Will China's Shale Gas Industry Achieve Its Production Goals with Subsidy Removal?

by

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Abstract

With the expectation of growing gas demand, a desire to improve environmental impact, the high resource potential of shale gas in China, and the success of the shale gas revolution in the U.S., the Chinese government has implemented incentive policies for shale gas development, such as quantity subsidy and taxes relief. These policy-incentives cover the time frame till 2021 and the government hasn't announced their intention to continue any supportive action thereafter. After introducing current policy environment, this paper is devoted to analyse the influence of the policy removal on shale gas industry by identifying and measuring the potential impact of key variables on shale gas development through system dynamics methodology. Our findings show that the persistently phasing out incentive policies will dampen investors and negatively impact future production. More precisely, the investment solely funded by shale gas enterprise profit is insufficient in meeting the medium-term objective of China's shale gas production. These findings are sustained by the sensitivity analysis we have performed.

Introduction

China has joined the ranks of the major industrialised gas consuming economies, with economic growth continuing apace. The expectation is that gas demand will continue to rise, enhanced by a desire to improve air quality and mitigate other tangible environmental impacts of heavy reliance on coal (falling to 60.4% in 2017) in the energy mix [1]. China's natural gas consumption increased to $2404*10^8$ m^3 in 2017, representing 6.6% of primary energy consumption, making it the third largest gas consumer in the world after the US and Russia, while domestic gas production was $1492*10^8$ m^3[1]. China National Development and Reform Commission, the agency representing China's government introducing regulatory policies, sets the goal to optimize the structure of energy consumption, as gas will account for 10% of primary energy consumption at 2020, and strives to increase this ratio to 15% at 2030 [2]. Though domestic conventional gas production has grown considerably, it will soon peak and usher in a stable development period [3]. China has already realized the need to import pipeline gas and LNG from a variety of suppliers in order to meet its soaring requirements [4].

In addition to the conventional gas resource endowment, it's clearly that unconventional gas should play a significant role in contributing towards future energy needs. China is assessed as having the third largest Coal Bed Methane (CBM) resources and the highest shale gas resources, by the EIA assessment of international potential (2011). Tight gas, being considered as one of three forms of unconventional gas in most countries, is classified as conventional natural gas

in China [5]. The medium-term objective, set by China National Development and Reform Commission, include that CBM production reaches the volumes of $100*10^8$ m³ annually by 2020 and $300*10^8$ m³ in 2025, and shale gas production reaches the volumes of $300*10^8$ m³ annually by 2020 and 800-$1000*10^8$ m³ in 2030 [2]. In 2018, CBM production is $72.6*10^8$ m³, shale gas production is $100*10^8$ m³.

Our research cautions against optimistic assumptions of a steady and robust acceleration of shale gas production prior to 2030. Drawing lessons from the rather disappointing progress on CBM production in China, this research is applied to the question of how China might achieve shale gas production goals by 2020 and 2030. The challenges include but not limited to water availability, funds and application of technology.

This paper provides a SD model of China's shale gas industry and builds a better understanding of how fiscal subsidy and tax relief will affect the production, and what will be required for China's shale gas development to succeed.

China's shale gas development policy environment

Domestic gas production becomes increasingly unable to satisfy industrial and residential needs for gas consumption in China. However, natural gas in China is trapped in smaller and less favourable reservoirs that are more difficult to develop compared with other gas-rich countries. As a new pathfinder to gas development, China is significantly restricted by lack of expertise, technology and infrastructure. Soaring gas price and upgrading concern about deteriorating environmental conditions pushed the government to seek for foreign suppliers to bridge the supply-demand gap.

The rise of shale gas and its profound impact in US has aroused considerable interest in China, the government has paid a great deal of attention to global unconventional gas trends and has implemented incentive policies for shale gas development. Since 2010, shale gas development issues have been discussed and guided twenty-four times at national level long-term development plans and work reports, showing its strategic importance obviously. The articles cover government regulation, fiscal subsidy and technical research. We classified these policies into 4 categories including technology, cost, market activities and environment, shorted as T, C, M, and E in table 1. It's obvious that most attention is paid to market and technical issues, as 16 and 13 times respectively from 2010 to 2016. There is no specific policy on the environment up to now, expect in some compound policies. Key information is summarized in Table 1.

Table 1 China's shale gas development policy

No.	File Published	Publishing Department	Time	Core Contents	Matching Problems
1	Notice of NEA on the establishment of 22 national energy research and development centres (National energy technology [2010] no.215)	NEA	2010	Establishing national energy shale gas research and development centre, focus on the research in key technologies in shale gas development.	T

No.	File Published	Publishing Department	Time	Core Contents	Matching Problems
2	Notice of new mineral discoveries (no. 30, 2011)	MLR	2011	Setting shale gas as China's 172nd independent mineral	M
3	MLR held the first public tender for the sale of shale gas exploration rights	MLR	2011	Innovating the oil and gas resource management system, inviting bids for 4 shale gas exploration rights	M
4	Catalogue of industrial guidance for foreign investment (revised in 2011) (NDRC no. 12)	NDRC, MC	2011	Encouraging foreign investment into the exploration and development of unconventional natural gas resources such as shale gas (limited to joint ventures and cooperation)	M
5	Opinions on further encouraging and guiding private capital investment in land and resources (land resources development [2012] no. 100)	MLR, ACFIC	2012	Supporting the participation of private capital in shale gas exploration and exploitation, and protecting the legitimate rights and interests of private capital in accordance with the law	M
6	Notice on promoting advanced and applicable technologies to improve the level of saving and comprehensive utilization of mineral resources (no.154 [2012] of MLR)	MLR	2012	Working hard to popularize advanced, applicable and efficient development technologies in key areas such as shale gas	T
7	Notice on the issuance of the 12th five-year plan for natural gas development (FGD [2012] no. 3383)	NDRC	2012	1. Conducting national shale gas resource potential survey and evaluation;2. Improving basic measures for shale gas transportation; 3. Carrying out special exploration and development of shale gas; 4. Researching and formulating the special plan for major equipment independence of shale gas; 5. Implementing policies to encourage shale gas industry and strengthening international cooperation; 6. Paying attention to environmental protection measures, strengthening management and environmental monitoring.	T, C, M, E
8	Notice on the introduction of shale gas development and utilization subsidy policy (MF [2012] no. 847)	MF, NEA	2012	From 2012 to 2015, the subsidy standard from the central government is 0.4 yuan per cubic meter.	C
9	Notice on the issuance of shale gas development plan (2011-2015) (FGD [2012] no. 612)	NDRC, MF, MLR, NEA	2012	1. Strengthening the investigation and evaluation of shale gas resource potential; 2. Strengthening scientific and technological research; 3.	T, C, M, E

No.	File Published	Publishing Department	Time	Core Contents	Matching Problems
				Implementing incentive policies for shale gas industry; 4. Strengthening supervision and paying attention to environmental protection.	
10	Notice on strengthening the work related to the exploration, exploitation, supervision and administration of shale gas resources (MLR (2012) no. 159)	MLR	2012	1. Establishing norms and standard systems for shale gas investigation and evaluation, exploration, exploitation and reserve estimation; 2. Strengthening technological breakthroughs in shale gas exploration and exploitation; 3. Encouraging all types of social investors to enter the market according to law; 4. Encouraging the exploration and exploitation of shale gas in oil and natural gas blocks; 5. Strengthening supervision and implementing shale gas exploration commitment system; 6. Strengthening environmental protection and production safety according to law; 7. Shale gas mining royalties and mineral resource compensation fees shall be reduced or exempted according to law.	T, C, M, E
11	Notice on agreeing to build 46 key laboratories including natural gas hydrate (no.83 [2012] of MLR)	MLR	2012	1. Setting up the key laboratory for shale gas exploration; 2. Establishing the key laboratory for strategic evaluation of shale gas resources.	T
12	Measures for the management of special funds for the conservation and comprehensive utilization of mineral resources (MF [2013] no. 81)	MF, MLR	2013	Special funds for the conservation and comprehensive utilization of mineral resources are mainly used to support the comprehensive development and utilization of shale gas and other resources, and are mainly used to tackle key scientific research, formulate and promote technical standards.	T, C, M
13	Notice of bidding for shale gas exploration rights of MLR	MLR	2013	Bidding for 20 blocks of shale gas exploration rights; 2. 16 bid-winning candidates from 19 blocks were selected.	M
14	Announcement of NEA on shale gas industry policy (no. 5, 2013)	NEA	2013	1. Strengthening the supervision of shale gas development and production	T, C, M, E

No.	File Published	Publishing Department	Time	Core Contents	Matching Problems
				process, paying attention to conservation and environmental protection; 2. Encouraging local enterprises to cooperate with foreign enterprises through joint ventures and cooperation; 3. Incorporating new strategic industries and increase financial support; 4. Developing the shale gas technology innovation mechanism with enterprises as the main body and the combination of production, study, research and application; 5. Attaching importance to the industrial technology policy of shale gas, and accelerating the pace of independent exploration technology and localization of equipment; 6. Implementing market pricing for ex-factory prices, encouraging various investors to enter the shale gas sales market, and encouraging shale gas to be used nearby and connected to the pipe network; 7. Bringing shale gas into the national strategic emerging industry and increasing financial support; 8. Reducing or exempting relevant taxes and fees of mining enterprises.	
15	Government work report 2014	SC	2014	Promoting the reform of energy production and consumption mode, and strengthening the exploration, exploitation and application of natural gas, coal bed methane and shale gas.	M
16	Measures for the construction and operation management of natural gas infrastructure (NDRC no. 8)	NDRC	2014	Strengthening the construction, operation and management of natural gas infrastructure, establishing and improving the national natural gas pipeline network	T, M
17	Notice of the general office of the state council on the issuance of strategic action plan for energy development (2014-2020) (SC [2014] no. 31)	SC	2014	1. Strengthening shale gas geological survey and research; 2. Listing shale gas as a key innovation direction and carrying out relevant major shale gas demonstration projects; 3.	C, T, M

No.	File Published	Publishing Department	Time	Core Contents	Matching Problems
				Implementing major science and technology projects to strengthening core technologies of shale gas; Improving policies on energy taxes and fees, energy investment and industrial policies, and energy consumption.	
18	Notice on the issuance of recommended industry standards for shale gas resources/reserves calculation and evaluation technical specification (no. 6, 2014)	MLR	2014	Technical requirements for shale gas resources/reserves classification and classification, definition, reserves calculation method and reserves evaluation are specified.	T
19	Notice on the disposal result of the expiration of the exploration period of the tendered shale gas exploration right (no. 25, 2014)	MLR	2014	1. The area of "Nanchuan block" of Sinopec will be reduced to 593.44 square kilometres; 2. The area of "Xiushan block" of Henan CBM development and utilization co., LTD is 994.15 square kilometres.	M
20	Measures for fair and open supervision of oil and gas pipeline network facilities (trial) (NEA [2014] no. 84)	NEA	2014	1. Encouraging and guiding private capital to enter the shale gas field, and realizing the gradual diversification of upstream and downstream market players; 2. Clarifying regulatory content, promoting fair and open oil and gas pipeline network, and improving the utilization efficiency of pipeline network facilities.	M
21	Government work report 2015	SC	2015	The revolution in energy production and consumption is crucial with development and people's livelihood.	M
22	Notice on the issuance of standardized management measures and implementation rules for the energy sector (no. 52 [2009] of NEA)	NEA	2015	Approving 10 shale gas-related industry standards (NB)	T
23	Notice on fiscal subsidy policy for shale gas development and utilization (MF [2015] no. 112)	MF	2015	The central government will provide subsidies to shale gas extraction companies, 0.3 yuan per cubic meter for 2016-2018 and 0.2 yuan per cubic meter for 2019-2020.	C
24	Notice on the issuance of the 13th five-year plan for national science and technology innovation (issued by SC in 2016 (43))	SC	2016	Launching a major national science and technology project to develop key technologies and core equipment for	T

No.	File Published	Publishing Department	Time	Core Contents	Matching Problems
				shale gas and coal-bed methane in an economical and effective manner.	

MLR: Ministry of Land and Resources; NEA: National Energy Administration; MC: Ministry of Commerce; NDRC: National Development and Reform Commission; ACFIC: All-China Federation of Industry and Commerce; MF: Ministry of Finance; SC: the State Council.

T: Technology; C: Cost; M: Market Activities; E: Environment.

The implementation of stimulus measures indeed shows their impact, key technologies such as microseismic monitoring technology and tight shale fracturing technology are promoted, through which the development cost has been decreasing significantly.

These policies bring certain development opportunities to China's shale gas industry. However, some deficiencies are hard to cope with. Shale gas industry is capital-intensive, which requires large investments, and the early investment yield is low. In order to attract capitals, a series of policies such as fiscal subsidies and tax relief, reducing or exempting shale gas mining royalty, and mineral resource compensation are enacted. However, the requirement of subsidies is so rigorous that only limited enterprises are willing to invest. Meanwhile, these incentive policies have poor executive possibility, and pay limited attention to environmental issues.

Considering its advantages on integrity and dynamics during the complex analysis, this paper plans to establish a SD model to simulate the development processes of shale gas production. The simulated results can help us figure out the policy mechanism and the development pathway of shale gas industry.

Methodology

Considering both technical and economic factors, a shale gas development simulation model, using System Dynamics Analysis ("SD"), has been built. SD is a system modelling and dynamic simulation methodology for analysis of dynamic complexity in socio-economic and biophysical systems [6]. Based on the principle of system thinking and feedback control theory, SD helps in understanding the time varying behaviour of complex systems [7]. The method has been previously used to simulate the evolution of energy system and national incentive policies [8]. We use SD model to simulate how current incentive policies affect China's shale gas's demonstrated capacity, production, investment and enterprise profit.

Many articles and forecasts about shale gas development trends in China rely on either reviewing policies qualitatively or simulating industrial expansion planning with analysis based on a limited number of factors. In comparison, the SD model uses more relevant factors and has stronger competence to illustrate the behaviour over time of China's shale gas development in the long-term.

In this paper, the period of simulation realized in Vensim is from 2017 to 2030, which is valid since it's shorter than a life cycle of shale gas well, time step is 1 year. Current published incentive policies are as follows: a quantitative subsidy which is 0.3 CNY/ m^3 from 2017 to

2018, 0.2 CNY/ m³ from 2019 to 2020, and resource tax reduction, from 6% to 4.2% between April 2018 and March 2021. We assume both the subsidy and resource tax reduction will end in 2021. There are three aspects of China's incentive policies that may influence the dynamic system: (1) Liberalize shale gas wellhead price, making it fluctuate with market equilibrium; (2) Quantity subsidy and tax relief; (3) Lower development and operating cost by additional investment in technical research.

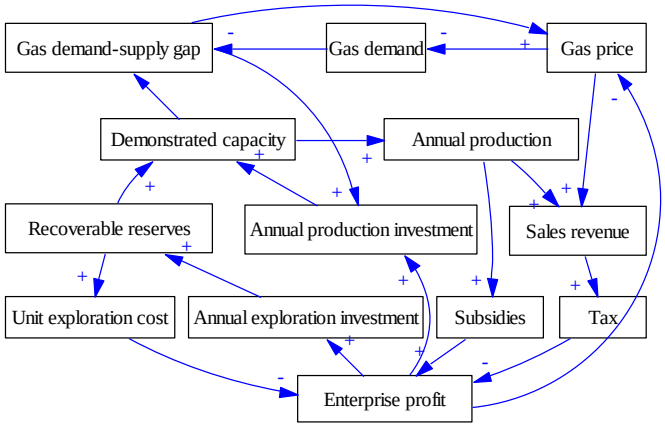

Fig. 1 SD Model

The hypothesis of this SD model is represented by a major causal loop as shown in Fig.1, which involves four principal blocks: 'gas supply and demand', 'shale gas exploration and development', 'fiscal subsidy and tax relief', and 'enterprise profit'. The directions of arrows indicate the influence interaction between those parameters.

To avoid introducing variables unrelated to the system and to better understand the relationship between the subsystems, this paper firstly discusses the stock flow diagram among the four subsystems, then analyses the relationship between the subsystems and their mutual influence, and finally couples them into the modelling system of China's shale gas development system.

(1) Shale gas exploration &development module

The cycle of shale gas exploration and development, which varies from 20 to 50 years, is such a long process that affected by various external environment. It is general to divide shale gas exploration and development into three links of exploration, development and production, as shown in Fig. 2.

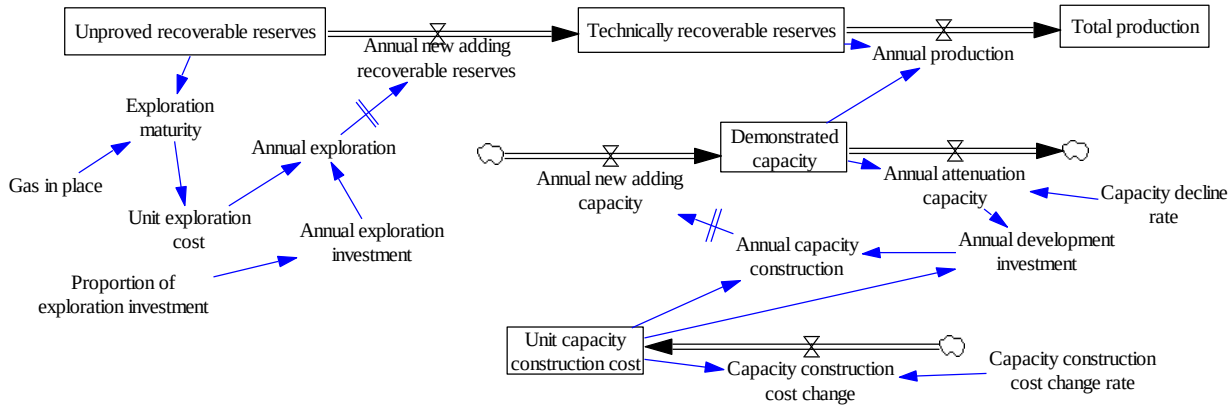

Fig. 2 Shale gas exploration &development module

With the enhancement of exploration maturity, unit exploration cost will increase along with exploration difficulty.

Exploration maturity= (Gas in place-Unproved recoverable reserves)/Gas in place

To clarify the relationship of Unit exploration cost and Exploration maturity, we use fitting method in MATLAB, related data is drawn from experts of CNPC and Sinopec, the two biggest oil companies and shale gas investors of China.

*Unit exploration cost=0.02809*EXP (0.02362*Exploration maturity)*

The main job of exploration is to explore new technically recoverable reserves through geological survey. Considering the hysteresis of annual exploration investment in discovering new recoverable reserves, one auxiliary variable is introduced into this subsystem:

Annual exploration=Annual exploration investment/Unit exploration cost

Annual new adding recoverable reserves= DELAY1 (Annual exploration, 4) [9]

The core of shale gas development is to improve the capacity construction and turn the technically recoverable reserves into actual shale gas production. Shale gas production capacity decreases significantly over time, in order to make up for the declining capacity and the increasing market demand, enterprises need to invest into capacity construction every year.

Annual capacity construction=Annual development investment/Unit capacity construction cost

Annual new adding capacity= DELAY1 (Annual capacity construction, 3)

(2) Enterprise profit module

In the subsystem of enterprise profit as shown in Fig. 3, after-tax profit is key variable, since it determines the annual investment accumulation and is determined by sales revenue, taxes and subsides.

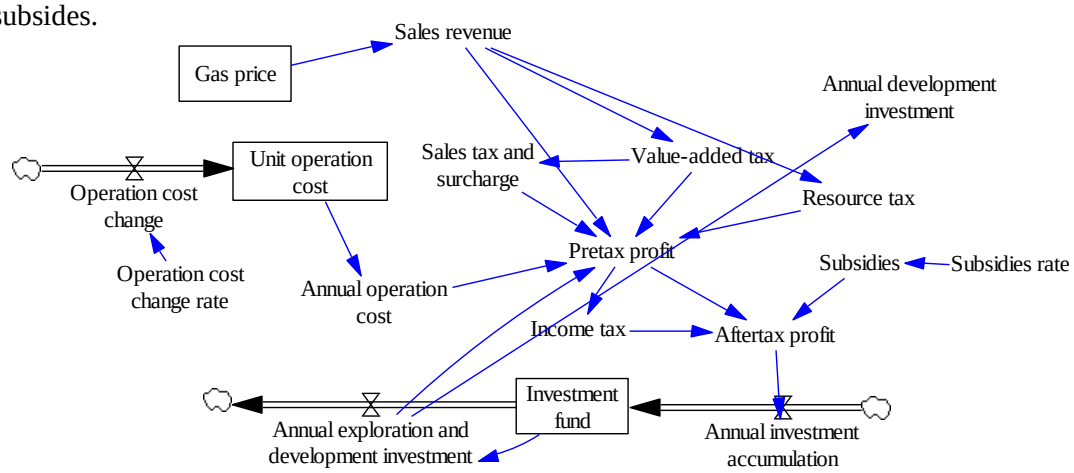

Fig. 3 Enterprise profit module

Pre-tax profit=Sales revenue-Annual operation cost-Annual development investment-Sales tax and surcharge-Resource tax- Value-added tax

After-tax profit=Pre-tax profit+ Subsidies-Income tax

*Shale gas annual production*0.3CNY/m³(2017-2018)*

*Subsidies= Shale gas annual production*0.2CNY/m³(2019-2020)*

0(After 2020)

With expert survey method, we assume that 55% of after-tax profit will be put into annual investment accumulation, 70% of investment fund will be invest into exploration and development.

*Annual development investment=MIN (Annual exploration and development investment-Annual exploration investment, IF THEN ELSE ("Demand-supply gap">0, MAX (Annual attenuation capacity*Unit capacity construction cost, "Demand-supply gap"*Unit capacity construction cost)))*

(3) Fiscal subsidy and tax relief module

The influence of subsidies and taxes on the after-tax profits of enterprises in the process of shale gas development is illustrated in this module as shown in Fig. 4.

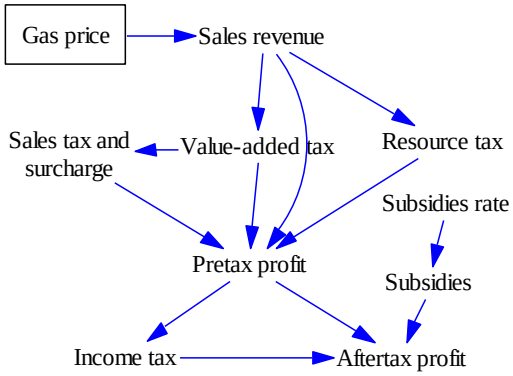

Fig. 4 Fiscal subsidy and tax relief module

It's obvious that gas price has perceptible impact on sales revenue. The goal of China's natural gas price revolution is to achieve full marketization, which requires harsh terms such as highly developed, independent and open infrastructure, diversified suppliers and rich resources. Currently, China's natural gas industry is in its adolescence growth spurt, some developed areas can become the pilot of gas price marketization, natural gas hub price will become market price benchmark.

In the process of shale gas exploration and development, resource tax, value-added tax, sales tax and surcharge, income tax are four taxes mainly levied.

*Resource tax=Sales revenue*0.06*0.7 (From 2018-2021)*

*Sales revenue*0.06 (After 2021)*

*Value-added tax=Sales revenue*0.16*

Sales tax and surcharge=Value-added tax(0.07+0.03)*

After-tax profit=Pre-tax profit(1-0.25) +subsidies*

(4) Gas supply and demand module

Though China's acute shortage of gas is well known, it's still indispensable to construct the simulation of gas supply and demand as shown in Fig. 5, since the demand-supply gap has a direct impact on China's shale gas subsidies and tax policies.

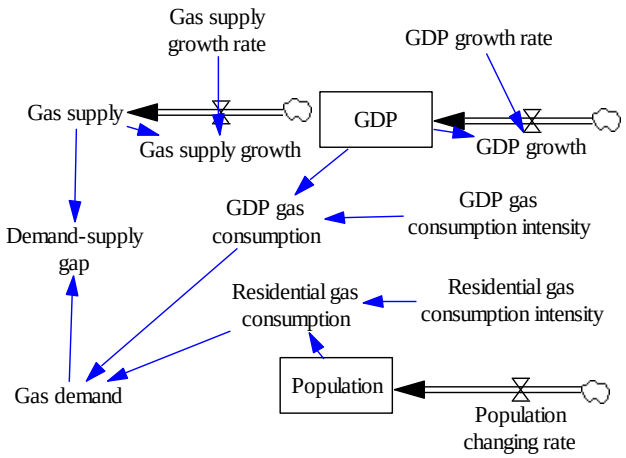

Fig. 5 Gas supply and demand module

*GDP gas consumption=GDP*GDP gas consumption intensity*

*Residential gas consumption=Population*Residential gas consumption intensity*

(5) China's shale gas development system

We couple these four subsystems and draw the flow graph of China's shale gas development system as shown in Fig. 6.

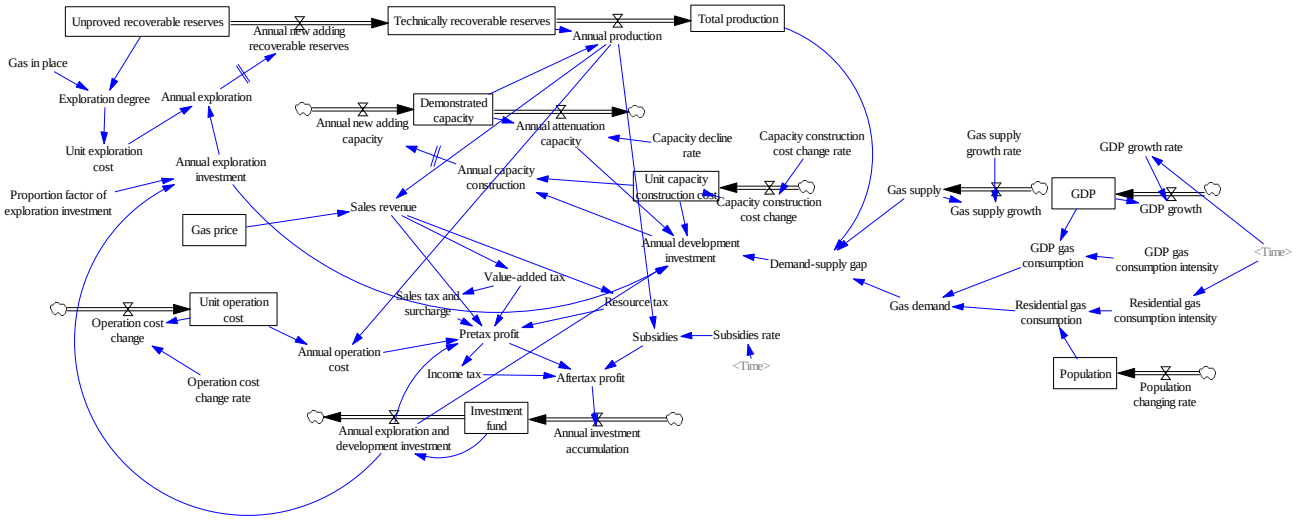

Fig. 6 Flow graph of China's shale gas development system

In this system we set 49 variables and model parameters, as shown in Table 2.

Table 2 Variable Setting

Variable	Unit	Interpretation	Initial value	Data source
GDP growth rate	Dmnl	WITHLOOKUP((2017,6.9%),(2018,6.6%),(2019,6.3%),(2020,6%),(2021,6%),(2022,6%),(2023,6%),(2024,6%),(2025,6%),(2026,6%),(2027,6%),(2028,6%),(2029,6%),(2030,6%))		National Bureau of Statistics
GDP growth	CNY	GDP*GDP growth rate		
GDP	CNY	INTEG（GDP growth）	8.208E+13	National Bureau of Statistics
GDP gas consumption intensity	m^3/CNY	0.0026		National Bureau of Statistics
GDP gas consumption	m^3	GDP*GDP gas consumption intensity		
Residential gas consumption intensity	m^3/person	WITHLOOKUP((2017,30.6),(2018,32.8),(2019,35),(2020,37.2),(2021,39.4),(2022,41.6),(2023,43.8),(2024,46),(2025,48.2),(2026,50.4),(2027,52.6),(2028,54.8),(2029,57),(2030,59.2))		National Bureau of Statistics
Residential gas consumption	m^3	Population*Residential gas consumption intensity		
Population changing rate	Dmnl	0.005		Author's assumption
Population	Person	INTEG（Population changing rate*Population）	1.39E+09	
Gas demand	m^3	GDP gas consumption+ Residential gas consumption		
Gas supply growth rate	Dmnl	0.1		Author's assumption
Gas supply growth	m^3	Gas supply*Gas supply growth rate		
Gas supply	m^3	INTEG（+Gas supply growth）	1.49E+11	Public Data
Demand-supply gap	m^3	Gas demand-Gas supply -Total production	8.86E+10	National Bureau of Statistics
Gas in place	m^3		1.34E+14	EIA,2015
Exploration degree	Dmnl	(Gas in place-Unproved recoverable reserves)/Gas in place		
Unproved recoverable reserves	m^3	INTEG (-Annual new adding recoverable reserves)	1.03E+14	EIA,2015
Unit exploration cost	CNY/m^3	0.02809*EXP (0.02362*Exploration degree)		
Annual exploration	m^3	Annual exploration investment/Unit exploration cost		
Annual new adding recoverable reserves	m^3	DELAY1(Annual exploration, 4)		
Technically recoverable reserves	m^3	INTEG(Annual new adding recoverable reserves-Annual production)	9.17E+11	Public Data
Annual production	m^3	IF THEN ELSE(Technically recoverable reserves>0, Demonstrated capacity, Technically recoverable reserves)		

Proportion factor of exploration investment	Dmnl	0.25		Expert survey method
Annual exploration investment	CNY	Annual exploration and development investment*Proportion factor of exploration investment		
Operation cost change	CNY/m³	Operation cost change rate*Unit operation cost		
Operation cost change rate	Dmnl	0.05		Author's assumption
Annual operation cost	CNY	Annual production*Unit operation cost		
Capacity construction cost change rate	Dmnl	0.05		Author's assumption
Capacity construction cost change	CNY/m³	Capacity construction cost change rate*Unit capacity construction cost		
Unit capacity construction cost	CNY/m³	INTEG (Capacity construction cost change)	0.9	CNPC
Annual capacity construction	m³	Annual development investment/Unit capacity construction cost		
Annual new adding capacity	m³	DELAY1(Annual capacity construction, 3)		
Demonstrated capacity	m³	INTEG (+Annual new adding capacity-Annual attenuation capacity)	1.00E+10	Public Data
Annual attenuation capacity	m³	Capacity decline rate*Demonstrated capacity		
Capacity decline rate	Dmnl	0.3		D Zhang, 2015
Annual development investment	CNY	MIN(Annual exploration and development investment-Annual exploration investment, IF THEN ELSE("Demand-supply gap">0, MAX(Annual attenuation capacity*Unit capacity construction cost, "Demand-supply gap"*Unit capacity construction cost)))		
Gas price	CNY/m³	3.3		Public Data
Sales revenue	CNY	Annual production*Gas price		
Value-added tax	CNY	Sales revenue*0.16		
Sales tax and surcharge	CNY	Value-added tax*0.1		
Resource tax	CNY	Sales revenue*0.042		
Pretax profit	CNY	Sales revenue-Annual exploration and development investment-Annual operation cost-"Value-added tax"-Resource tax-Sales tax and surcharge		
Income tax	CNY	Pretax profit*0.25		
After-tax profit	CNY	Pretax profit-Income tax+ Subsidies		
Subsidies rate	CNY/m³	WITHLOOKUP(2017,0.3),(2018,0.3),(2019,0.2),(2020,0.2),(2021,0),(2022,0),(2023,0),(2024,0),(2025,0),(2026,0),(2027,0),(2028,0),(2029,0),(2030,0))		Ministry of finance

Subsidies	CNY	Annual production*Subsidies rate		
Annual investment accumulation	CNY	After-tax profit*0.55		Expert survey method
Investment fund	CNY	INTEG(+Annual investment accumulation-Annual exploration and development investment)	9.25E+09	Public Data
Annual exploration and development investment	CNY	Investment fund*0.7		Expert survey method

Results

Simulation results can help seek the applicable development tendency of China's shale gas development, later the sensitivity of key parameters is analysed to know how they affect this SD model.

1. Shale gas production

Under the current incentive policy environment, China's domestic shale gas production will peak at $220*10^8$ m^3 in 2028, declining thereafter, as shown in Fig. 6. It's worth noting that shale gas proportion only accounts for 6% of total China's gas supply with slight fluctuations, and seems to drop every other year. Enterprise revenue will enjoy accelerating growth and peak at 72.6 billion CNY in 2027 and then gradually decline.

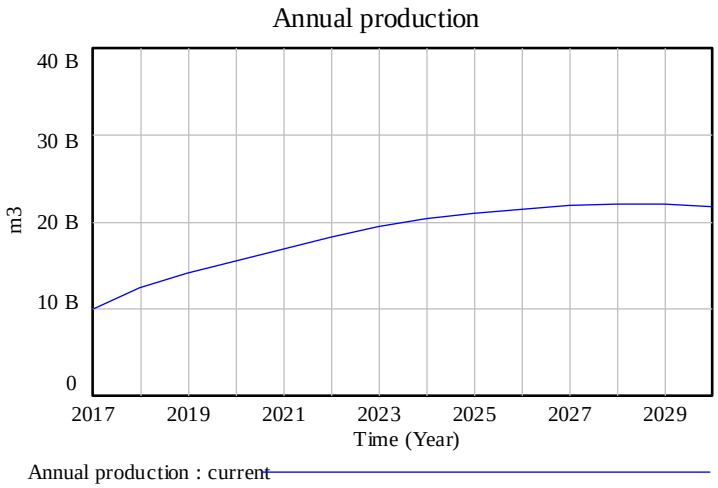

Fig. 6 China's shale gas production

Demonstrated capacity is directly impacted by annual investment. The capacity will experience decelerated growth between 2017 and 2027, due to incremental investment, and then decrease due to annual investment being outpaced by high-rate declining capacity. Annual investment will peak at 12.36 billion CNY in 2026, as shown in Fig. 7.

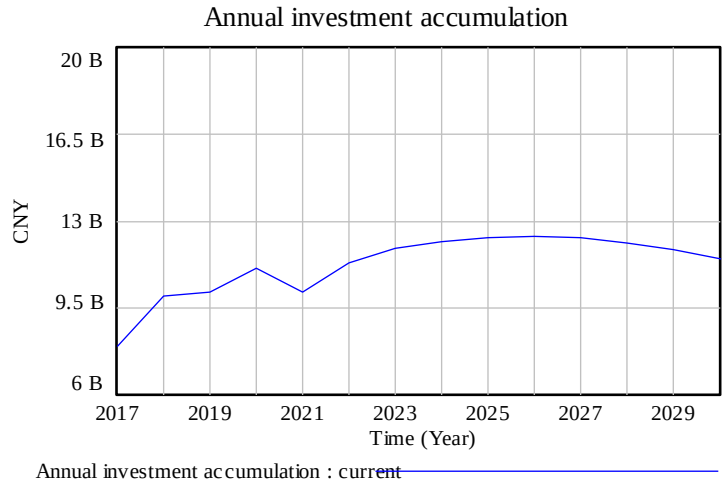

Fig. 7 Annual investment in shale gas

So far the Chinese government has not announced whether to continue the quantity subsidy for shale gas development after 2021, thus we assume this subsidy (0.2 CNY/m³) ends up in 2021, affected by the policy orientation and market expectation, the after-tax profit drops obvious in 2021, annual investment will temporarily return to pre-2018 levels, then creep up and maintain at around 12 billion CNY.

The medium-term objective, set by China's government, is to reach shale gas production volumes of $300*10^8$ m³ annually by 2020 and $800\text{-}1000*10^8$ m³ in 2030. However, this objective is unlikely to be achieved without a surge of additional investments or significant technological breakthroughs.

2. Sensitivity analysis

The current parameters setting of transfer functions have a certain degree of subjectivity, so we wander to see the variation ranges of the system's simulated results for different settings of key parameters based on existing SD model. This paper analysed the sensitivities of shale gas production (Fig. 8), pre-tax profit (Fig. 9) and annual investment (Fig. 10) in single-factor changes of fiscal subsidy (0.2, 0.3 and 0.4 CNY/ m³), wellhead price (raised by 5%, 10% and 20%) and tax relief (VAT, resource tax and income tax respectively). The results of sensitivity analysis are shown in Table 3.

Table 3 the results of sensitivity analysis

Variables / Scenarios / Parameters		Fiscal Subsidy (CNY/m³)			Tax relief			Wellhead Price		
		0.2	0.3	0.4	VAT	Resource tax	Income tax	5%	10%	20%
Shale gas production	2020	0.00%	0.00%	0.00%	2.92%	0.71%	2.53%	0.65 %	1.3%	2.59%
	2025	3.24%	4.85%	6.47%	22.45%	5.23%	18.03%	4.85%	9.8%	19.89%
	2030	12.54%	19.02%	25.59%	46.21%	10.15%	35.37%	9.42%	19.29%	40.56%
Pre-tax profit	2020	0.00%	0.00%	0.00%	34.11%	7.94%	-4.56%	7.37%	12.11%	17.66%

	2025	-1.37%	-2.15%	-2.95%	60.66%	13.04%	9.22%	14.86%	24.98%	37.3%
	2030	6.55%	9.57%	12.41%	96.04%	19.03%	24.71%	30.16%	53.12%	83.09%
Annual Investment	2020	0.00%	0.00%	0.00%	29.37%	6.85%	23.51%	6.4%	12.11%	17.61%
	2025	17.97%	27.4%	37.07%	60.65%	13.01%	45.61%	12.79%	24.96%	37.23%
	2030	29.99%	46.82%	64.78%	95.99%	19.01%	66.17%	26.04%	53.09%	83%

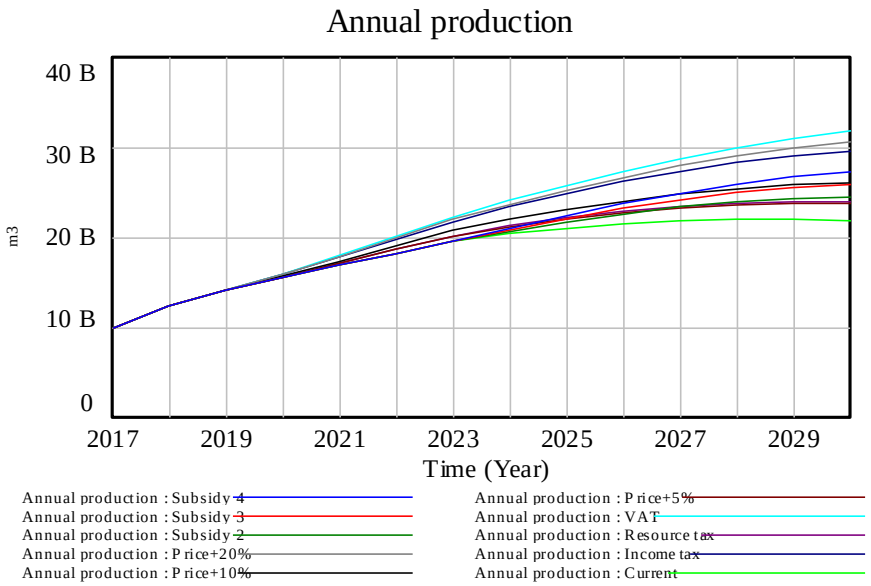

Fig. 8 Shale gas production (Bcm)

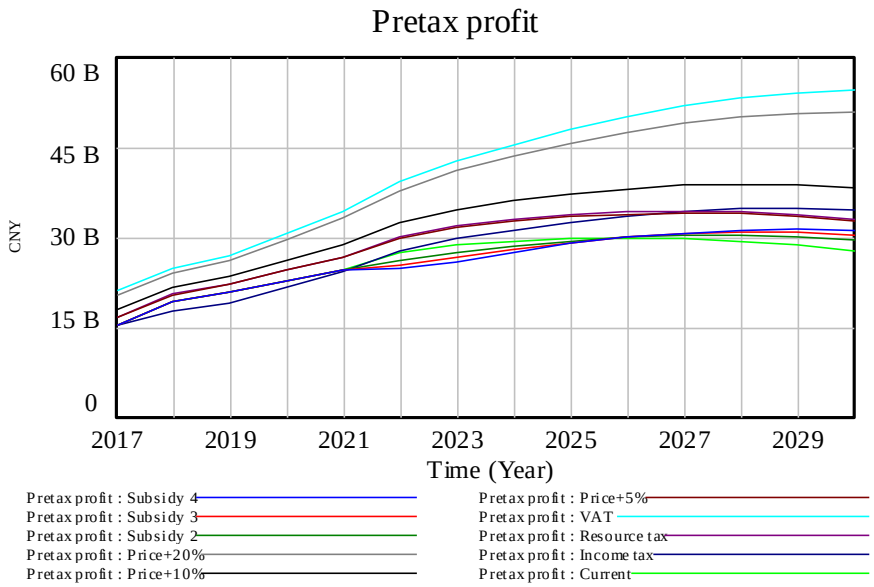

Fig. 8 Pre-tax profit (Billion CNY)

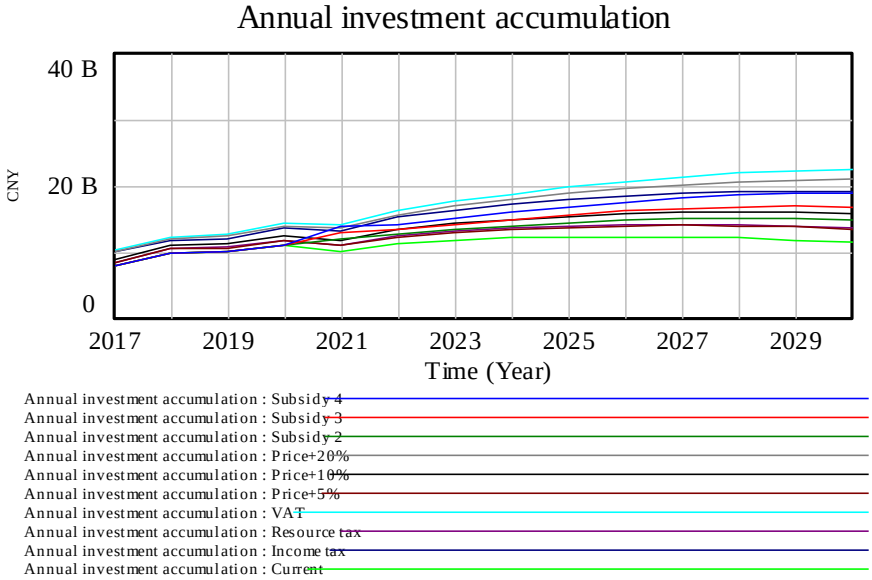

Fig. 8 Annual investment (Billion CNY)

From our findings, 1) Prolonging current level of direct subsidy (0.2 CNY/m³) can only retard but not reverse production falling tendency after 2027, and even raising subsidy rate to 0.4 CNY/m³ has also limited help in boosting capacity and production. In comparison, taxes relief has a stronger influence on shale gas capacity and production, especially VAT rate reduction. 2) Wellhead price adjustment has a noticeable impact on shale gas production, and has even more pronounced effect on pre-tax profit and investment. A 20% increase can boost production up to $306*10^8$ m³ by 2030. 3) In order to achieve the production target of $300*10^8$ m³ in 2020 and $900*10^8$ m³ in 2030, additional investment of 38.4 billion CNY is imperative to encourage technical research in the next two years, based on a series of trial and error analyses.

Conclusions

The simulation results of this paper indicate that: 1) Currently, China's shale gas development enterprises earn meagre profits, continuing current subsidy policy has limited help to increase production, but subsidy removal will result in scaling investment back and further undermine the growth of shale gas industry. As such, there is a lack of incentive to attract private capital into this high-investment and high-risk industry. We recommend the government prolong policy incentives because a supportive regulatory context in China is a key enabler of shale gas development. 2) Policy adjustments will guide the further expansions of investment of shale gas, however, gas price in China is regulated by government instead of market, solely increasing fiscal subsidy is not a good option to develop China's shale gas when “price ceiling” problem is still unsolved. 3) A surge of additional investment for exploration and development is imperative in the next two years to increase capacity. Additionally, continuous regulatory incentives have the potential to reduce shale gas production costs in the future.

Further research will be conducted to break through limitations of this SD model, the primary limitation is that our SD model set generations of other energies as exogenous variables and omits consideration of their interactions with shale gas. This is an area of additional research we are interested in addressing in subsequent research.

As a final note, it should be emphasized that, despite a potentially large resource base, production and costs may vary when further assessment is conducted in different stages of unconventional gas industry in China.

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