward FDI,

$$\frac{\Delta FDI_{in,t}}{FDI_{in,t-1}} = fdi_{in0} + fdi_{in1} \frac{\Pi_{f,t-1}}{P_{k,t} k_{1f,t-1}} \quad (72)$$

where  $fdi_{in0}$  is the autonomous inward FDI accumulation rate and  $fdi_{in1} > 0$  is the sensitivity of inward FDI to domestic firms' gross profit rate.

### 3 SIMULATION

We run the model to simulate different scenarios of carbon pricing from the Network for Greening the Financial System (NGFS) from 2019 to 2035. Our baseline scenario is the national determined contributions (NDCs) scenario from the NGFS, which follows the



*Note:* The NGFS scenarios are displayed every five years before 2060 and every decade afterward. Interpolations by assuming the same growth rate between grids. Converted using the US CPI and official exchange rate from the World Bank.

*Source:* NGFS.

*Figure 3 Carbon prices*

commitment of the country to the Paris Agreement. The baseline scenario only includes carbon pricing. Green subsidies are not implemented,  $GS_t = 0$ . We run two other scenarios for carbon prices to see their effects. One is the below 2°C scenario, and the other one is the net zero scenario (see Figure 3).

### 3.1 Initial values and parameters specifications

The initial values and parameters are obtained, calculated, estimated or calibrated from the real data or the NDC scenario (see Tables 1 and 2 in Appendix 1, available online at <https://doi.org/10.4337/ejeep.2024.0141>). Our data cover from year 2000 to 2019. Stock data, for example, NFAs and financial assets and liabilities, are obtained from China's National Balance. Transaction data are obtained from the NBSC. Data for energy and emissions are obtained from the NBSC, China Energy Portal, World Bank and Our World in Data.

The GDP deflator is obtained from World Development Indicators. Other price variables are obtained or estimated from NBSC. The nominal effective exchange rate is obtained from the European Central Bank. Capacity utilisation is obtained from Wang et al. (2021). Fiscal tax rates and interest rates are estimated using the transaction data and stock data, dividing the flows by the stocks. Employment data are obtained from the World Bank. The real wage is calculated by the wage bill payment over employment deflated by the GDP deflator. Equity price indices are calculated by the revaluation effect over the lagged stock in value. The revaluation effect of equities is calculated by the equity accumulation equation.

Capital for energy production is calculated by accumulating the fixed capital formation for energy production. We assume the same accumulation rate of capital for energy production as the accumulation rate of firms' fixed capital in 2000. Therefore, the share of

capital for energy production is the same as the share of fixed capital formation for energy production in firms' fixed capital formation. Then, we accumulate the flows by using the firms' capital depreciation rate and capital price. Green capital for renewable energy is calculated using equation (3).

Parameters are mostly estimated by running simple OLS regressions with Durbin–Watson to ensure they do not reject the homoskedasticity hypothesis. Moreover, we run augmented Dickey–Fuller (ADF) tests on the residuals to ensure cointegrations between the variables.  $\beta_{eg}$  is borrowed from Aleti/Hochman (2020).  $ce_1 = -ce_0$  is calibrated from equation (18) to have  $\theta = 0$  when  $\Gamma_{re} = 1$ , zero carbon emission when 100 per cent use of renewable energy.

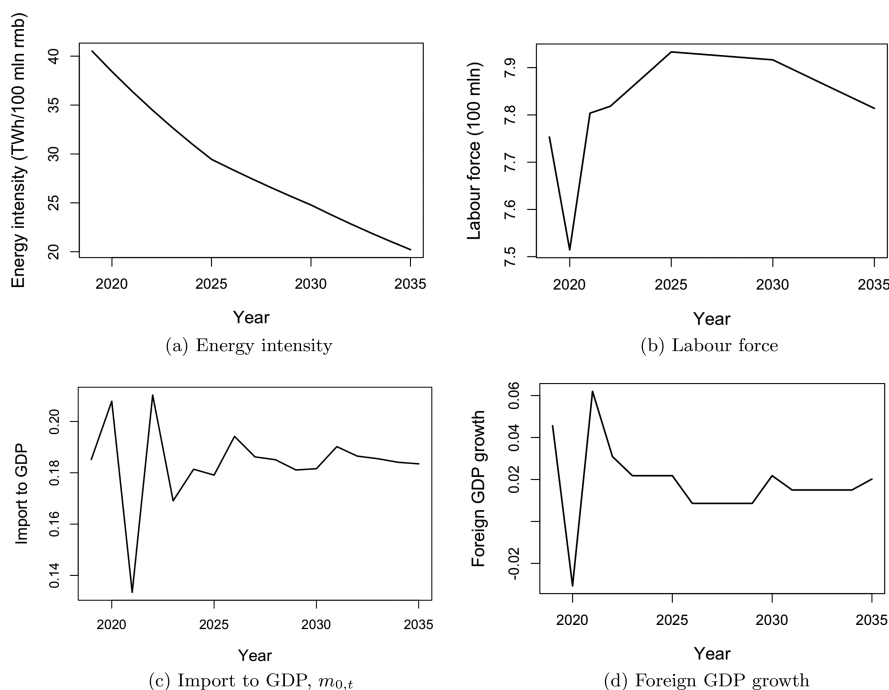
To avoid spikes in the initial period simulation, we assume the economy is at balanced growth in the initial period. Stock variables' initial values are set using the data. The initial value of foreign GDP is calculated using the world GDP substrates by China's GDP from the World Bank. Final goods prices are assumed to be 1 for the initial period. The balanced growth path requires stocks and flows to grow at the same rate as the initial GDP growth rate. Goods prices, interest rates and exchange rates are fixed. The price of equities grows at the real GDP growth rate. Energy consumption growth is assumed to be 0 in the initial period, so the energy prices remain constant. These conditions require some initial values of the variables and parameters to be calibrated using the equations.

We calibrate real GDP growth, energy intensity growth, labour force and foreign GDP growth to historical data until 2022 and our baseline scenario afterwards. Energy intensity growth,  $g_{ey,t}$ , is an exogenous variable. We simply set its values to the time series (see Figure 4(a)). The labour force is estimated based on the labour force data of the World Bank and the Chinese population prediction of the NGFS scenario by simply assuming the labour force proportion is fixed at the level of 2022, which is around 55.98 per cent (see Figure 4(b)). For real GDP growth, which is an endogenous variable, we let  $m_{0,t}$  from the import equation (equation (69)) to be a moving parameter to calibrate it (see Figure 4(c)). Foreign GDP growth is exogenous, and we employ the time series data (see Figure 4(d)).

## 3.2 Results

### 3.2.1 Carbon pricing

Figure 5 shows the main results of the simulations. The black line is our baseline scenario (NDCs). The blue and red lines are the results of carbon prices of the below 2°C scenario and the net zero scenario. Carbon pricing has a negative effect on real GDP (Figure 5(a) and 5(b)). Household consumption decreases due to higher carbon tax payments and also because of the inflation caused by the carbon tax (Figure 5(c) and 5(d)). Firms invest less under higher carbon tax payments because of lower profit rates and lower capacity utilisation (Figure 5(e) and 5(f)). Household investment decreases because of the rise of housing prices caused by carbon pricing (Figure 5(g) and 5(h)). Export decreases under higher carbon taxes because export goods become more expensive and less competitive (Figure 5(i)). Consequently, China runs a current account deficit under higher carbon taxes (Figure 5(j)). The real equity price of firms issued, which is the price of firms' equities issued deflated by GDP deflator, decreases under a higher carbon tax, showing that the firm's balance sheet worsens in real term (Figure 5(k)). Public debt to GDP drops in the short run because of higher carbon tax revenue but rises in the long run because the denominator, GDP, decreases even more, and green transition reduces carbon tax revenue to GDP in the long run (Figure 5(l) and 5(m)). Households' net worth in real terms, deflated by GDP, increases slightly in the medium run, mainly because of the revaluation



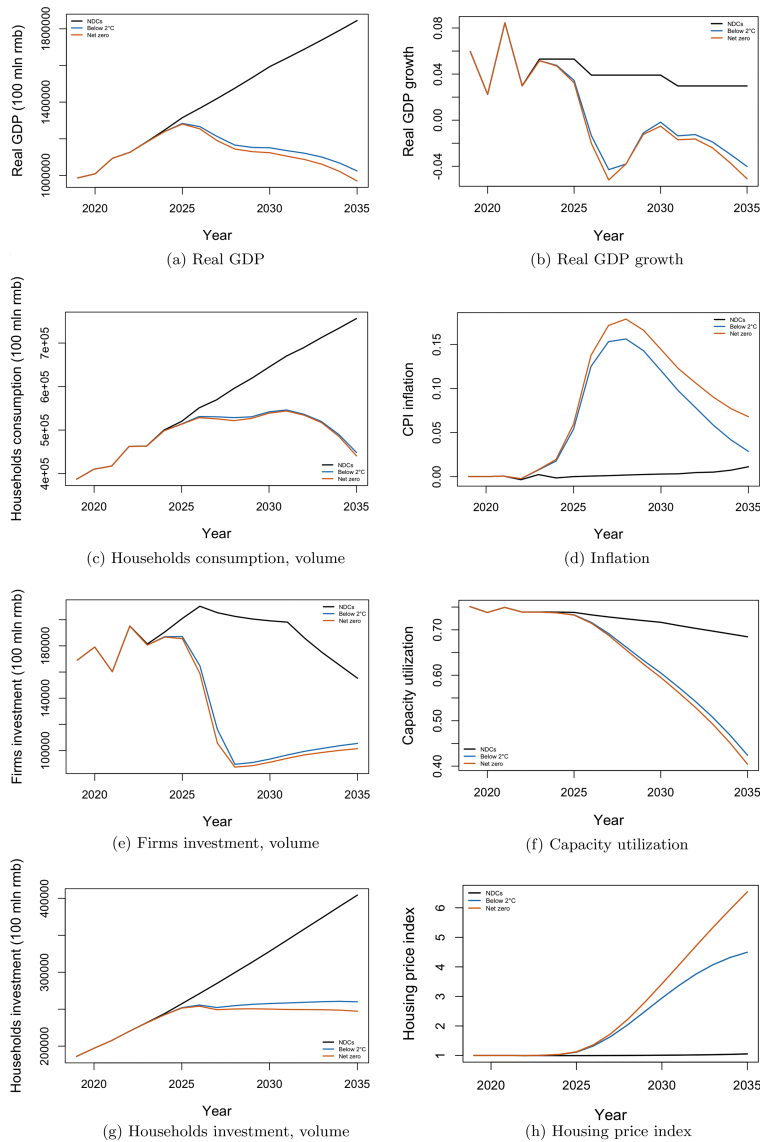
*Note:* We calibrate to historical data until 2022, and the NDCs of the NGFS scenario afterwards. The NGFS scenario is displayed every five years before 2060. Interpolations by assuming the same growth rate between grids. (a) Energy intensity, (b) labour force, (c) import to GDP,  $m_{0,t}$  and (d) foreign GDP growth.

*Source:* World Bank, NGFS.

*Figure 4 Calibration variables*

of housing. Although the model does not have heterogeneous agents to study inequality, the wealth inequality increases because only house owners benefit from this revaluation effect, and houses are less affordable for the unhoused people as shown household investment decreases (Figure 5(n)).

Energy consumption becomes smaller under higher carbon prices because of their negative impact on aggregate demand (Figure 5(o)). Carbon pricing stimulates green transitions as expected. Only the net zero carbon pricing scenario achieves the policy target described in Table 1, 25 per cent of renewable energy share by 2030. The below 2°C scenario shows a decline in renewable energy share in the long run because decreasing energy demand shrinks the energy sector and reduces the scale effect of renewable energy production. While the net zero scenario has a sufficient high carbon tax level to compensate for this negative effect (Figure 5(p)). Carbon intensity decreases over time as the energy intensity decreases. The positive effect of carbon pricing on green transition decreases carbon intensity further. Even the baseline scenario exceeds the policy target for carbon intensity described in Table 1, 65 per cent less than the level of 2005 by 2030



*Note:* The black line is our baseline scenario (NDCs). The blue and red lines are the results of carbon prices of the below 2°C scenario and the net zero scenario. The horizontal lines and vertical lines in (p)–(r) are the respective policy targets described in Table 1. (a) Real GDP, (b) real GDP growth, (c) households' consumption, volume, (d) inflation, (e) firms' investment, volume, (f) capacity utilization, (g) households' investment, volume, (h) housing price index, (i) export, volume, (j) current account to GDP, (k) real equity price of firms, (l) public debt to GDP, (m) carbon tax to GDP, (n) households' net worth, volume, (o) energy consumption, (p) share of renewable energy, (q) carbon intensity and (r) carbon emission

Figure 5 Simulation results, carbon price scenarios

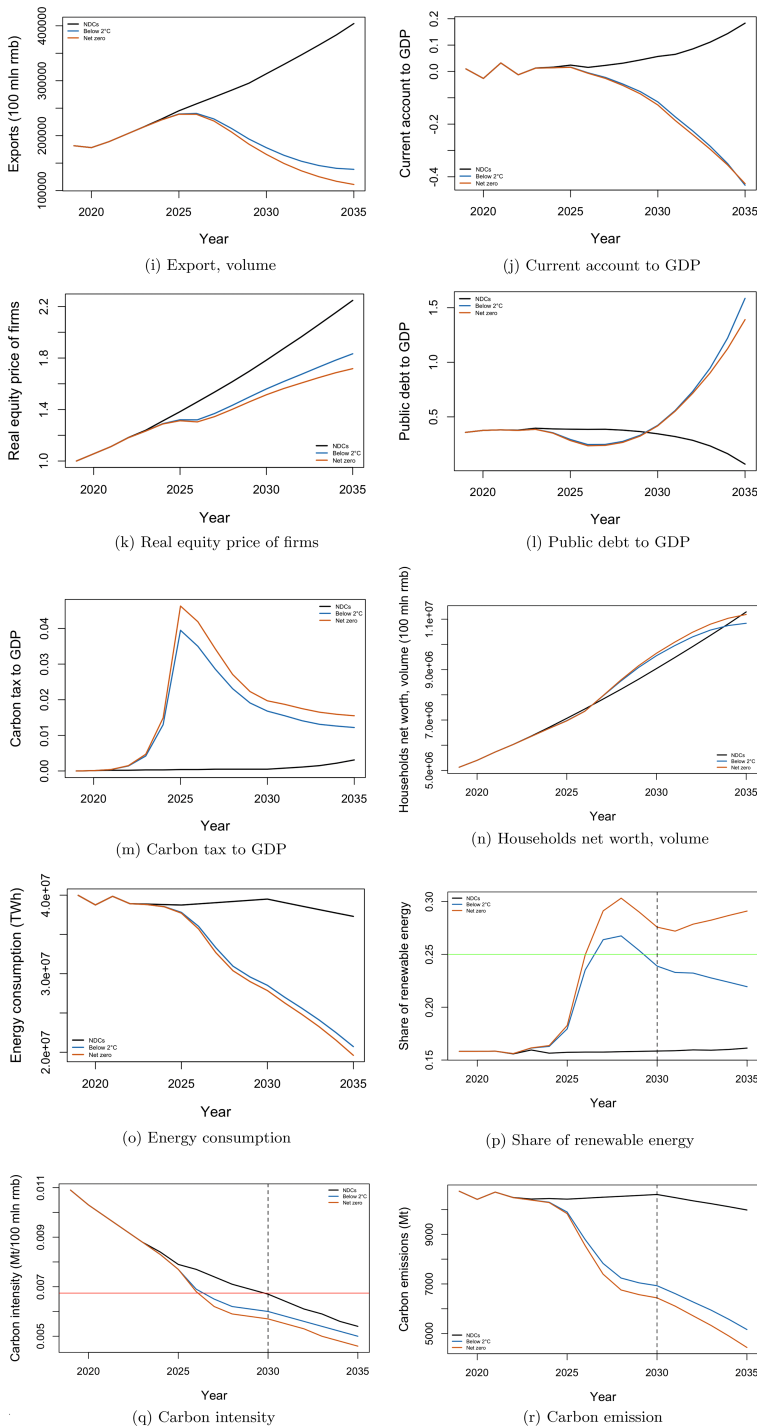


Figure 5 (continued)

(Figure 5(q)). Carbon pricing decreases carbon emission in two aspects: (i) it stimulates the green transition and reduces carbon intensity and (ii) it deteriorates aggregate demand and reduces energy consumption. Surprisingly, our baseline scenario just matches the policy target described in Table 1, carbon emission peaks in 2030, which we did not calibrate on purpose (Figure 5(r)).

### 3.2.2 Green and conventional fiscal policy

In this section, we compare the effect of green fiscal policy, green subsidies to renewable energy producers and two conventional fiscal policies, capital transfers to firms and social benefits to households (Figure 6). Based on our baseline scenario (NDCs), the government uses its carbon tax revenue to fund these policies (carbon tax rebate). Specifically, in the green subsidies scenario, green subsidies can only cover a maximum of 85 per cent of the total cost of renewable energy production.<sup>16</sup> If carbon tax revenue exceeds this amount, the remaining revenues are transferred to firms in terms of regular capital transfers,

$$GS_t = \min\{CT_t, 0.85(F_{re} + r_{k_{re},t}K_{re,t})\} \quad (73)$$

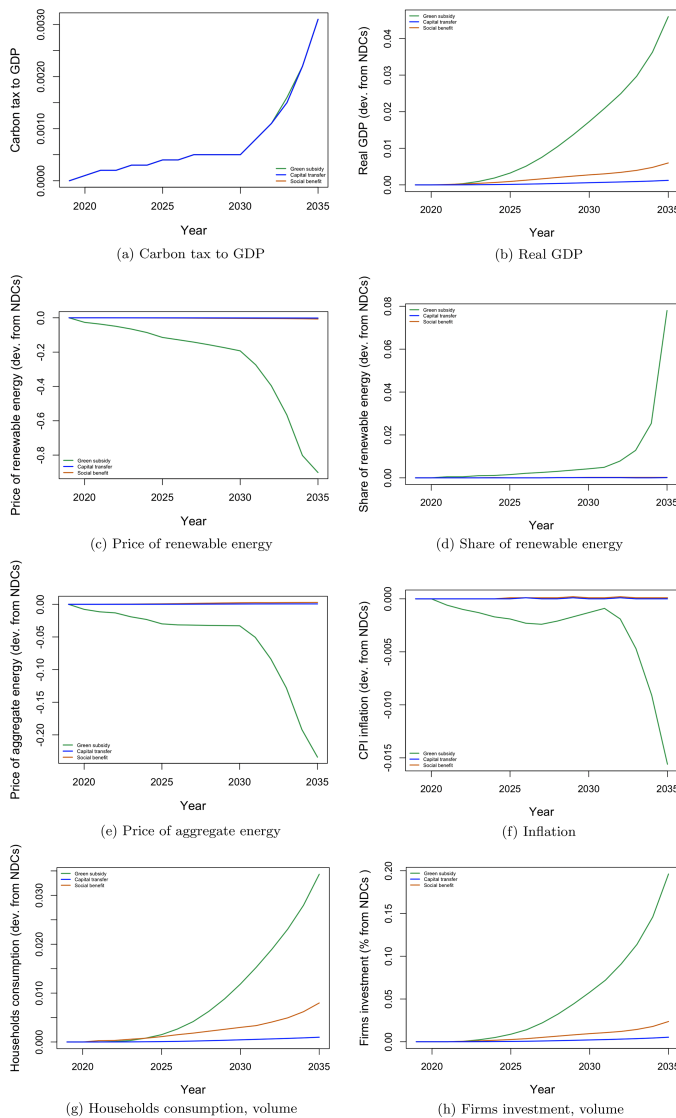
$$TRK_t = CT_t - GS_t \quad (74)$$

Figure 6(a) shows the carbon tax to GDP in these three scenarios. They stand for a maximum of around 0.3 per cent of GDP, which are small shocks. To better understand the scale of their effect, the figures we show later are deviations of the baseline, that is,

$\frac{Scenario_{shock}}{Scenario_{NDCs}} - 1$  for variables in level and  $Scenario_{shock} - Scenario_{NDCs}$  for variables in rate.

The green line is the green subsidies scenario, the blue line is the capital transfer scenario and the orange line is the social benefits scenario. Green subsidies, compared to conventional fiscal policies, have a more significant positive impact on economic growth by reducing inflation (Figure 6(b)). Green subsidies reduce the price of renewable energy and increase the share of renewable energy (Figure 6(c) and 6(d)). As a consequence, the price of aggregate energy becomes cheaper, which reduces inflation (Figure 6(e) and 6(f)). Under the green subsidies scenario, household consumption increases more significantly than firms' investment because the energy price reduction transmits to CPI reduction directly through equation (37) (Figure 6(g) and 6(h)). Capital transfers do not show a significant effect on firms' investment because firms do not take them into account in their profit, but they reduce the accumulation of firms' debt (Figure 6(i)). Public debt over GDP increases under all of the three fiscal scenarios. Green subsidies increase public debt over GDP more because of the revaluation effect of government bonds in the short run. In the long run, public debt to GDP decreases because of the positive effect of green subsidies on GDP, the denominator, and generates additional fiscal revenues from production taxes and income taxes (Figure 6(j) and 6(k)). Government bond price rises because the interest rates fall, targeting inflation (Figure 6(l)). Energy consumption with green subsidies increases because of the rebound effect (Figure 6(m)). As a consequence, carbon emissions

16. If we set an extreme cost coverage ratio for green subsidies, for example, 90 per cent, the simulation outcomes will be volatile, because if the share of renewable energy increases suddenly in one period, carbon tax revenue will shrink and cannot finance green subsidies in the next period.



*Note:* The green line is the green subsidies scenario, in which the government subsidizes 85 per cent of the production cost of renewable energy funded by the carbon tax revenue. If the carbon tax revenue exceeds this amount, the remaining revenues are transferred to firms in terms of regular capital transfers. The blue line is the capital transfer scenario, in which the government transfers all the carbon tax revenue to firms. The orange line is the social benefits scenario, in which the government increases social benefits to households by the amount of the carbon tax revenue. (a) Carbon tax to GDP, (b) real GDP, (c) price of renewable energy, (d) share of renewable energy, (e) price of aggregate energy, (f) inflation, (g) households' consumption, volume, (h) firms investment, volume, (i) firms' leverage ratio, (j) public debt to GDP, (k) price of government bonds, (l) 10-year government bond yield, (m) energy consumption and (n) carbon emissions

*Figure 6 Simulation results, green and conventional fiscal policy scenarios.*

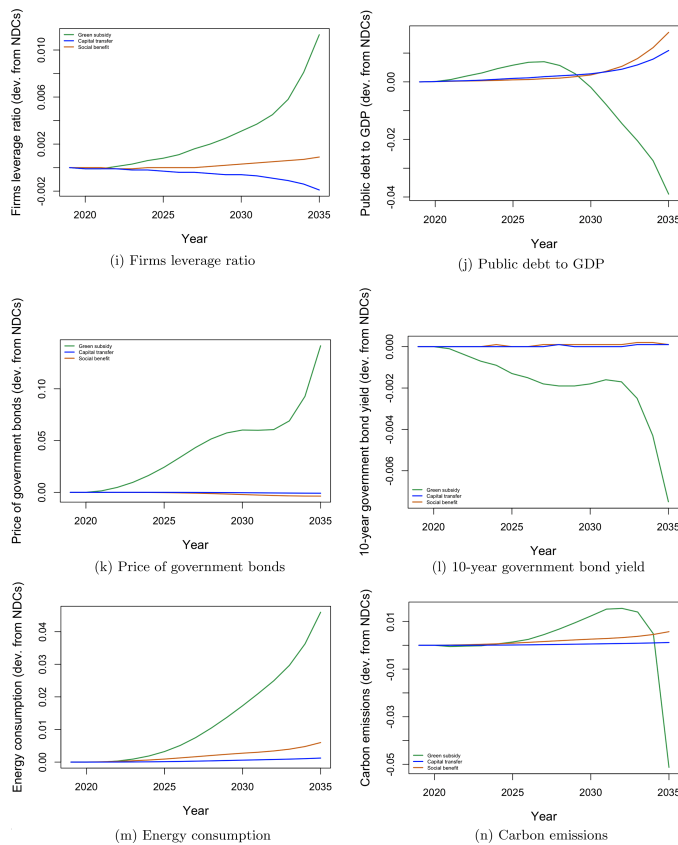


Figure 6 (continued)

increase in the medium run with green subsidies but decrease in the long run as the share of renewable energy increases significantly (Figure 6(n)).

In summary, carbon pricing stimulates green transition and reduces carbon intensity and emissions at the cost of deteriorating GDP and causing inflation. Export goods become more expensive and less competitive, resulting in a huge current account deficit. As the share of renewable energy increases, the cost of carbon tax to GDP decreases, but the economy remains in recession. Firms' balance sheets worsen. Governments receive more fiscal revenues from carbon tax and bear less public debt in the short run but face a higher public debt over the GDP ratio in the long run. Green subsidies, compared to conventional fiscal policy, stimulate green transition and have more positive effects on the economy, higher economic growth and less inflation.

#### 4 CONCLUSION AND REMARK

This paper develops an SFC macroeconomy model with an energy sector for China to investigate the effect of green policies on green transition and aggregate demand. The model is built empirically based on the national balance sheet and transaction-flow matrix of China. The energy sector is driven by aggregate demand and includes two types of

energy production, conventional energy and renewable. The allocation of these two types of energy consumption/production depends on a VES consumption preference/production technology function for aggregate energy and cost functions. We provide an analytical solution for green transition that shows the relative cost of using conventional energy with respect to renewable energy determines the share of renewable energy, and the development of the energy sector promotes green transition. As the energy sector develops, green transition happens in the short run but hits a ceiling in the long run because the price of renewable energy stops decreasing as the financing cost accumulates. It calls for the necessity of green policies such as carbon taxes, green subsidies and green finance.

We calibrate the model to the NDC scenarios from the NGFS and run simulations with different carbon pricing scenarios, below 2 °C and net zero. The simulation results demonstrate that carbon pricing stimulates green transition but has a negative impact on the economy, low growth and high inflation. Firms' investment falls down sharply and their book value decreases in real terms. Governments benefit from carbon taxes in the short run by receiving additional fiscal revenue but bear a higher public debt over GDP in the long run because of the negative impact of carbon taxes on the economy. Carbon taxes reduce carbon intensity and carbon emissions. Only the net zero scenario achieves the green share policy target in 2030. Then, we ran more scenarios to compare the effects of green fiscal policy, green subsidies to renewable energy producers and two conventional fiscal policies, capital transfers to firms and social benefits to households, which are all financed by the carbon tax revenue from the baseline scenario. The results show that green subsidies stimulate green transition and have more positive effects on the economy, including higher economic growth and less inflation.

One caveat of our model is that the assumption in the energy sector is too strong due to a lack of data. Renewable energy having the same production technology as conventional energy is unrealistic. The model also does not capture the effect of disaggregated investment. On the one hand, the green transition requires investment in renewable energy production, which generates economic growth. On the other hand, it reduces investment in conventional energy production and deteriorates growth.

The model can also be extended in some directions. We could model the energy sector more realistically with more detailed data when they are available. We could explore the effect of green finance by disaggregating bonds/loans into green and brown bonds/loans, assuming that conventional energy producers are financially constrained by banks (credit rationing).

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