Modelling Green Transition of the Chinese Economy

David An

September 2023

Abstract

This paper develops a stock-flow consistent (SFC) macroeconomy model with an energy sector for China to investigate the effect of green policies on green transition and aggregate demand. Our model illustrates the scale of the energy sector matters to green transition, and the relative cost of using conventional energy with respect to renewable energy determines the share of renewable energy. 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 2060. The results demonstrate carbon pricing stimulates green transition but has a negative impact on the economy, accompanied by a reduction of output and a rise in inflation. Carbon pricing makes firms more indebted and the government less indebted in the long run. As the share of renewable energy increases, carbon emissions decrease. As a consequence, the economic cost of carbon pricing decreases. The results also show that the revaluation effect of fixed capital determines firms' leverage in the short run. An expansionary fiscal policy targeting firms can stimulate aggregate demand without a significant increase in public debt over GDP ratio. Green subsidies benefit economic growth and stimulate green transition at a slight cost of raising public debt over GDP ratio. Green regulation has a dramatic short-run effect in boosting green transition.

1 Introduction

China, the largest carbon emitter in the world, has recently formulated a series of policy targets aiming at reducing carbon emissions (summarized in Table 1). According to the "14th Five-Year Plan", carbon emissions per GDP in 2025 and 2030 should not go beyond 18% of the level in 2020 and 65% of the 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% in 2030 and more than 80% by 2060

Table 1: China climate change policy targets

	2025	2030	2060
Carbon emission per 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*

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 16/07/2021), 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.

There are a few studies using different modelling techniques that have addressed some ecological issues in China. Carraro and Massetti (2013) examine future energy and emissions 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 and 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 with KLEM-CHN, a dynamic recursive Solow-Swan growth type model. However, all of these studies lack attention to the 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, i.e. Euler equation.

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, e.g. the Great Recession (Rezai et al., 2013). Another advantage of the SFC approach is that it pays explicit attention to macro-financial feedback loops. The balance sheets in SFC models could reflect the 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 one of 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 these literatures 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, e.g. IPCC scenarios. This paper, different from them, attempts to model the system of the economy empirically[1]. The model setups are based on the national Balance Sheet and Transaction Flow matrix, which makes it capable of capturing the specific features of the Chinese economy (Zezza and Zezza, 2019). Behaviour equations are designed based on economic theory but adjusted to the empirical correlation 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 characterized 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 results of the scenarios. And lastly, Section 4 concludes and remarks.

2 The Model

Energy production is driven by aggregate demand. There are two types of capital in the energy sector. Conventional energy capital produces fossil-fuel energy and green energy capital produces renewable energy. Technology progress is characterized as an increase in the proportion of green energy capital that reduces carbon emissions per energy used. The economy consists of 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 to implement monetary policy. The private sector pays carbon taxes to the government according to their emissions, which depends on their value-added and carbon intensity. Accounting equations such as changes in loans and bonds and accumulation of assets and liabilities are modelled to guarantee stock-flow consistency. Behaviour equations, e.g. consumption and investment decisions and deposit savings, are determined by econometric regression. Prices are endogenous and depend on the unit cost of production.

2.1 Energy Sector

Energy consumption depends on aggregate demand,

$$E_t = EY_t Y_t, \tag{1}$$

[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.

where E_t denotes energy consumption, EY_t, energy intensity and Y_t, GDP. For simplicity we set energy intensity exogenous. Its value is calibrated 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,

$$EY_t = EY_{t-1}(1 + ey_{g,t}),\ ey_{g,t} < 0, \tag{2}$$

where $ey_{g,t}$ is the energy intensity growth we are going to calibrate.

Capitals for energy production, ke_t, are required giving the level of energy consumption followed by a simple technology,

$$E_t = e_0 ke_{t-1}^{e_1},\ e_1 > 0. \tag{3}$$

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

$$ke_t = \left(\frac{E_{t+1}^{exp}}{e_0}\right)^{\frac{1}{e_1}} = \left(\frac{E_t(1 + ey_g)(1 + g_{y,t})}{e_0}\right)^{\frac{1}{e_1}}, \tag{4}$$

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

There is imperfect substitution between conventional energy and renewable energy, because energy users/producers need capitals, i.e. facilities, to consume/produce renewable energy, and these initial capitals demand conventional energy to produce. When green capital for renewable energy production does that exists, conventional energy is a complement for renewable energy. As renewable energy production expands, conventional energy and renewable energy becomes substitute. 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 and Hochman (2020),

$$\begin{gathered} E_t = V(CE_t,\ RE_t) = \gamma CE_t^{\omega(1-\delta\rho)}\left[RE_t + (\rho - 1)CE_t\right]^{\omega\delta\rho}, \\ \gamma > 0,\ \omega > 0,\ 0 < \delta < 1,\ 0 \le \delta\rho \le 1,\ \frac{RE_t}{CE_t} > \frac{1-\rho}{1-\delta\rho}. \end{gathered} \tag{5}$$

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

$$\min_{CE_t,\ KE_t} P_{CE,t}CE_t + P_{RE,t}RE_t, \tag{6}$$

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

$$\frac{P_{CE,t}}{P_{RE,t}} = \frac{\frac{\partial V}{\partial CE_t}}{\frac{\partial V}{\partial RE_t}} = \beta_{eg} + \alpha_{eg}\frac{RE_t}{CE_t}{}^2, \tag{7}$$

where $\alpha_{eg} = \frac{1-\delta\rho}{\delta\rho}$ and $\beta_{eg} = \frac{\rho-1}{\delta\rho}$. We define the share of green capitals for renewable energy production as $\Gamma_{eg,t} = \frac{keg_t}{ke_t}$, and assume the same energy production technology (equation 3) for green capitals, then the share of renewable energy, $\Gamma_{re,t} = \frac{RE_t}{E_t}$, follows

$$\Gamma_{re,t} = (\Gamma_{eg,t-1})^{e_1} = \left(\frac{keg_{t-1}}{ke_{t-1}}\right)^{e_1}. \tag{8}$$

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, then we obtain a function that governs the share of green capitals,

$$\Gamma_{eg,t} = \left[\frac{\alpha_{eg}}{\frac{P_{CE,t}+\frac{CT_t}{CE_t}}{P_{RE,t}} - \beta_{eg}} + 1\right]^{-\frac{1}{e_1}},\ \alpha_{eg} > 0,\ \beta_{eg} < 0. \tag{9}$$

[2] Notice that the elastcity of substitution of renenwable energy with respect to conventional energy is, $\varepsilon = \frac{\frac{dRE_t}{RE_t}}{\frac{dCE_t}{CE_t}} = -\beta_{eg}\frac{CE_t}{RE_t} - \alpha_{eg}$. At the early stage, when the share of renewable energy is small, the elasticity of substitution is small, conventional energy and renewable energy are compliments (if $RE_t = 0$, $\varepsilon = +\infty$, perfect complimentarity). As the share of renewable energy increases, the elasticity of substitution increases to $-\alpha_{eg}$, when the share of renewable energy approaches to 1.

Here, we have an additional element, $\frac{CT_t}{CE_t}$, is the unit cost of carbon tax (CT_t) for producing conventional energy. Equation (9) tells us the share of green 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 α_{eg} 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 green capital for producing renewable energy.

We assume perfect competition among firms that produce conventional energy and they bear a linear variable production cost, $r_{kce,t}kce_t$. $r_{kce,t}$ is an exogenous variable. It is increasing to represent the fact that fossil fuel becomes more and more costly as we extract them. Its value is calibrated and we will introduce in Section 3. This assumption also guarantees that the share of renewable energy would not decrease in our baseline scenario. The conventional energy producers face the following profit maximization problem,

$$\begin{aligned} \max_{kce_t} &= P_{CE,t+1}CE_{t+1} - r_{kce,t}kce_t \\ &s.t.\, CE_{t+1} = e_0 kce_t^{e_1}. \end{aligned} \tag{10}$$

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

$$P_{CE,t+1} = \frac{r_{kce,t}}{e_0 e_1} kce_t^{1-e_1},\ e_1 < 1. \tag{11}$$

For firms producing renewable energy, we assume they only bear a fixed cost, F_{re}, and are subsidised a proportion by the government, $GS_t = \gamma_{GS,t}F_{re}$. Assuming they earn zero profit, the price of renewable energy simply equals to the unit cost of renewable energy production,

$$P_{RE,t+1} = \frac{F_{re} - GS_t}{e_0} keg_t^{-e_1}. \tag{12}$$

From equation (11) and (12), it is obvious that price and quantity for conventional energy production are positively correlated and negatively correlated for renewable energy. 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 of its electricity price. A potential interpretation of this phenomenon is that the conventional energy industries are already well established, they do not bear any fixed cost but only variable costs such as buying coals, paying wages and rents. Thus, the marginal production decrease as the quantity increases, and price goes up. However, the green energy sectors do not bear variable cost, because the inputs (e.g. wind, solar) are free from nature, but they face a fixed cost for the equipment construction or technology R&D expenditure. As the production expands, the fixed cost is amortized and renewable energy becomes cheaper.

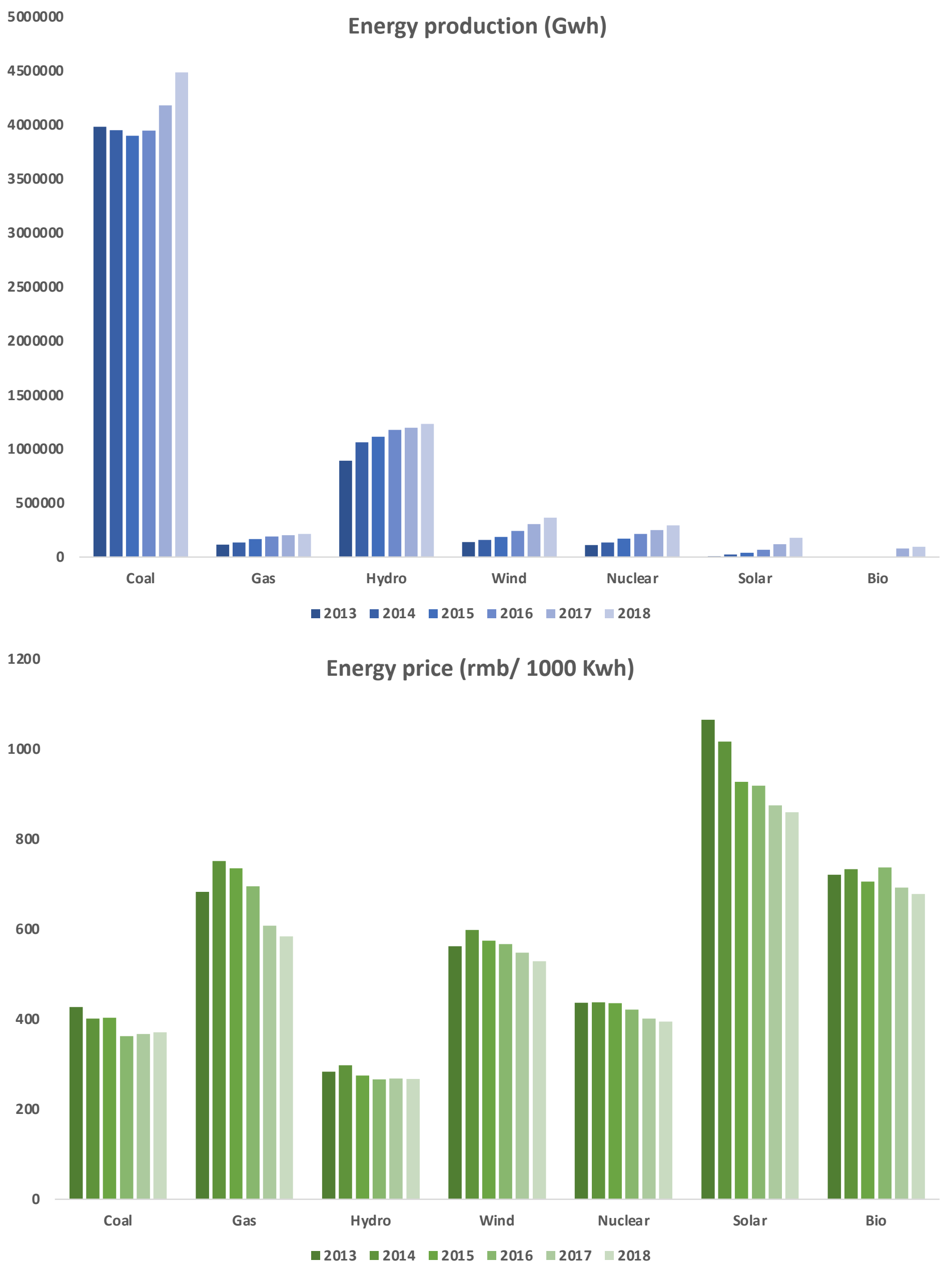


Figure 1: Electric production and price by energy type
Data source: China Energy Portal

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

Proposition 1: *The scale of the energy sector accelerates the green transition in the early stage.*

Proposition 2: *Green transition takes place as the energy sector develops.*

Proposition 3: *Carbon pricing or carbon tax accelerates green transition at the early stage.*

Proposition 4: *Carbon pricing or carbon tax are less effective when green transition is already sizeable in the sense that it does not increase the speed of green transition.*

Proof:

Dividing equation (11) by (12), we get the price ratio,

$$\frac{P_{CE,t+1}}{P_{RE,t+1}} = \frac{r_{kce,t}ke_t}{e_1F_{re}}(1-\Gamma_{eg,t})^{1-e_1}(\Gamma_{eg,t})^{e_1}. \tag{13}$$

ke_t appears in the numerator, as it increases, the share price ratio would increase, so does the share of the green capitals through equation (9). Taking the partial derivative of the price ratio with respect to the share of green capital,

$$\frac{\partial \frac{P_{CE,t+1}}{P_{RE,t+1}}}{\partial \Gamma_{eg,t}} = \frac{r_{kce,t} ke_t}{e_1 F_{re}} \left(\frac{\Gamma_{eg,t}}{1-\Gamma_{eg,t}} \right)^{e_1} \left(e_1 \frac{1-\Gamma_{eg,t}}{\Gamma_{eg,t}} + e_1 - 1 \right). \tag{14}$$

If $\Gamma_{eg} < e_1$, $\frac{\partial \frac{P_{CE,t+1}}{P_{RE,t+1}}}{\partial \Gamma_{eg,t}} > 0$; if $\Gamma_{eg} > e_1$, 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, $\Gamma_{eg,t}$, increases when the share of green capital is lower than the elasticity of energy production with respect to capital, e_1. Combining with equation (9), we know that there is a positive feedback loop between the price ratio and the share of green capital. Thus, the share of green capital will rise as itself, i.e. green transition is spontaneous when green transition is at the early stage. And it is easy to see, the level of capital stock in the energy sector enhances this effect.

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

$$\frac{\partial^2 \Gamma_{eg,t}}{\partial \left(\frac{P_{CE,t}}{P_{RE,t}} \right)^2} = \frac{\alpha_{eg}}{e_1} (\Gamma_{eg,t})^{1+e_1} \left(\frac{P_{CE,t}}{P_{RE,t}} - \beta_{eg} \right)^4 \left[\frac{1+e_1}{e_1} \alpha_{eg} (\Gamma_{eg,t})^{e_1} - 2 \left(\frac{P_{CE,t}}{P_{RE,t}} - \beta_{eg} \right) \right]. \tag{15}$$

Notice that when the price ratio is very small, the second-order partial derivative is positive, the share of green capital is a convex function with respect to the price ratio. When the share of green capital is small, it is an increasing convex function of its own lag and it grows exponentially (see Figure 2). Carbon price or carbon tax can be seen as a positive shock on the share of green transition, which let it jump to higher increasing speed.

One caveat of the propositions is that we do not consider the negative impact of carbon taxes on the economy growth and on the energy sector development. This will lead to reduction of the speed of the accumulation of energy capital, slowing down the green transition.

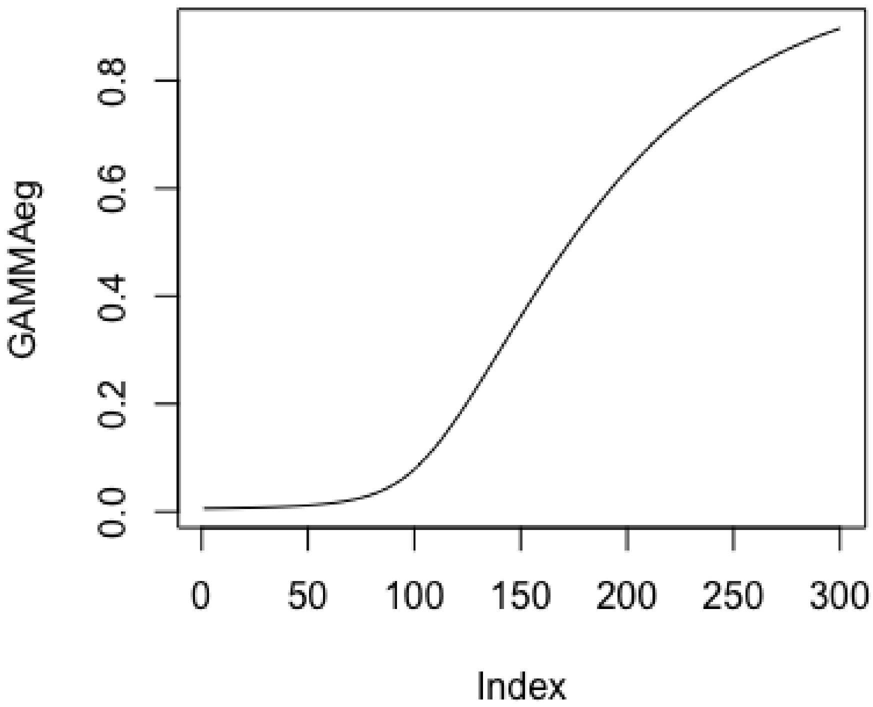


Figure 2: The dynamic motion of the share of green capital for renewable energy production
Note: The x-axis represents the number of periods. Simulation result without carbon tax, $g_{y,t} = 0.03054753$ and $ey_{g,t} = -0.0219135$.

2.2 Carbon Emissions

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

$$EMIS_t = \theta_t E_t. \tag{16}$$

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

$$\theta_t = ce_0 + ce_1 \Gamma_{re,t},\ ce_1 < 0. \tag{17}$$

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

$$CI_t = \frac{EMIS_t}{Y_t}. \tag{18}$$

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

$$CT_t = \tau_{CT,t} EMIS_t, \tag{19}$$

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 do not pay carbon taxes, or they pay to themselves. Carbon tax received by the government is the sum of the private sectors carbon tax payment,

$$CT_{g,t} = \sum_i CT_{i,t} = \tau_{CT,t} CI_t Y_{i,t},\ i = f,\ b,\ h, \tag{20}$$

where $i = f,\ b,\ h$ that represents firms, banks and households, respectively.

2.3 Macroeconomy

The economy consists of five sectors, firms, banks, governments, households and the RoW (see Table 2). Firms, governments and households hold fixed capital, K_f, K_g and K_h, respectively. Within firms, energy industries hold capital for energy production, KE, and part of the capital is green that is for renewable energy production, KEG. Banks hold international reserves, G. Non-financial sectors save deposits into the banks, D_f, D_g and D_h. Governments issue bonds to banks, B_g. Firms and households borrow from banks through loans, L_f and L_h. Households buy insurance from banks, A. Other payable/receivables, Z, capture the net position of all the other instruments that are not included in this model, i.e. currencies, equities and derivatives. 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, $V_f + V_b + V_g + V_h + V_r = K = K_f + K_g + K_h$.

Table 2: The national balance sheet

	Firms	Banks	Governments	Households	RoW	Total
Fixed capitals	$+K_f$		$+K_g$	$+K_h$		$+K$
Capitals for energy production	$+KE$					
Green capitals for energy production	$+KEG$					
International reserves		$+G$			$-G$	0
Deposits	$+D_f$	$-D$	$+D_g$	$+D_h$		0
Bonds		$+B_g$	$-B_g$			0
Loans	$-L_f$	$+L$		$-L_h$		0
Insurance		$-A$		$+A$		0
Other payables/receivables (+/-)	Z_f	Z_b	Z_g	Z_h	Zr	0
Networth	V_f	V_b	V_g	V_h	V_r	$+K$

Note: + denotes assets, - denotes liabilities.

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 (see Appendix equation 51 for the example of households). 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.

Table 3: The 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	$+I$	$+I_f$		$+I_g$	$+I_h$		0
Fixed capital formation for energy production	$+IE$	$-IE$					0
Green Fixed capital formation for energy production	$+IEG$	$-IEG$					0
Export	$+X$					$-X$	0
Import	$-M$					$+M$	0
Wages		$-W_f$	$-W_b$	$-W_g$	$+W$		0
Net taxes on production		$-TL_f$	$-TL_b$	$+TL$	$-TL_h$		0
Carbon taxes		$-CT_f$	$-CT_b$	$+CT$	CT_h		0
Interest on deposits		$+r_D D_{f-1}$	$-r_D D_{-1}$	$+r_D D_{g-1}$	$+r_D D_{h-1}$		0
Interest on bonds			$+r_B B_{-1}$	$-r_B B_{-1}$			0
Interest on loans		$-r_{L_f} L_{f-1}$	$+r_L L_{-1}$		$-r_{L_h} L_{h-1}$		0
Distributed income of firms		$-DIVF$		$+DIVF_g$	$+DIVF_h$	$+DIVF_r$	0
Distributed income of banks			$-DIVB$	$+DIVB_g$	$+DIVB_h$		0
Other income from properties			$-OIP$		$+OIP$		0
Taxes on income and wealth		$-T_f$	$-T_b$	$+T$	$-T_h$		0
Social contributions				$+SC$	$-SC$		0
Social benefits				$-SB$	$+SB$		0
Green subsidies		$+GS_t$		$-GS_t$			0
International reserves			$-\Delta G$			$+\Delta G$	0
Deposits		$-\Delta D_f$	$+\Delta D$	$-\Delta D_g$	$-\Delta D_h$		0
Bonds			$-\Delta B_g$	$+\Delta B_g$			0
Loans		$+\Delta L_f$	$-\Delta L$		$+\Delta L_h$		0
Insurance			$+\Delta A$		$-\Delta A$		0
Other payable/receivables (+/-)		ΔZ_f	ΔZ_b	ΔZ_g	ΔZ_h	ΔZ_r	0
Total	0	0	0	0	0	0	0

Note: + denotes transactions received, - denotes transactions paid.

The following subsections present the main equations of the sectors. Other simplified behaviour equations and accounting equations are shown in detail in the Appendix.

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, $I_{f,t}$, fixed capital formation by households (mainly dwelling acquisition), $I_{h,t}$, fixed capital formation by governments, $I_{g,t}$ and net exports, $X_t - M_t$,

$$Y_t = C_{h,t} + C_{g,t} + I_{h,t} + I_{f,t} + I_{g,t} + X_t - M_t. \tag{21}$$

Aggregate demand in real term (in volume),

$$y_t = c_{h,t} + c_{g,t} + i_{h,t} + i_{f,t} + i_{g,t} + x_t - m_t{}^3, \tag{22}$$

where $c_{h,t} = \frac{C_{h,t}}{P_{c,t}}$, $c_{g,t} = \frac{C_{g,t}}{P_{c,t}}$, $i_{h,t} = \frac{I_{h,t}}{P_{kh,t}}$, $i_{f,t} = \frac{I_{f,t}}{P_{k,t}}$, $i_{g,t} = \frac{I_{g,t}}{P_{k,t}}$, $x_t = \frac{X_t}{P_{x,t}}$, and $m_t = \frac{M_t}{P_{m,t}}$ are the aggregate demand components in real value. $P_{c,t}$ is the consumer price index (CPI), $P_{kh,t}$ is the capital price index of households, $P_{k,t}$ is the general capital price index, $P_{x,t}$ and $P_{m,t}$ are the export and import price index, respectively. By definition, then, 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,

$$y_t \leq \min\{y_{kf0}k_{f,t-1}^{y_{kf1}},\ y_{kg0}k_{g,t-1}^{y_{kg1}},\ y_{n0}y_{n,t}NN_t^{y_{n2}}\}, \tag{23}$$

where k_f, k_g denotes the fixed capital in volume held by firms and the government, respectively. $y_{n,t} = (1 + y_{n1})y_{n,t-1}$ represents the exogenous labor productivity improvement. NN_t denotes the total labour force, which is exogenous. We will determine its value in section 3. If the economy output hits the supply constraints, firms' investment would be constrained by residual savings, as in supply-led models (e.g. Solow, 1956),

$$i_{f,t} = y_t - c_{h,t} - c_{g,t} - i_{h,t} - i_{g,t} - x_t + m_t. \tag{24}$$

The capacity utilisation of the firms' fixed capital, $U_{k,t}$, is derived based on their productivity from equation (23),

$$y_t = y_{kf0}(k_{f,t-1}U_{k,t})^{y_{kf1}}. \tag{25}$$

2.3.2 Labour market

Following Keynes (1937), the employment level is determined by aggregate demand. Employment in our model, N_t, is determined by the production technology with respect to labor shown in equation (23),

$$y_t = y_{n0}y_{n,t}N_t^{y_{n2}} \tag{26}$$

Real wage, w_t, is determined by unemployment and labor productivity,

$$w_t = w_0(u_t - u_{ss}) + w_1\frac{y_t}{N_t},\ w_0 < 0,\ w_1 > 0, \tag{27}$$

where $u_t = \frac{NN_t - N_t}{NN_t}$ is the unemployment rate. u_{ss} stands for its steady-state value. $\frac{y_t}{N_t}$ is real output per labour that represents labour productivity referring to Reati (2001). w_0 and w_1 denote the sensitivity of real wage to the unemployment rate and labour productivity, respectively. The unemployment rate has a negative effect on real wages because it decreases the searching probability of finding new jobs for workers and reduces the value of their outside options consequently. Conversely, firms have a higher searching probability to fill their vacancy under a higher unemployment labour market. In summary, workers are worse off, and firms are better off in the wage bargaining process as the unemployment rate increases (Pissarides, 2000).

Total wage bill, W_t, is nominal wage times labor,

$$W_t = P_{y,t}w_tN_t, \tag{28}$$

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

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

2.3.3 Prices

Producers fulfil aggregate demand but set their prices based on the effective unit cost of production,

$$P_{j,t} = p_{j0}\left(\frac{W_{t-1} + CT_{t-1}}{y_{t-1}}\right)^{p_{j1}}, \ j = c,\ k,\ kh,\ x. \tag{29}$$

where p_{j1} denotes the elasticity of prices to effective wage.

The price setters do not take into account the cost of capital, i.e. interest rates. Otherwise, we may have a cost-push inflation by the interest rate. And we ignore energy prices in the price equations. So our model does not consider the micro-economic rebound effect (Sorrell and Dimitropoulos, 2008)[4].

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 expected disposable income deflated by consumption price, under static expectation that is their past income, $\frac{Y_{t-1}}{P_{c,t}}$ (income effect), and their net worth in unit of consumption goods carried from the last period, $\frac{V_{h,t-1}}{P_{c,t}}$ (wealth effect, Wang et al., 2021),

$$c_{h,t} = c_0 c_{h,t-1}^{c_1}\left(\frac{Y_{d,t-1}}{P_{c,t}}\right)^{c_2}\left(\frac{V_{h,t-1}}{P_{c,t}}\right)^{c_3}, \ c_1 > 0,\ c_2 > 0,\ c_3 > 0, \tag{31}$$

where c_0 denotes the consumption level when $c_{h,t-1} = \frac{Y_{d,t-1}}{P_{c,t}} = \frac{V_{h,t-1}}{P_{c,t}} = 1$, c_1 is the sensitivity of habit formation, c_2 is the elasticity of consumption with respect to income, c_3 is the elasticity of consumption with respect to wealth.

Households' fixed capital formation only depends on their past net worth deflated by their capital price, $P_{kh,t}$,

$$i_{h,t} = i_{h0}\left(\frac{V_{h,t-1}}{P_{kh,t}}\right)^{i_{h1}}, i_{h1} > 0, \tag{32}$$

where i_{h1} is the sensitivity of investment to net assets.

Households have liquidity preferences. They save proportionally of their last period net worth as deposits and follow a portfolio choice decision, they adjust deposits based on the interest rate gap,

$$D_{h,t} = d_{h0} V_{h,t-1}^{d_{h1}} e^{d_{h2}(r_{D,t} - r_{Lh,t})}, \ d_{h1} > 0,\ d_{h2} > 0, \tag{33}$$

where $r_{Lh,t}$ is the loans rate paid by households. d_{h1} denotes the sensitivity of deposits to net assets, and d_{h2} is the sensitivity to the interest rate gap between the deposit rate and household loan rate. r_{Dt} is the deposit rate and $r_{L_h,t}$ is the households loans rate.

2.3.5 Firms

Firms earn revenue and interest from deposits. They pay taxes, wages, and interest for loans and dividends.

Firms fixed capital formation rate, $\frac{i_{f,t}}{k_{f,t-1}}$, is driven by the net profit rate, $\frac{FP_{t-1}+DIVF_{t-1}}{P_{k,t}k_{f,t-1}}$[5],

$$\frac{i_{f,t}}{k_{f,t-1}} = i_{f0} + i_{f1}\frac{FP_{t-1} + DIVF_{t-1}}{P_{k,t}k_{f,t-1}}, \ i_{f1} > 0, \tag{34}$$

[4] The aggregate energy price is,

$$P_{E,t} = \frac{1}{\omega\gamma}\left(\frac{P_{CE,t} + \frac{CT_t}{CE_t} - (\rho - 1)P_{RE,t}}{1 - \delta\rho}\right)^{\omega(1-\delta)\rho}\left(\frac{P_{RE,t}}{\delta\rho}\right)^{\omega\delta\rho}, \tag{30}$$

derived from the expenditure minimization problem of choosing between conventional energy and renewable energy (equation 6). However, due to data scarcity, we cannot estimate ω and γ. Potentially, as the share of renewable energy increases and the price of renewable energy decreases, the aggregate energy price decreases, and all the prices decrease. As a consequence, demand would increase, causing more energy consumption and emissions.

[5] The capacity utilisation of firms' fixed capital, $U_{k,t}$, has a positive effect on firms' investment. We did not include it in the investment function because it will create pro-cyclical investment behaviour for firms and the model becomes very likely non-stationary, which requires a narrow parameter space to stabilise.

where i_{f0} is the autonomous capital formation rate, i_{f1} is the sensitivity to the net profit rate.

The accumulation of firms' fixed capital is

$$K_{f,t} = K_{f,t-1}(1 - \delta_{f,t}) + I_{f,t} + \frac{\Delta P_{k,t}}{P_{k,t-1}} K_{f,t-1}, \tag{35}$$

where $\delta_{f,t} = \delta_{f0} + \delta_{f1} U_{k,t}$, $\delta_{f1} > 0$, denotes the depreciation rate of firms' fixed capital. When firms produce under a high level of capacity utilisation rate, firms' fixed capital depreciates faster.

Firms hold deposits as a proportion of their fixed capital in need of operation expenditure and adjust to the interest rate gap,

$$\frac{D_{f,t}}{K_{f,t-1}} = d_{f0} + d_{f1}(r_{D,t} - r_{L_f,t}),\ d_{f1} > 0, \tag{36}$$

where d_{f0} denotes the ratio of deposits over capitals when the interest gap is 0, and d_{f1} is the sensitivity to the interest rate gap.

2.3.6 Banks

Banks earn revenue and interest from loans. They pay wages, taxes, interest for deposits, dividends and insurance indemnity. Banks are the closing sector of the model, the vertical consistency of the banks' transaction flows, i.e. budget constraint, is inherently fulfilled.

Central bank are included in the banking sector and run a counter-cyclical monetary policy by adjusting the policy rate. This will transit to the lending rate to the private sectors. Therefore, we could write down a policy rule on the loans rate to firms as

$$r_{L_f,t} = r_{f0} + r_{f1} L_{f,t-1} + r_{f2}(g_{y,t-1} - g_{y,ss}),\ r_{f2} > 0. \tag{37}$$

Other interest rates are positively correlated to $r_{L_f,t}$ (see Appendix).

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

$$c_{g,t} = c_{g0} y_{t-1}. \tag{38}$$

For simplicity, we also assume government investments are proportional to real output,

$$i_{g,t} = i_{g0} y_{t-1}. \tag{39}$$

2.3.8 The rest of the world

The rest of the world demands export goods, supplies import goods, and receives dividends from domestic firms.

Exports depend on foreign demand, $y_{r,t}$, and export price, $P_{x,t}$[6],

$$x_t = x_0 \left(\frac{y_{r,t}}{P_{x,t}}\right)^{x_1},\ x_1 > 0, \tag{40}$$

where $y_{r,t}$ is exogenous and calibrated for the baseline scenario that we would discuss in Section 3.

Imports depend on domestic income, Y_{t-1}[7],

$$m_t = m_0 Y_{t-1}^{m_1}. \tag{41}$$

[6] For simplicity, we do not consider the exchange rate. Adding the exchange rate complicates the effect of carbon taxes on export. On the one hand, carbon taxes raise export prices and reduce export. On the other hand, carbon taxes cause inflation and exchange rate depreciation and may increase export demand. The overall effect depends on the parameter values.

[7] For simplicity, we set import price as 1.

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 2060. Our baseline scenario is the National Determined Contributions (NDCs) scenario from the NGFS, which follows the commitment of the country to the Paris Agreement. 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).

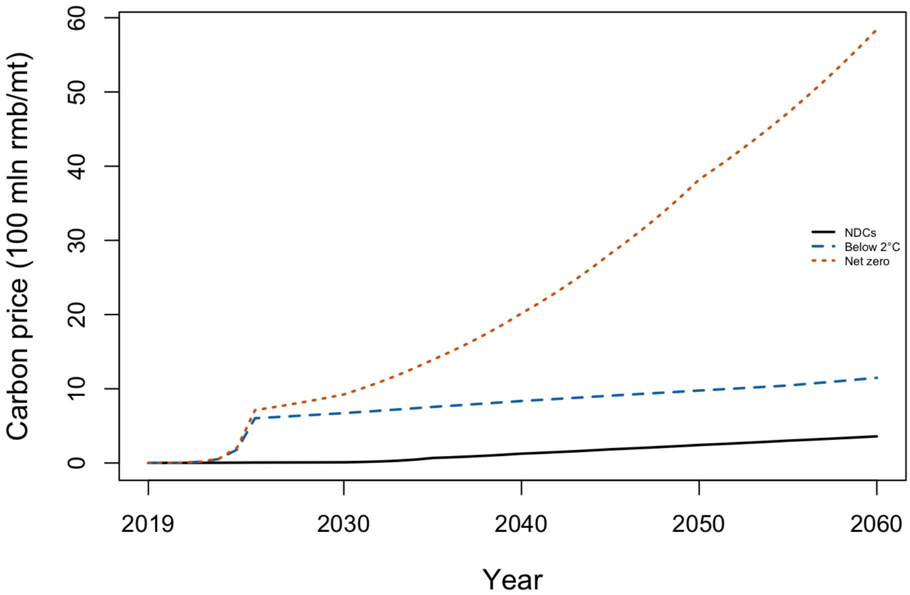


Figure 3: Carbon prices

Note: The NGFS scenarios are displayed every 5 years before 2060 and every decade afterwards. Interpolations by assuming the same growth rate between grids. Converted using the US CPI and official exchange rate from World Bank.

Source: NGFS

3.1 Initial values and parameters specifications

The initial values and parameters are obtained, calculated, estimated or calibrated from the real data or the NDCs scenario (see Table 4 and 5 in the Appendix). Our data covers from year 2000 to 2019. Stock data, e.g. fixed capital, international reserves, deposits, bonds, loans and other payable/receivables, are obtained from the China's National Balance. Transaction data are obtained from the National Bureau of Statistics of China (NBSC). Data for energy and emissions are obtained from the NBSC, China Energy Portal, World Bank and Our World in Data.

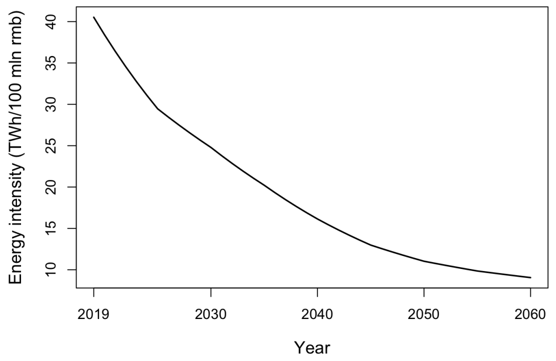
GDP deflator is obtained from World Development Indicators. CPI (P_c), capital price (P_k) and households' capital price (P_{kh}) are obtained or estimated from NBSC. Fiscal tax rates and interest rates are estimated using the transaction data and stock data, dividing the flows by the stocks. Employment data are obtained from World Bank. The real wage is calculated by the wage bill payment over employment.

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. So 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).

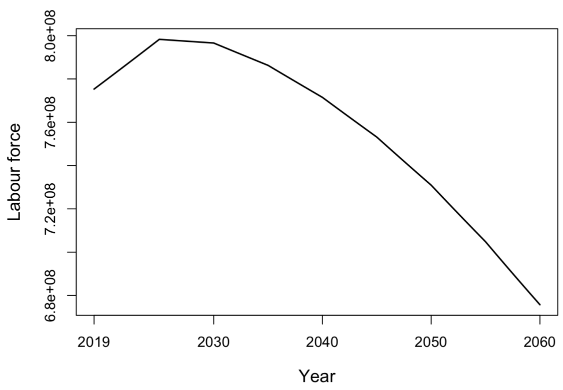
Parameters are mostly estimated by running simple OLS regressions. We run Augmented Dickey-Fuller (ADF) test on the residuals to ensure co-integrations between the variables. β_{eg} is borrowed from Aleti and Hochman (2020). $ce_1 = -ce_0$ is calibrated from equation (17) to have $\theta = 0$ when $\Gamma_{re} = 1$, zero carbon emission when 100% 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. GDP initial value is calculated by subtracting change in inventories and other non-financial assets investment from the original GDP. And GDP growth initial value is calculated based on this series. 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. Prices and interest rates are fixed. These conditions require some initial values of the variables and parameters to be calibrated using the equations.

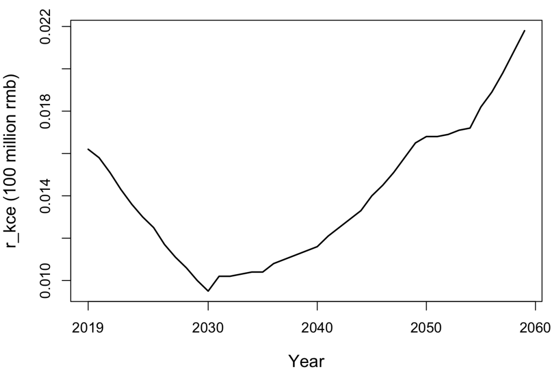
We calibrate real GDP growth, price of conventional energy, energy intensity growth, labour force and foreign GDP growth to our baseline scenario. Energy intensity growth, $ey_{g,t}$, is an exogenous variable. We simply set its values to the time series (see Figure 4a). For real GDP growth, which is an endogenous variable, we let i_{h0} from the households investment function, equation (32), to be a moving parameter to calibrate it. The labour force is estimated based on the labour force data of 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% (see Figure 4b). For conventional energy price, we have $r_{kce,t}$ to calibrate from the conventional energy pricing equation, equation (11) (see Figure 4c). Foreign GDP growth is exogenous and we employs the time series data (see Figure 4d).



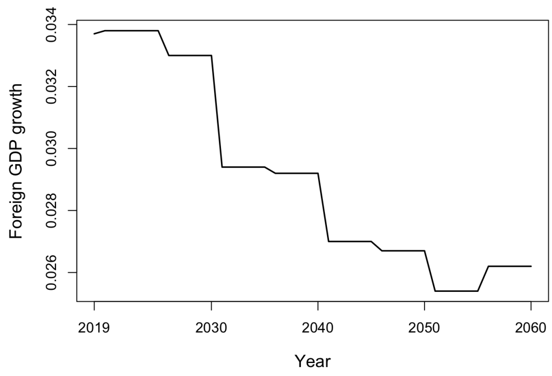
(a) Energy intensity



(b) Labor force



(c) Unit cost of conventional energy production



(d) Foreign GDP growth

Figure 4: Calibration variables

Note: The NGFS scenario are displayed in every 5 year before 2060 and every decades afterwards. Interpolations by assuming the same growth rate between grids.

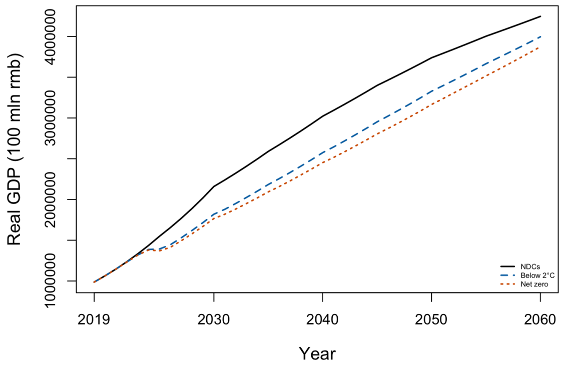
Source: NGFS

3.2 Results

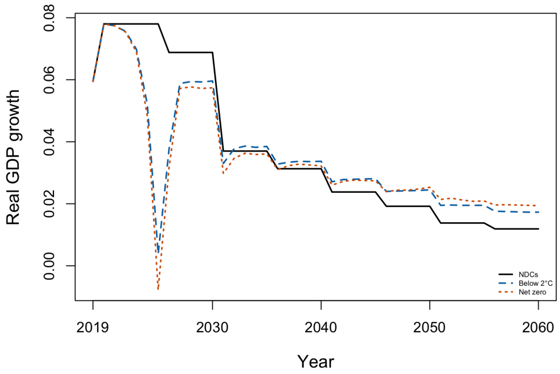
3.2.1 Carbon pricing scenarios

Figure 5 shows the main results of the simulations. The black solid line is our baseline scenario (NDCs). The blue and the red dashed line are results with carbon prices of the below 2°C scenario and the net zero scenario. Carbon price has a negative effect on real output (Figure 5a and 5b). Before 2025, unemployment increases because of the increase in labor force, though China still has a positive economic growth. After that, unemployment rate rises over time because of decreasing GDP growth, though labor force is also decreasing. Unemployment increases under high carbon pricing because of the negative impact on growth (Figure 5c). Private consumption and investment decrease due to higher carbon tax payment and also because of the inflation caused by the carbon pricing (Figure 5d, 5e and 5h). Export decreases under higher carbon taxes because export goods become more expensive and less competitive (Figure 5f). In contrast, import demand increases in the short run under higher carbon taxes because foreign goods are relatively cheaper, though domestic income decreases. The substitution effect surpasses the income effect. In the long run, domestic prices drop because of green transition and imports becomes smaller under higher carbon taxes. The negative income effect dominates (Figure 5g). There is a deflation regime before 2030 in the baseline scenario because of over-supplied of labor force as we mentioned. Under higher carbon prices, inflation increases, but decreases later as carbon price stimulates green transition and the unit cost of carbon price decreases significantly (Figure 5h and 5o). The price effect determines the change of firms' leverage ratio in the short run, which is the revaluation effect of firms' fixed capital in the denominator of the leverage ratio. As the price stabilizes, firms' leverage increases overtime, and more significantly under higher carbon taxes because of the carbon tax payment (Figure 5i and 5j). Public debt over GDP increases temporally when carbon taxes perform a jump in 2025 because of its negative impact on GDP. In the long run, public debt over GDP becomes smaller under higher carbon taxes but rises over time since GDP growth is decreasing (Figure 5k).

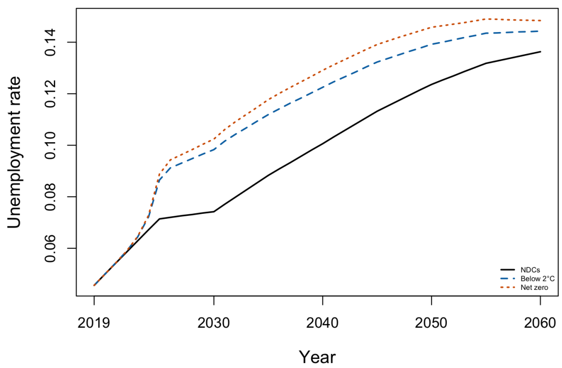
Energy consumption becomes smaller under higher carbon prices because of their negative impact on the aggregate demand. It decreases over time after 2030 because both aggregate demand and energy intensity are decreasing (Figure 5l). Carbon pricing stimulates green transitions as expected. Only the net zero scenario succeeds the policy target described in Table 1, 80% of renewable energy share by 2030 (Figure 5m). Carbon intensity decreases over time as the energy intensity is decreasing. The positive effect of carbon pricing on green transition decreases carbon intensity further. Even the baseline scenario succeeds the policy target for carbon intensity described in Table 1, 65% less than the level of 2005 by 2030 (Figure 5n). As a consequence, the carbon tax unit cost per output decreases overtime when green transition proceeds significantly, though carbon price is increasing. While, this is not the case for the baseline scenario because green transition is not sufficient (Figure 5o). Carbon pricing decreases carbon emission in two aspects, i. it stimulates green transition and reduces carbon intensity; 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 in purpose. Our model does not consider carbon absorption, so it cannot tell if the scenarios will reach carbon neutrality in 2060 (Figure 5p).



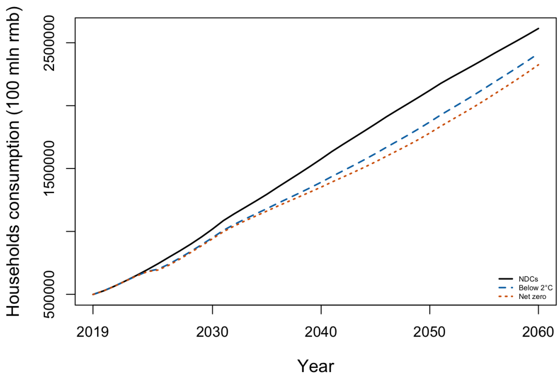
(a) Real output



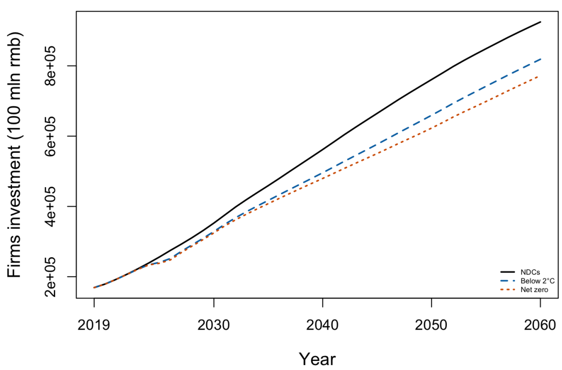
(b) Real output growth



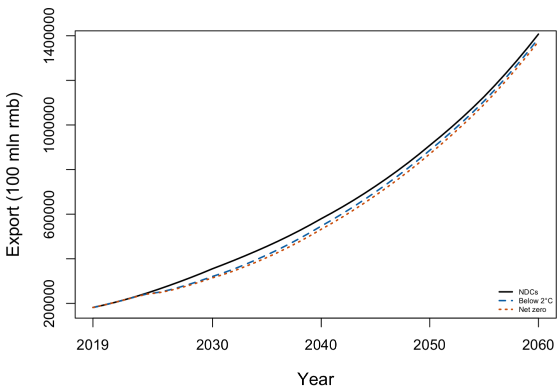
(c) Unemployment



(d) Households consumption



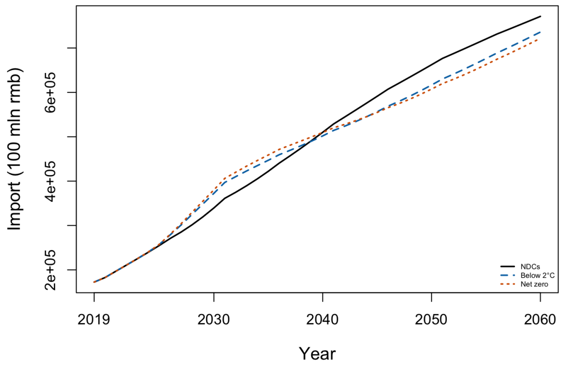
(e) Firms investment



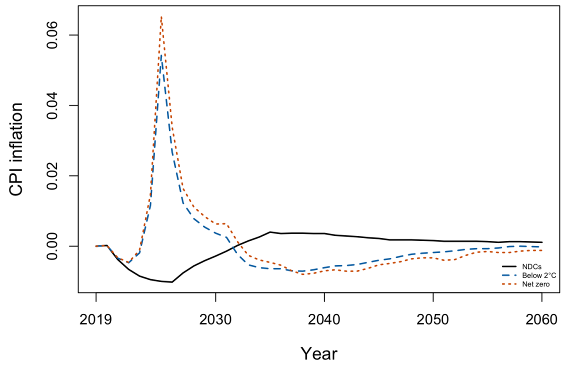
(f) Export

Figure 5: Simulation results, carbon price scenarios

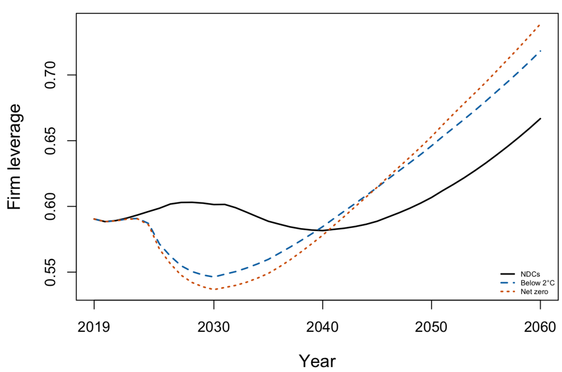
Note: The black solid line is our baseline scenario (NDCs). The blue and the red dashed line are results with carbon prices of the below 2°C scenario and the net zero scenario. The horizontal lines and vertical lines in (5m), (5n) and (5p) are the respective policy targets described in Table 1.



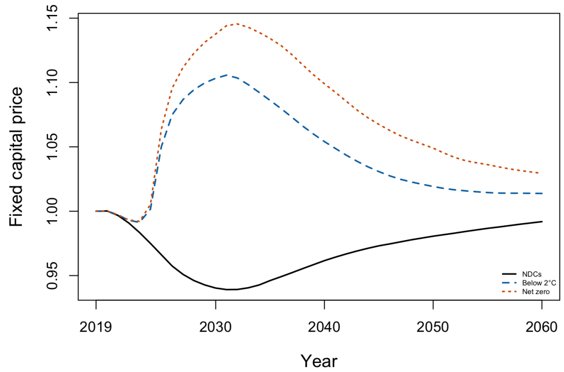
(g) Import



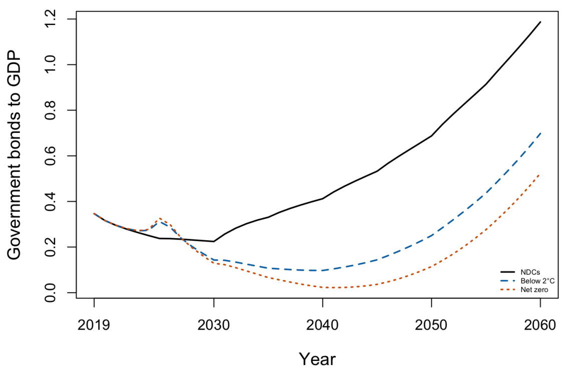
(h) Inflation



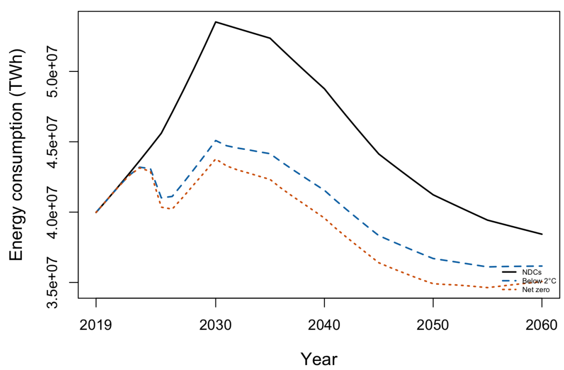
(i) Firms' leverage ratio



(j) Fixed capital price



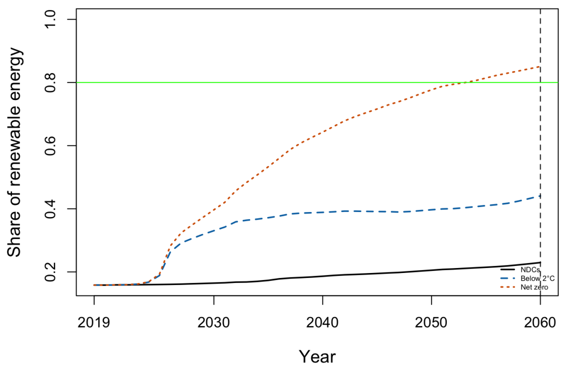
(k) Public debt over GDP



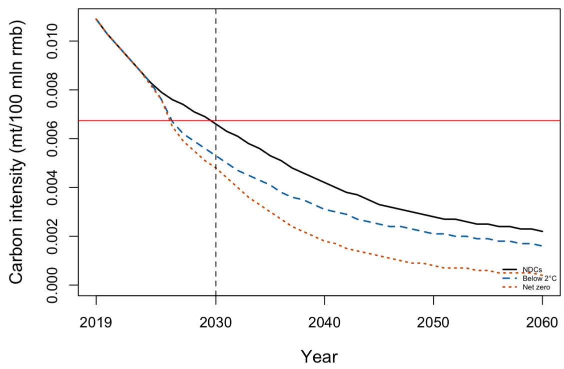
(l) Energy consumption

Figure 5: Simulation results, carbon price scenarios

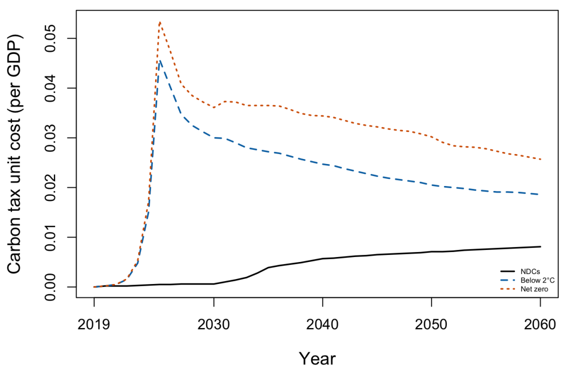
Note: The black solid line is our baseline scenario (NDCs). The blue and the red dashed line are results with carbon prices of the below 2°C scenario and the net zero scenario. The horizontal lines and vertical lines in (5m), (5n) and (5p) are the respective policy targets described in Table 1.



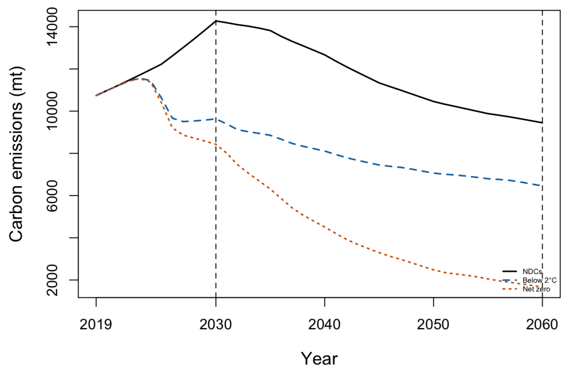
(m) Share of renewable energy



(n) Carbon intensity



(o) Carbon tax unit cost



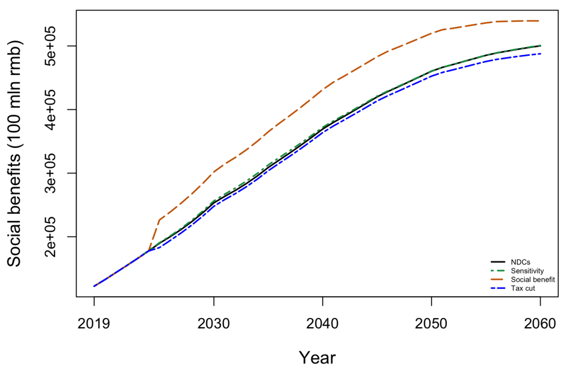
(p) Carbon emission

Figure 5: Simulation results, carbon price scenarios

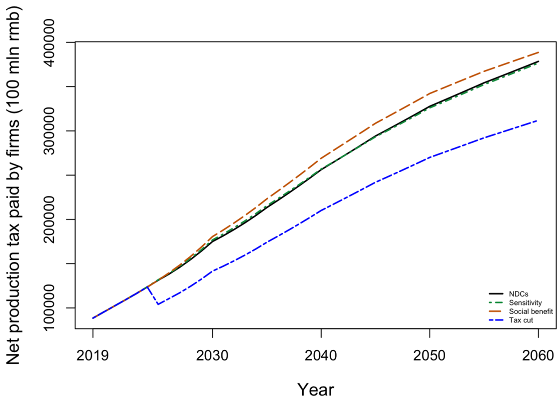
Note: The black solid line is our baseline scenario (NDCs). The blue and the red dashed lines are results of carbon prices of the below 2°C scenario and the net zero scenario. The horizontal lines and vertical lines in (5m), (5n) and (5p) are the respective policy targets described in Table 1.

3.2.2 Sensitivity test and fiscal policy scenarios

Next, we run a sensitivity test for the parameter p_{k1}, the elasticity of fixed capital price to unit cost of production, by reducing it from 0.51 to 0.01. In such a case, the capital price remains around 1. Simultaneously, we run a subsidy scenario and a cut tax scenario (see Figure 6). In the former, the government increases social benefits to households. In the latter, the government cuts the firms' net production tax. Both policies start from 2027, when economic growth starts to decline in the baseline scenario, to see if these expansionary fiscal policies would cushion the recession. The parameter γ_{SB}, the share of social benefits out of government net profit, increases from around 0.52 to 0.62. And the net production tax rate paid by firms decreases from 0.14 to 0.11.



(a) Social benefits

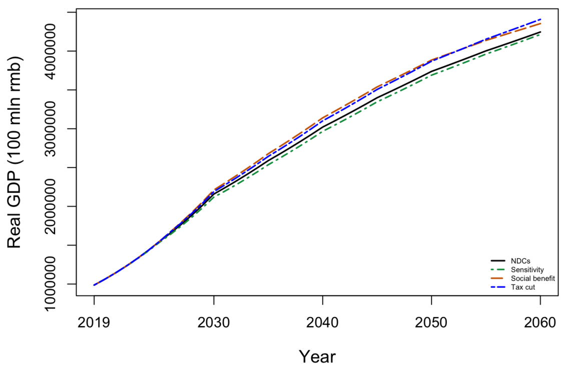


(b) Net production tax paid by firms

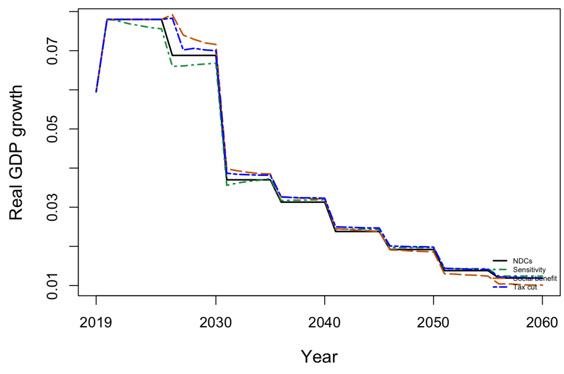
Figure 6: Expansionary fiscal policies

Note: The black solid line is our baseline scenario. The green dashed line is the sensitivity test that reduces the elasticity of fixed capital price to the unit cost of production (p_{k1} decreases from around 0.51 to 0.01). The orange dashed line is the subsidy scenario. Social benefit increases starting from 2027. The share of social benefits out of government net profit, γ_{SB}, increases from around 0.52 to 0.62. The blue dash line is the tax cut scenario. The net production tax paid by firms, τ_{L_f}, decreases from 0.14 to 0.11 starting from 2027.

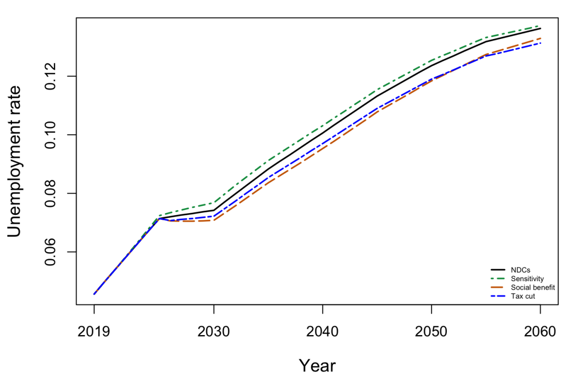
The results of the sensitivity test and fiscal policies are shown in Figure 7. Expansionary fiscal policies have a positive effect on aggregate demand and employment (Figure 7a - 7e). Firms' leverage ratio remains stable in the short run under the sensitivity scenario because the price effect is eliminated. A tax cut on firms decreases their leverage ratio because they receive higher net profit (Figure 7f and 7g). Increasing social benefits makes government more indebted, though real output also increases. While, although a tax cut reduces government revenue, firms invest more significantly, the denominator, GDP increases at the same speed of public accumulation. As a consequence, public debt over GDP rises way less than the case with increasing social benefits. (Figure 7h).



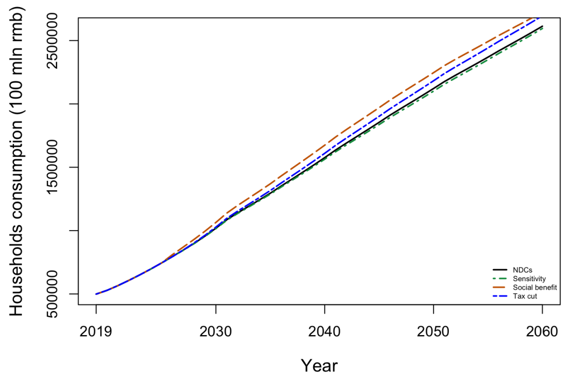
(a) Real output



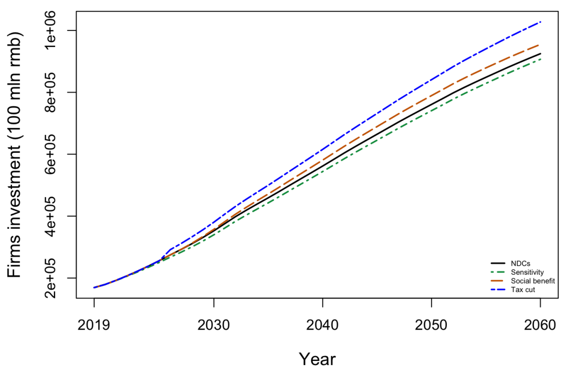
(b) Real output growth



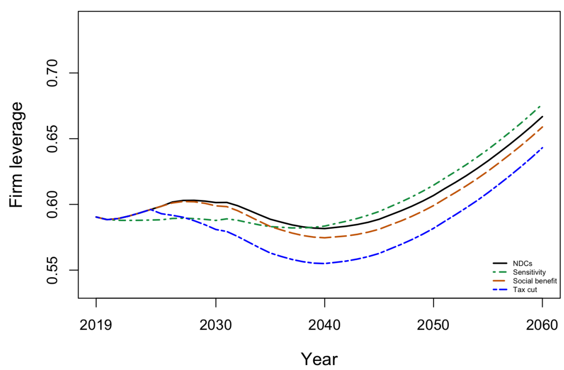
(c) Unemployment



(d) Households consumption



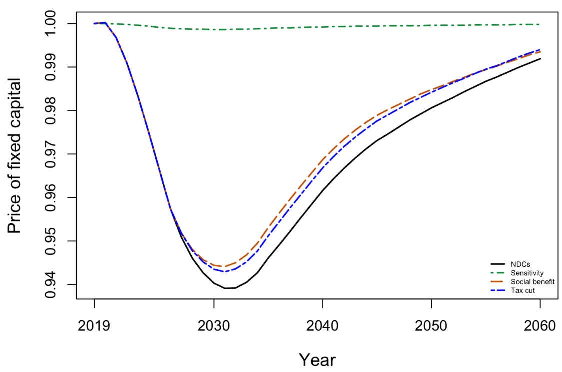
(e) Firms investment



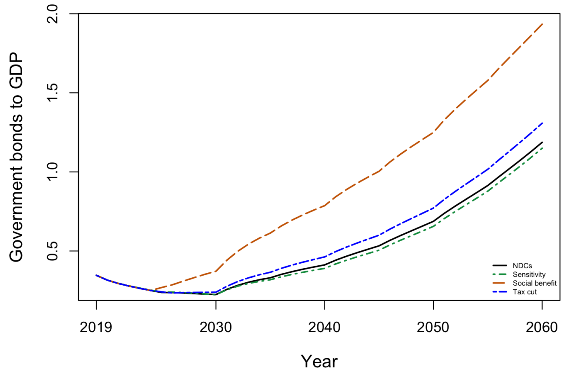
(f) Firms' leverage ratio

Figure 7: Simulation results, sensitivity and fiscal policy scenarios

Note: The black solid line is our baseline scenario. The green dashed line is the sensitivity test that reduces the elasticity of fixed capital price to the unit cost of production (p_{k1} decreases from around 0.51 to 0.01). The orange dashed line is the subsidy scenario. Social benefit increases starting from 2027. The share of social benefits out of government net profit, γ_{SB}, increases from around 0.52 to 0.62. The blue dash line is the tax cut scenario. The net production tax paid by firms, τ_{L_f}, decreases from 0.14 to 0.11 starting from 2027. The horizontal lines and vertical lines in (5m), (5n) and (5p) are the respective policy targets described in Table 1.



(g) Fixed capital price



(h) Public debt over GDP

Figure 7: Simulation results, sensitivity and fiscal policy scenarios

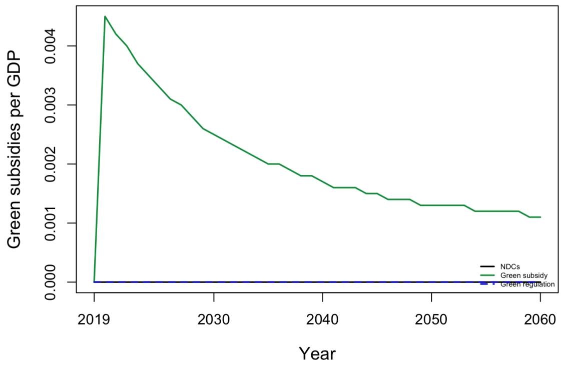
Note: The black solid line is our baseline scenario. The green dashed line is the sensitivity test that reduces the elasticity of fixed capital price to the unit cost of production (p_{k1} decreases from around 0.51 to 0.01). The orange dashed line is the subsidy scenario. Social benefit increases starting from 2027. The share of social benefits out of government net profit, γ_{SB}, increases from around 0.52 to 0.62. The blue dashed line is the tax cut scenario. The net production tax paid by firms, τ_{L_f}, decreases from 0.14 to 0.11 starting from 2027. The horizontal lines and vertical lines in (5m), (5n) and (5p) are the respective policy targets described in Table 1.

3.2.3 Green subsidies and regulation scenarios

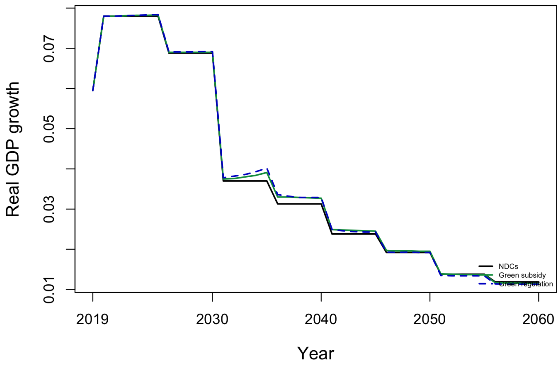
Lastly, we run a green subsidies scenario in which the government compensates the cost of renewable energy production by 90% and a green regulation scenario in which the level of fixed capital for producing conventional energy ($k_{ce,t}$) cannot increase more than 2% annually after depreciation. Figure 8 reports the results. Green subsidies account for around 0.45% of the GDP in 2020, then decrease over time since the numerator is fixed and the denominator increases (Figure 8a). Green subsidies have a positive effect on economic growth because it stimulates firms' investment by improving firms' financial situation. Green regulation also benefits economic growth since it reduces carbon tax payments through green transition (Figure 8b, 8c and 8d)[8]. Public debt over GDP increases slightly under the green subsidies scenario because the government is transferring money to firms (Figure 8e).

Green subsidies increase the share of renewable energy over time by reducing the price of renewable energy. And it achieves the policy target described in Table 1. The effect of green regulation is rapid. It forces green transition in the short term. While, green transition hits a ceiling in the long run when the demand of energy consumption decreases and the price of renewable energy remains stable (Figure 8f, 8g and 8h). As a consequence, carbon intensity decreases steadily in the green subsidies scenario. While, green regulation decreases carbon intensity in the short run but remains stable in the long run (Figure 8i). Lastly, green subsidies decrease carbon emission overtime. Green regulation shows an effective drop of carbon emissions in the short run (Figure 8j).

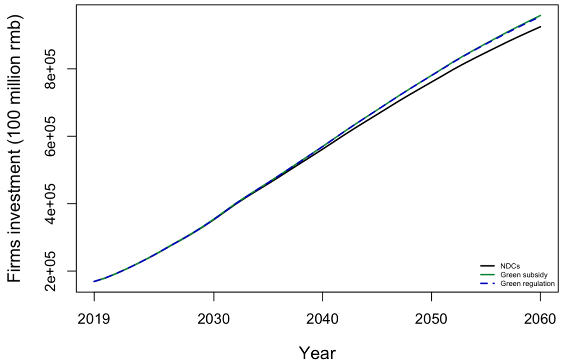
[8] As we discussed previously in equation (29), we did not consider the aggregate energy price in our model. If we have it, intuitively, green regulations would also cause inflation and deteriorate aggregate demand in the short run because energy consumers are forced to consume renewable energy, which is more expensive than conventional energy in the early stage. The overall effect of green regulations on economic growth in the short run would be ambiguous.



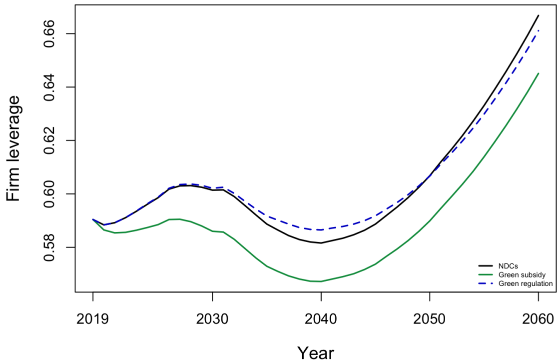
(a) Green subsidies per GDP



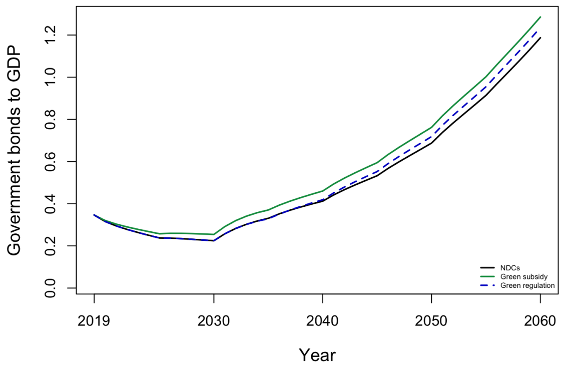
(b) Real output growth



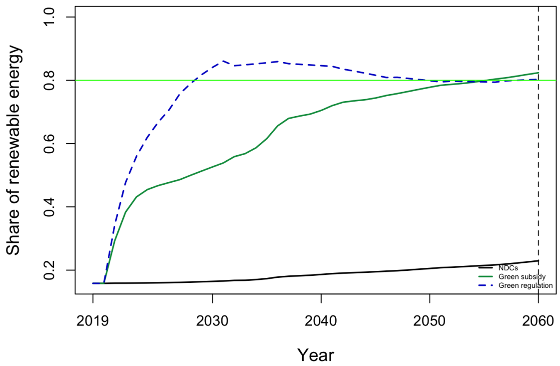
(c) Firms investment



(d) Firms' leverage ratio



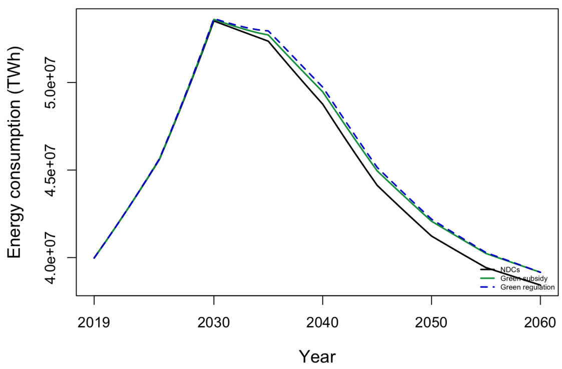
(e) Public debt over GDP



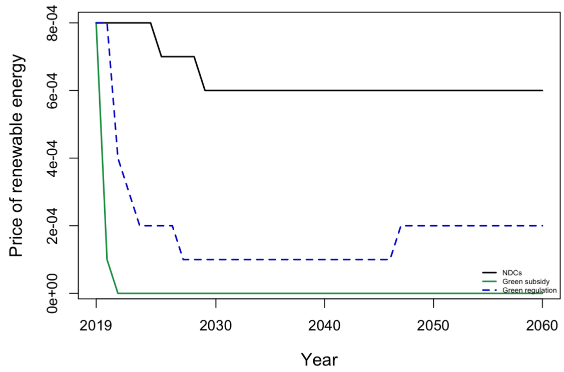
(f) Share of renewable energy

Figure 8: Simulation results, green subsidies and regulation

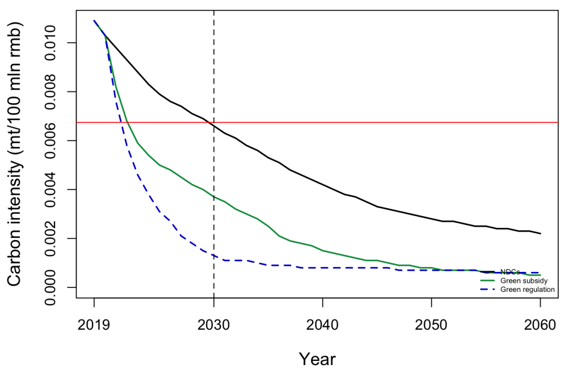
Note: The black solid line is our baseline scenario. The green solid line is the green subsidies scenario in which government compensates 90% of the cost of renewable energy production. The blue dashed line is the green regulation scenario in which capital for producing conventional energy cannot increase. The horizontal lines and vertical lines in (5m), (5n) and (5p) are the respective policy targets described in Table 1.



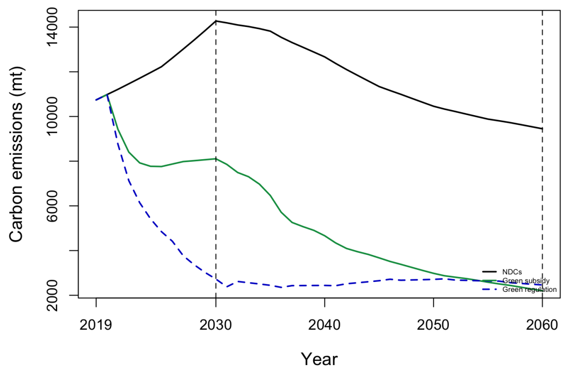
(g) Energy consumption



(h) Price of renewable energy



(i) Carbon intensity



(j) Carbon emission

Figure 8: Simulation results, green subsidies and regulation

Note: The black solid line is our baseline scenario. The green solid line is the green subsidies scenario in which the government compensates 90% of the cost of renewable energy production. The blue dashed line is the green regulation scenario in which capital for producing conventional energy cannot increase. The horizontal lines and vertical lines in (5m), (5n) and (5p) are the respective policy targets described in Table 1.

In summary, carbon pricing can stimulate green transition, reducing carbon intensity, at the cost of deteriorating output and causing inflation. As the share of renewable energy increases, the unit cost of carbon pricing per output decreases. The strong revaluation effect of fixed capital determines firms' leverage in the short run. Firms' leverage increases in the long run under higher carbon taxes. Conversely, public debt over GDP becomes small with more carbon tax revenues. An expansionary fiscal policy targeting firms can stimulate aggregate demand without increasing public debt over GDP ratio too much. Green subsidies stimulate green transition at a slight cost of raising public debt over GDP ratio. Green regulation has a dramatic short-run effect in boosting green transition.

4 Conclusion and Remark

This paper developed a stock-flow consistent 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. It suggests that the scale of the energy sector matters to green transition, and the relative cost of using conventional energy with respect to renewable energy determines the share of renewable energy.

We calibrate the model to the NDCs scenarios from the NGFS and run simulations with different carbon pricing scenarios, below 2°C and net zero. The simulation results demonstrate carbon pricing stimulates green transition but has a negative impact on the economy, low growth and high inflation. But as the share of renewable energy increases, carbon emissions decrease. As a consequence, the economic cost of carbon pricing becomes smaller in the long run. Additionally, we ran a sensitivity test and two expansionary fiscal policy scenarios. The former shows that the revaluation effect of fixed capital price plays a significant role in firms' leverage. The expansionary fiscal policy scenarios suggest that a tax cut or a subsidy to firms is more effective in countering the reduction of output caused by carbon pricing without increasing public debt per GDP significantly. We also run simulations with two alternative green policies, green subsidies and green regulation. The results show that green subsidies benefit economic growth and stimulate green transition at a slight cost of raising public debt over GDP ratio. Green regulation has a dramatic short-run effect in boosting green transition.

Our model has several issues that need to be improved. Firstly, the assumptions we made in the energy sector are too strong. Renewable energy has the same production technology as conventional energy is unrealistic. Secondly, we did not consider the aggregate energy price in the model. As a consequence, our model does not perform the micro-economic rebound effect. Thirdly, the calibration of the model produces some weird parameter values. The social contribution payment rate is negative, around -31%. The income tax rate paid by banks, τ_b, is too high, around 85%. Lastly, the quality of the parameters estimated can be improved, given the limited amount of data. A potential solution is to employ micro panel data to estimate the parameters in the behaviour equations of households and firms.

The model can be also extended in some directions. Modelling more explicit fiscal policy rules for public expenditures, including government consumption, government investment and the tax rates. Adding more instruments, e.g. changes in inventories, other non-financial assets investment, equities, and financial derivatives, to make the model more realistic.

References

Aleti, S., & Hochman, G. (2020). Non-constant elasticity of substitution and intermittent renewable energy. *Agricultural and Resource Economics Review*, *49*(2), 321–359.

Bezemer, D. J. (2010). Understanding financial crisis through accounting models. *Accounting, organizations and society*, *35*(7), 676–688.

Carnevali, E., Deleidi, M., Pariboni, R., & Veronese Passarella, M. (2020). Cross-border financial flows and global warming in a two-area ecological sfc model. *Socio-Economic Planning Sciences*.

Carraro, C., & Massetti, E. (2013). Energy and climate change in china. In *Nature, environment and culture in east asia* (pp. 353–380). Brill.

Dafermos, Y., Nikolaidi, M., & Galanis, G. (2017). A stock-flow-fund ecological macroeconomic model. *Ecological Economics*, *131*, 191–207.

Dafermos, Y., Nikolaidi, M., & Galanis, G. (2018). Climate change, financial stability and monetary policy. *Ecological Economics*, *152*, 219–234.

Godley, W., & Lavoie, M. (2006). *Monetary economics: An integrated approach to credit, money, income, production and wealth*. Springer.

Huang, B., Punzi, M. T., & Wu, Y. (2021). Do banks price environmental transition risks? evidence from a quasi-natural experiment in china. *Journal of Corporate Finance*, *69*, 101983.

Keynes, J. M. (1937). The general theory of employment. *The quarterly journal of economics*, *51*(2), 209–223.

Lavoie, M. (2022). Essentials of heterodox and post-keynesianeconomics. In *Post-keynesian economics* (pp. 1–74). Edward Elgar Publishing.

Pissarides, C. A. (2000). *Equilibrium unemployment theory*. MIT press.

Reati, A. (2001). Total factor productivity-a misleading concept. *PSL Quarterly Review*, *54*(218).

Revankar, N. S. (1971). A class of variable elasticity of substitution production functions. *Econometrica: Journal of the Econometric Society*, 61–71.

Rezai, A., Taylor, L., & Mechler, R. (2013). Ecological macroeconomics: An application to climate change. *Ecological Economics*, *85*, 69–76.

Solow, R. M. (1956). A contribution to the theory of economic growth. *The quarterly journal of economics*, *70*(1), 65–94.

Sorrell, S., & Dimitropoulos, J. (2008). The rebound effect: Microeconomic definitions, limitations and extensions. *Ecological Economics*, *65*(3), 636–649.

Su, X., Ghersi, F., Teng, F., Le Treut, G., & Liang, M. (2022). The economic impact of a deep decarbonisation pathway for china: A hybrid model analysis through bottom-up and top-down linking. *Mitigation and Adaptation Strategies for Global Change*, *27*(1), 11.

Wang, Y., Zhou, Y., Yu, X., & Liu, X. (2021). Is domestic consumption dragged down by real estate sector?—evidence from chinese household wealth. *International Review of Financial Analysis*, *75*, 101749.

Yang, X., & Teng, F. (2018). Air quality benefit of china's mitigation target to peak its emission by 2030. *Climate Policy*, *18*(1), 99–110.

Zezza, G., & Zezza, F. (2019). On the design of empirical stock–flow consistent models. *European Journal of Economics and Economic Policies: Intervention*, *16*(1), 134–158.

Appendix

Final good equilibrium:

Final goods or services are produced by each sectors given a fixed proportions,

$$Y_{i,t} = \gamma_i Y_t, \sum_i \gamma_i = 1. \tag{42}$$

Households:

The gross operating surplus of households is defined as,

$$\Pi_{h,t} = Y_{h,t} + W_t - TL_{h,t} - CT_{h,t}, \tag{43}$$

where $TL_{h,t}$ is the net production tax paid by households, $TL_{h,t} = \tau_{L,h} Y_{h,t}$. $\tau_{L,h}$ is the net production tax rate paid by households.

The gross disposable income of households is,

$$Y_{gd,t} = \Pi_{h,t} + r_{D,t} D_{h,t-1} - r_{L_h,t} L_{h,t-1} + DIVF_{h,t} + DIVB_{h,t} + OIP_t, \tag{44}$$

where $DIVF_{h,t}$ is the dividend paid by firms to households under a fixed proportion of the total firms' dividend, $DIVF_{h,t} = \gamma_{DIVF_h} DIVF_t$, similarly, $DIVB_{h,t}$ is the dividend paid by banks to households under a fixed proportion of the total, $DIVB_{h,t} = \gamma_{DIVB_h} DIVB_t$, OIP_t are mainly insurance indemnity paid by banks.

The net disposable income of households is,

$$Y_{d,t} = Y_{gd,t} - T_{h,t} - SC_t + SB_t, \tag{45}$$

where $T_{h,t}$ is the income tax paid by households, $T_{h,t} = \tau_{h,t} Y_{gd,t}$, SC_t is the social contribution paid by households to the governments, proportional to total wages, $SC_t = \tau_{sc} W_t$, and SB_t is the social benefits received from the governments.

Households' fixed capital depreciates at a fixed rate, δ_h. Assuming no other changes in value (OCV), the accumulation of households capital follows,

$$K_{h,t} = K_{h,t-1}(1 - \delta_h) + I_{h,t} + \frac{\Delta P_{kh,t}}{P_{kh,t-1}} K_{h,t-1}. \tag{46}$$

Households fixed capital in volume is

$$k_{h,t} = \frac{K_{h,t}}{P_{kh,t}}. \tag{47}$$

The accumulation of households deposits is

$$D_{h,t} = D_{h,t-1} + \Delta D_{h,t}. \tag{48}$$

Households are risk adverse and would hold assurance under a given share of their net worth, $A_t = a_0 V_{h,t-1}$. The accumulation of insurance is

$$A_t = A_{t-1} + \Delta A_t. \tag{49}$$

We assume change in other payables/receivables are proportional to households disposable income, $\Delta Z_{h,t} = \gamma_{Z_h} Y_{d,t}$. And the accumulation of this instrument is

$$Z_{h,t} = Z_{h,t-1} - \Delta Z_{h,t}. \tag{50}$$

Noted that the sign is negative for the $\Delta Z_{h,t}$, because $Z_{h,t}$ is treated as assets in the balance sheet and $\Delta Z_{h,t}$ is treated as flows received in the transaction matrix.

Households' loans close the households budget constraint,

$$C_{h,t} + I_{h,t} + \Delta D_{h,t} + \Delta A_t = Y_{d,t} + \Delta L_{h,t} + \Delta Z_{h,t}. \tag{51}$$

The accumulation of households' loans is

$$L_{h,t} = L_{h,t-1} + \Delta L_{h,t}. \tag{52}$$

Households' net worth is

$$V_{h,t} = K_{h,t} + D_{h,t} - L_{h,t} + A_{h,t} + Z_{h,t}. \tag{53}$$

Firms:

The gross operation surplus of firms is

$$\Pi_{f,t} = Y_{f,t} - TL_{f,t} - W_{f,t} - CT_{f,t}, \tag{54}$$

where $TL_{f,t} = \tau_{L,f} Y_{f,t}$ is the net production tax paid by firms. $W_{f,t}$ denotes wages paid by firms, assumed to be a proportion of total wage bill, $W_{f,t} = \gamma_{W_f} W_t$.

The gross profit of firms is

$$FP_{g,t} = \Pi_{f,t} + r_{D,t} D_{f,t-1} - r_{L_f,t} L_{f,t-1} - DIVF_t, \tag{55}$$

where firms dividends are paid proportionally to gross operating surplus, $DIVF_t = \gamma_{DIVF} \Pi_{f,t}$.

Firms' net profit is

$$FP_t = FP_{g,t} - T_{f,t}, \tag{56}$$

where $T_{f,t} = \tau_{f,t}$ is the income tax paid by firms.

Firms' fixed capital in volume is

$$k_{f,t} = \frac{K_{f,t}}{P_{k,t}}. \tag{57}$$

The accumulation of firms' deposits is

$$D_{f,t} = D_{f,t-1} + \Delta D_{f,t}. \tag{58}$$

Firms' other payables/receivables are proportional to net profit, $\Delta Z_{f,t} = \gamma_{Z_f} FP_t$. And the accumulation of this instrument is

$$Z_{f,t} = Z_{f,t-1} - \Delta Z_{f,t}. \tag{59}$$

Firms' loans close the firms' budget constraint,

$$I_{f,t} + \Delta D_{f,t} = FP_t + GS_t + \Delta L_{f,t} + \Delta Z_{f,t}. \tag{60}$$

Accumulation of firms' loans is

$$L_{f,t} = L_{f,t-1} + \Delta L_{f,t}. \tag{61}$$

Firms' leverage ratio is

$$LEV_{f,t} = \frac{L_{f,t}}{K_{f,t} + D_{f,t}}. \tag{62}$$

Firms' net worth is

$$V_{f,t} = K_{f,t} + D_{f,t} - L_{f,t} + Z_{f,t}. \tag{63}$$

Banks:

Deposit rate,

$$r_{D,t} = r_{d0} + r_{d1} r_{L_f,t},\ r_{d1} > 0. \tag{64}$$

Government bonds rate,

$$r_{B_g,t} = r_{b0} + r_{b1} r_{D,t},\ r_{b1} > 0. \tag{65}$$

Households' loans rate,

$$r_{L_h,t} = r_{h0} + r_{h1} r_{L_f,t},\ r_{h1} > 0. \tag{66}$$

Banks' gross operating surplus is

$$\Pi_{b,t} = Y_{b,t} - W_{b,t} - TL_{b,t} - CT_{b,t}, \tag{67}$$

where $W_{b,t} = \gamma_{W_b} W_t$ is the wage paid by banks, proportional to total wage bill. $TL_{b,t} = \tau_{L_b} Y_{b,t}$ is the net production tax paid by banks.

Banks' gross profit is

$$BP_{g,t} = \Pi_{b,t} - r_{D,t} D_{t-1} + r_{B_g,t} B_{g,t-1} + r_{L_h,t} L_{h,t-1} + r_{L_f,t} L_{f,t-1} - DIVB_t - OIP_t, \tag{68}$$

where $D_t = D_{h,t} + D_{f,t} + D_{g,t}$ is the total deposits. $DIVB_t = \gamma_{DIVB} \Pi_{b,t}$ is dividends paid by banks, proportional to their gross operating surplus. $OIP_t = \gamma_{OIP} A_{t-1}$ is the other income from properties paid by banks to households, assuming a fixed rate of insurance indemnity.

Banks' net profit is

$$BP_t = BP_{g,t} - T_{b,t}, \tag{69}$$

where $T_{b,t} = \tau_{b,t} BP_{g,t}$ denotes banks' income tax paid.

Banks receive deposits saving from the other sectors,

$$\Delta D_t = \Delta D_{f,t} + \Delta D_{g,t} + \Delta D_{h,t}. \tag{70}$$

The accumulation of banks' deposits is

$$D_t = D_{t-1} + \Delta D_t. \tag{71}$$

Banks loans lending is the sum of firms' loans and households' loans,

$$\Delta L_t = \Delta L_{f,t} + \Delta L_{h,t}. \tag{72}$$

The accumulation of banks' loans is

$$L_t = L_{t-1} + \Delta L_t. \tag{73}$$

Banks' other payable/receivables close the instrument line (horizontal consistency),

$$\Delta Z_{b,t} = -(\Delta Z_{f,t} + \Delta Z_{g,t} + \Delta Z_{h,t}). \tag{74}$$

The accumulation of banks' other payable/receivables is

$$Z_{b,t} = Z_{b,t-1} - \Delta Z_{b,t}. \tag{75}$$

Governments:

Governments' gross operating surplus is

$$\Pi_{g,t} = Y_{g,t} - W_{g,t} + TL_t + CT_{g,t}, \tag{76}$$

where $W_{g,t} = W_t - W_{f,t} - W_{b,t} = (1 - \gamma_{W_f} - \gamma_{W_b}) W_t$ is the wage paid by governments, proportional to the total wage bill. $TL_t = TL_{f,t} + TL_{h,t} + TL_{b,t}$ is the net production tax received by governments.

Governments' gross profit is

$$GP_{g,t} = \Pi g, t + r_{D,t} D_{g,t-1} - r_{B_g,t} B_{g,t-1} + DIVF_{g,t} + DIVB_{g,t}, \tag{77}$$

where $DIVF_{g,t} = DIVF_t - DIVF_{h,t} - DIVF_{r,t}$ and $DIVB_{g,t} = DIVB_t - DIVB_{h,t}$ are the dividends of firms and banks received by governments, respectively.

Governments' net profit is

$$GP_t = GP_{g,t} + T_t + SC_t - SB_t, \tag{78}$$

where $T_t = T_{f,t} + T_{b,t} + T_{h,t}$ is the total income tax received by governments. $SB_t = \gamma_{SB} GP_{g,t}$ is the social benefits pay to households, proportional to governments' gross profit.

Governments' fixed capital depreciates at a fixed rate, δ_g. The accumulation of governments capital is

$$K_{g,t} = K_{g,t-1}(1 - \delta_g) + I_{g,t} + \frac{\Delta P_{g,t}}{P_{g,t-1}} K_{g,t-1}. \tag{79}$$

Governments save part of their net profit as deposits,

$$\Delta D_{g,t} = d_{g0} GP_t. \tag{80}$$

The accumulation of governments deposits is

$$D_{g,t} = D_{g,t-1} + \Delta D_{g,t}. \tag{81}$$

Governments' other payable/receivables are proportional to net profit, $\Delta Z_{g,t} = \gamma_{Z_g} GP_t$. And the accumulation of this instrument is

$$Z_{g,t} = Z_{g,t-1} - \Delta Z_{g,t}. \tag{82}$$

Governments' bonds close the fiscal constraint,

$$C_{g,t} + I_{g,t} + GS_t + \Delta D_{g,t} = GP_t + \Delta B_{g,t} + \Delta Z_{g,t}. \tag{83}$$

Assuming each unit of government bonds pays 1 rmb after one year, then the price of government bonds can be derived by the inverse of its interest rate (Godley and Lavoie, 2006),

$$P_{B_g,t} = \frac{1}{r_{B_g,t}}. \tag{84}$$

The accumulation of government bonds is

$$B_{g,t} = B_{g,t-1} + \Delta B_{g,t} + \frac{\Delta P_{B_g,t}}{P_{B_g,t-1}} B_{g,t-1}. \tag{85}$$

The rest of the world:

The current account is

$$CA_t = X_t - M_t - DIVF_{r,t}, \tag{86}$$

where $DIVF_{r,t} = \gamma_{DIVFr} DIVF_t$ is the dividend paid/received by the rest of the world under a fixed proportion of the total firms' dividend.

The rest of the world's other payable/receivables are proportional to the current account, $\Delta Z_{r,t} = \gamma_{Z_r} CA_t$. And the accumulation of this instrument is

$$Z_{r,t} = Z_{r,t-1} - \Delta Z_{r,t}. \tag{87}$$

International reserves close the balance of payment,

$$CA_t = \Delta G_t + \Delta Z_{r,t}. \tag{88}$$

The accumulation of international reserves is

$$G_t = G_{t-1} + \Delta G_t. \tag{89}$$

Table 4: Initial values for variables

Symbol	Description	Value	Remark/sources
A	Households insurance (100 million rmb)	129690	Based on China's National Balance Sheet
B_g	Government bonds (100 million rmb)	341774	Based on China's National Balance Sheet
BP	Banks' net profit (100 million rmb)	11562	Calculated from equation (69)
BPg	Banks' gross profit (100 million rmb)	77458	Calculated from equation (68)
CA	Current account surplus/deficit (100 million rmb)	15562	Calculated from equation (86)
C_g	Governments consumption (100 million rmb)	106974	Based on National Bureau of Statistics of China
c_g	Governments consumption in volume	106974	Based on the assumption that initial
C_h	Households consumption (100 million rmb)	498677	Calculated from equation (21)
c_h	Households consumption in volume (100 million rmb)	498677	Based on the assumption that initial prices are 1
CI	Carbon intensity (Mt/100 million rmb)	0.0109	Calculated from equation (18)
E	Energy consumption (TWh)	39435420	Calculated from equation (3)
$EMIS$	Carbon emissions (Mt)	10741	Calculated from equation (16)

D	Total deposits (100 million rmb)	2080995	Calculated from equation (71)
δ_f	Firms' capital depreciation rate	0.0428	Based on the China's National Balance Sheet
D_f	Firms deposits (100 million rmb)	621147	Based on China's National Balance Sheet
D_g	Governments deposits (100 million rmb)	339179	Based on China's National Balance Sheet
D_h	Households deposits (100 million rmb)	1120669	Based on China's National Balance Sheet
ΔA	Insurance savings (100 million rmb)	7284	Calibrated from equation (49) for initial steady state
ΔB_g	Governments' bonds borrowing (100 million rmb)	19195	Calibrated from equation (85) for initial steady state
ΔD	Total deposits saving (100 million rmb)	116875	Calculated from equation (70)
ΔD_f	Firms' deposits saving (100 million rmb)	34886	Calibrated from equation (58) for initial steady state
ΔD_g	governments' deposits saving (100 million rmb)	19049	Calibrated from equation (81) for initial steady state
ΔD_h	Households deposits saving (100 million rmb)	62940	Calibrated from equation (48) for initial steady state
ΔG	Change in international reserves (100 million rmb)	12279	Calibrated from equation (89) for initial stead state
ΔL	Total loans flows (100 million rmb)	112883	Calculated from equation (72)
ΔL_f	firms loans borrowing (100 million rmb)	78679	Calculated from equation (60)
ΔL_h	Households loans borrowing (100 million rmb)	34213	Calculated from equation (51)
ΔZ_b	Banks other payable/receivables flows (100 million rmb)	8637	Calibrated from equation (74)
ΔZ_f	Firms other payable/receivables flows (100 million rmb)	54569	Calibrated from equation (59) for initial steady state
ΔZ_g	Governments other payable/receivables flows (100 million rmb)	39914	Calibrated from equation (82) for initial steady state
ΔZ_h	Households other payable/receivables flows (100 million rmb)	-106403	Calibrated from equation (50) for initial steady state
ΔZ_r	The rest of the world's other payable/receivables flows (100 million rmb)	3283	Calibrated from equation (87) for initial steady state
$DIVB$	Banks' distributed income paid (100 million rmb)	1684	Based on National Bureau of Statistics of China
$DIVB_g$	Banks' distributed income received by governments (100 million rmb)	1287	Based on National Bureau of Statistics of China
$DIVB_h$	Banks' distributed income received by households (100 million rmb)	396	Based on National Bureau of Statistics of China
$DIVF$	Firms' distributed income paid (100 million rmb)	143096	Based on National Bureau of Statistics of China
$DIVF_g$	Firms' distributed income received by governments (100 million rmb)	132805	Based on National Bureau of Statistics of China
$DIVF_h$	Firms' distributed income received by households (100 million rmb)	16680	Based on National Bureau of Statistics of China
$DIVF_r$	Firms' distributed income received/paid by the rest of the world (100 million rmb)	-6389	Based on National Bureau of Statistics of China
EY	Energy intensity (TWh/100 million rmb)	40.52	Based on World Bank and Our World in Data
FP	Firms' net profit (100 million rmb)	70742	Calculated from equation (56)
FP_g	Firms' gross profit (100 million rmb)	82049	Calculated from equation (55)
Γ_{eg}	Share of green capital for renewable energy production	0.0061	Calculated by $\Gamma_{eg} = \frac{keg}{ke}$
Γ_{re}	Share of renewable energy	0.1582	Calculated from equation (8)
G	International reserves (100 million rmb)	218639	Based on China's National Balance Sheet
GP	Governments' net profit (100 million rmb)	83611	Calculated from equation (78)
GP_g	Governments' gross profit (100 million rmb)	235831	Calculated from equation (77)
g_y	Real GDP growth	0.0595	Calculated from the series of y
I_f	Firms' fixed capital formation (100 million rmb)	169096	Calibrated from equation (35) for initial steady state
i_f	Firms' fixed capital formation in volume (100 million rmb)	169096	Based on the assumption that initial prices are 1
I_g	Governments' fixed capital formation (100 million rmb)	16697	Calibrated from equation (79) for initial steady state
i_g	Governments' fixed capital formation in volume (100 million rmb)	16697	Based on the assumption that initial prices are 1
I_h	Households' fixed capital formation (100 million rmb)	185898	Calibrated from equation (46) for initial steady state
i_h	Households' fixed capital formation in volume (100 million rmb)	185898	Based on the assumption that initial prices are 1

K	Total capital (100 million rmb)	4459879	Based on China's National Balance Sheet
k	Total capital in volume (100 million rmb)	4459879	Based on the assumption that initial prices are 1
ke	Capital for energy production in volume, calculated by accumulating fixed capital formation in the energy sector (100 million rmb)	350247	Based on National Bureau of Statistics of China and China's National Balance Sheet
keg	Capital for renewable energy production in volume (100 million rmb)	2125	Calculated from equation (3) under the assumption that renewable energy are produced with the same technology
K_f	Firms fixed capital (100 million rmb)	1751211	Based on China's National Balance Sheet
k_f	Firms fixed capital in volume (100 million rmb)	1751211	Based on the assumption that initial prices are 1
K_g	Governments fixed capital (100 million rmb)	209337	Based on China's National Balance Sheet
k_g	Governments fixed capital in volume	209337	Based on the assumption that initial
K_h	Households fixed capital (100 million rmb)	2499331	Based on China's National Balance Sheet
k_h	Households fixed capital in volume (100 million rmb)	2499331	Based on the assumption that initial prices are 1
L	Total loans (100 million rmb)	2009917	Based on China's National Balance Sheet
L_f	Firms' loans, sum of firms' loans and bonds (100 million rmb)	1400738	Based on China's National Balance Sheet
L_h	Households loans (100 million rmb)	609179	Based on China's National Balance Sheet
LEV_f	Firms' leverage ratio	0.5904	Calculated from equation (62)
M	Import (100 million rmb)	172444	Based on World Bank
m	Real import (100 million rmb)	172444	Based on the assumption that initial prices are 1
N	Employment	7.4e+8	Based on World Bank
NN	Labor force	7.75e+8	Based on World Bank
OIP	Other income from properties (100 million rmb)	6117	Based on National Bureau of Statistics of China
P_{B_g}	Price of government bonds	20.24	Calculated from equation (84)
P_c	CPI (2019 = 1)	1	Assumed
P_{ce}	Price of conventional energy (100 million rmb/TWh)	3.8e-4	Based on China Energy Portal
Π_b	Banks' gross operating surplus	47832	Calculated from equation (67)
Π_f	Firms' gross operating surplus	256999	Calculated from equation (54)
Π_g	Governments' gross operating surplus	108935	Calculated from equation (76)
π	CPI inflation	0	Assumed for initial steady state
P_k	Capital price index (2019 = 1)	1	Assumed
P_{kh}	Households capital price index (2019 = 1)	1	Assumed
P_{re}	Price of renewable energy, solar (100 million rmb/TWh)	8.5e-4	Based on China Energy Portal
P_x	Export price index (2019 = 1)	1	Assumed
P_y	GDP deflator (2019 = 1)	1	Assumed
r_{B_g}	Government bonds rate	0.0494	Based on National Bureau of Statistics of China and China's National Balance Sheet
r_D	Deposits rate	0.0273	Based on National Bureau of Statistics of China and China's National Balance Sheet
r_{L_f}	Firms loans rate	0.0362	Based on National Bureau of Statistics of China and China's National Balance Sheet
r_{L_h}	Households loans rate	0.0474	Based on National Bureau of Statistics of China and China's National Balance Sheet
SB	Social benefits (100 million rmb)	122269	Calculated from $SB = \gamma_{SB} GP$
SC	Social contributions (100 million rmb)	-117552	Calculated from $SC = \tau_{sc} W$
T	Income tax received by governments (100 million rmb)	87601	Based on National Bureau of Statistics of China
T_b	Income tax paid by firms (100 million rmb)	65897	Based on National Bureau of Statistics of China
T_f	Income tax paid by firms (100 million rmb)	11306	Based on National Bureau of Statistics of China
T_h	Income tax paid by households (100 million rmb)	10398	Based on National Bureau of Statistics of China
θ	Carbon emission per energy consumption (Mt/TWh)	0.00027	Based on Our World in Data

TL	Net production tax received by the government (100 million rmb)	97613	Based on National Bureau of Statistics of China
TL_b	Net production tax paid by banks	7595	Based on National Bureau of Statistics
TL_f	Net production tax paid by firms (100 million rmb)	88519	Based on National Bureau of Statistics of China
TL_h	Net production tax paid by households (100 million rmb)	1500	Based on National Bureau of Statistics of China
u	Unemployment rate	0.0456	Based on World Bank
U_k	Capacity utilization	0.7511	Wang and Zeng (2022) [9]
V_h	Households net worth (100 million rmb)	5035046	Calculated from equation (53)
W	Wage bill (100 million rmb)	376938	Based on National Bureau of Statistics of China
w	Real wage (100 million rmb)	0.0005	Calculated from equation (28)
W_b	Wage paid by banks (100 million rmb)	20824	Based on National Bureau of Statistics of China
W_f	Wage paid by firms (100 million rmb)	266648	Based on National Bureau of Statistics of China
W_g	Wage paid by governments (100 million rmb)	89467	Based on National Bureau of Statistics of China
X	Export (100 million rmb)	181617	Based on World Bank
x	Real export (100 million rmb)	181617	Based on the assumption that initial prices are 1
Y	GDP excluding change in inventories and other non-financial investment (100 million rmb)	986515	Based on National Bureau of Statistics of China
y	Real GDP excluding change in inventories and other non-financial investment (100 million rmb)	986515	Based on the assumption that initial prices are 1
Y_b	Banks' output (100 million rmb)	76251	Calculated by $Y_b = Y - Y_f - Y_g - Y_h$
Y_d	Households' disposable income (100 million rmb)	826989	Calculated from equation (45)
Y_f	Firms' output (100 million rmb)	612165	Calculated from equation (42)
Y_g	Governments' output (100 million rmb)	100788	Calculated from equation (42)
Y_{gd}	Households' gross disposable income (100 million rmb)	597566	Calculated from equation (44)
Y_h	Households' output (100 million rmb) (100 million rmb)	197312	Calculated from equation (42)
y_r	Real GDP of the rest of the world (100 million rmb)	733743	Based on World Bank
Z_b	Other payable/receivables of banks (100 million rmb)	-270696	Based on China's National Balance Sheet
Z_f	Other payable/receivables of firms (100 million rmb)	-971620	Based on China's National Balance Sheet
Z_g	Other payable/receivables of governments (100 million rmb)	-710673	Based on China's National Balance Sheet
Z_h	Other payable/receivables of households (100 million rmb)	1894535	Based on China's National Balance Sheet
Z_r	Other payable/receivables of the rest of the world (100 million rmb)	58454	Based on China's National Balance Sheet

Table 5: Values for parameters

Symbol	Description	Value	Remark/sources
a_0	Share of insurance savings out of disposable income	0.0273	Calibrated for initial steady state
α_{eg}	Maximum elasticity of substitution of renewable energy with respect to conventional energy	18.74	Calibrated from equation (9) for initial steady state
β_{eg}	Sensitivity of elasticity of substitution of renewable energy with respect to conventional energy to the ratio of conventional energy over renewable energy	-3.07	Aleti and Hochman (2020)
c_0	Consumption level when $c_{h,t-1} = \frac{Y_{d,t-1}}{P_{c,t}} = \frac{V_{h,t-1}}{P_{c,t}}$ = 1 (100 million rmb)	0.5325	Calibrated from equation (31) for initial steady state
c_1	Consumption habit formation parameter	0.2663	Calibrated from equation (31) for initial steady state
c_2	Elasticity of consumption with respect to disposable income	0.5583	Estimated from OLS regression
c_3	Elasticity of consumption with respect to wealth	0.1754	Estimated from OLS regression
ce_0	Carbon emission per conventional energy	0.0003	Calibrated from equation (17) for

[9] Chinese article. Wang and Zeng (2022). Research on the Macro Measurement Indicators and Methods of Capital Utilization Rate. *Statistical Research, 39*(7), 43-55.

			initial steady state
ce_1	Sensitivity of carbon emission per energy to the share of renewable energy	-0.0003	Calibrated from equation (17) to have $\theta = 0$ when $\Gamma_{eg} = 1$
c_{g0}	Government consumption per real GDP	0.1149	Calibrated from equation (38) for initial steady state
δ_{f0}	Firms' capital depreciation rate without usage	0.039	Calibrated from $\delta_{f,t} = \delta_{f0} + \delta_{f1} U_{k,t}$ for initial steady state
δ_{f1}	Sensitivity of firms' fixed capital depreciation rate to capacity utilization	0.005	Estimated from OLS regression
δ_g	Governments' capital depreciation rate	0.025	Based on the China's National Balance Sheet
δ_h	Households' capital depreciation rate	0.0428	Based on the China's National Balance Sheet
d_{f0}	Liquidity preference of firms	0.4151	Calibrated from equation (36) for initial steady state
d_{f1}	Sensitivity of firms' deposits to interest rate gap	4.4186	Estimated from OLS regression
d_{g0}	Governments' deposits saving rate out of net profit	0.2278	Calibrated from equation (80) for initial steady state
d_{h0}	Households deposits level when $V_{h,t-1} = 1$ and $r_{D,t} = r_{L_h,t}$	0.2619	Calibrated from equation (33) for initial steady state
d_{h1}	Sensitivity of households deposits to net worth	1	Calibrated from equation (33) for initial steady state
d_{h2}	Sensitivity of households deposits to interest rate gap	5.2276	Estimated from OLS regression
e_0	Energy production level when $KE_t = 1$	412005	Calibrated from equation (3) for initial steady state
e_1	Sensitivity of energy production to capital for energy production	0.3612	Estimated from OLS regression
F_{re}	Fixed cost of renewable energy production	5352.1	Calibrated from equation (12) for initial steady state
γ_{DIVB}	Share of banks' distributed profit paid	0.0352	Based on National Bureau of Statistics of China
γ_{DIVB_h}	Share of banks' distributed profit received by households	0.2354	Based on National Bureau of Statistics of China
γ_{DIVF}	Share of firms' distributed profit paid	0.5568	Calibrated from equation (55), (56) and (60) for initial steady state
γ_{DIVF_h}	Share of firms' distributed profit received by households	0.2354	Based on National Bureau of Statistics of China
γ_{DIVF_r}	Share of firms' distributed profit received/paid by the rest of the world	-0.0446	Calibrated from equation (86) and (88) for initial steady state
γ_{OIP}	Insurance payment rate	0.05	Based on National Bureau of Statistics of China
γ_{SB}	Share of social benefit paid out of governments' gross profit	0.5185	Based on National Bureau of Statistics of China
γ_{W_b}	Share of banks' wage payment out of total wage bill	0.0552	Based on National Bureau of Statistics of China
γ_{W_f}	Share of firms' wage payment out of total wage bill	0.7074	Based on National Bureau of Statistics of China
γ_{Y_f}	Share of firms' output	0.6205	Based on National Bureau of Statistics of China
γ_{Y_g}	Share of governments' output	0.1022	Based on National Bureau of Statistics of China
γ_{Y_h}	Share of households' output	0.2	Based on National Bureau of Statistics of China
γ_{Z_f}	Share of other payable/receivables transaction out of firms' net profit	0.7714	Based on National Bureau of Statistics of China
γ_{Z_g}	Share of other payable/receivables transaction out of governments' net profit	0.4774	Based on National Bureau of Statistics of China
γ_{Z_h}	Share of other payable/receivables transaction out of disposable income	-0.1287	Based on National Bureau of Statistics of China
γ_{Z_r}	Share of other payable/receivables transaction out of current account surplus/deficit	0.2110	Based on National Bureau of Statistics of China
m_0	Import level when $Y_t = 1$ (100 million rmb)	0.1852	Calibrated from equation (41) for initial steady state
m_1	Elasticity of import to domestic income	1	Calibrated from equation (41) for initial steady state
i_{f0}	Autonomous firms' investment rate	0.0248	Calibrated from equation (34) for initial steady state
i_{f1}	Sensitivity of firms' investment rate to net profit rate	0.6343	Estimated from OLS regression
i_{g0}	Government investment per real GDP	0.0179	Calibrated from equation (39) for initial steady state
i_{h1}	Sensitivity of households investment to net worth	1	Calibrated from equation (32) for

			initial steady state
p_{c0}	Mark-up of CPI	1.7389	Calibrated from equation (29) for initial steady state
p_{c1}	Elasticity of CPI to unit cost of production	0.5750	Estimated from OLS regression
p_{k0}	Mark-up of capital price	1.6399	Calibrated from equation (29) for initial steady state
p_{k1}	Elasticity of capital price to unit cost of production	0.5141	Estimated from OLS regression
p_{kh0}	Mark-up of households capital price	5.2739	Calibrated from equation (29) for initial steady state
p_{kh1}	Elasticity of households' capital price to unit cost of production	1.7283	Estimated from OLS regression
p_{x0}	Mark-up of export price	1.1988	Calibrated from equation (29) for initial steady state
p_{x1}	Elasticity of export price to unit cost of production	0.1885	Estimated from OLS regression
r_{b0}	Government bonds rate when $r_D = 0$	2.74e-05	Calibrated from equation (65) for initial steady state
r_{b1}	Sensitivity of government bonds rate to deposits rate	1.8105	Estimated from OLS regression
r_{d0}	Deposits rate when $r_{Lf} = 0$	0.0116	Calibrated from equation (64)
r_{d1}	Sensitivity of deposits rate to firms' loans rate	0.4332	Estimated from OLS regression
r_{f0}	Firms' loans rate when $r_{L_f,t-1} = 0$ and $g_{y,t-1} = g_{y,ss}$	0.0173	Calibrated from equation (37) for initial steady state
r_{f1}	Persistence of firms' loans interest rate	0.5215	Estimated from OLS regression
r_{f2}	Sensitivity of firms' loans rate to GDP growth rate	0.1811	Estimated from OLS regression
r_{h0}	Households' loans rate when $r_{L_f} = 0$	-0.0002	Calibrated from equation (66) for initial steady state
r_{h1}	Sensitivity of households' loans rate to firms' loans rate	1.3159	Estimated from OLS regression
r_{kce}	Marginal cost of conventional energy production	0.0172	Calibrated from equation (11) for initial steady state
τ_b	Income tax rate paid by banks	0.8507	Calibrated from equation (78) and (83) for initial steady state
τ_f	Income tax rate paid by firms	0.1378	Based on National Bureau of Statistics of China
τ_h	Income tax rate paid by households	0.0174	Based on National Bureau of Statistics of China
τ_{Lb}	Net production tax rate paid by banks	0.0996	Based on National Bureau of Statistics of China
τ_{Lf}	Net production tax rate paid by firms	0.1446	Based on National Bureau of Statistics of China
τ_{Lh}	Net production tax rate paid by households	0.0076	Based on National Bureau of Statistics of China
τ_{sc}	Social contribution ratio over wages	-0.3119	Calibrated from equation (45) and (51) for initial steady state
w_1	Sensitivity of real wage to unemployment	-0.0009	Estimated from OLS regression
w_2	Sensitivity of real wage to labor productivity	0.3873	Calibrated from equation (27) for initial steady state
x_0	Export level when $\frac{Y_{r,t}}{P_{x,t}} = 1$ (100 million rmb)	1.04e-05	Calibrated from equation (40) for initial steady state
x_1	Elasticity of export to foreign demand	1.7463	Estimated from OLS regression
y_{kf0}	Inverse of firms' fixed capital intensity	0.7946	Calibrated from equation (23) for initial steady state
y_{kf1}	Elasticity of output to firms fixed capital	1	Calibrated from equation (23) for initial steady state
y_{kg0}	Inverse of government's fixed capital intensity	6.6476	Calibrated from equation (23) for initial steady state
y_{n0}	Inverse of labor intensity	2.09e-52	Calibrated from equation (23) for initial steady state
y_{n1}	Labor productivity growth rate	0.076	Estimated from OLS regression
y_{n2}	Elasticity of output to labor	0.076	Estimated from OLS regression