Sveriges lantbruksuniversitet
Swedish University of Agricultural Sciences

Department of Economics

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Master's thesis · 30 hec · Advanced level
Environmental Economics and Management — Master's Programme
Degree thesis No 765 · ISSN 1401-4084
Uppsala 2012

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Credits: 30 hec
Level: A2E
Course title: Degree Project in Economics
Course code: EX0537
Programme/Education: Environmental Economics and Management, Master's Programme
Faculty: Faculty of Natural Resources and Agricultural Sciences

Place of publication: Uppsala
Year of publication: 2012
Cover picture: Internet resource
Name of Series: Degree project/SLU, Department of Economics
No: 765
ISSN 1401-4084
Online publication: http://stud.epsilon.slu.se

Key words: China's energy demand, prediction, factor-augmenting knowledge, relative price of energy, directed technological change, endogenous growth

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Acknowledgements

I would like to send my thankfulness to all the authors of the papers that I refer to, this paper is based on their contributions.

I would greatly appreciate the patience and instruction of my supervisor, Dr. Rob Hart, it might takes me double time or more to do the study without the knowledge imparted by him.

This paper is a tiny token of my gratitude for my parents' everlasting benediction, they bless me with their love always.

Abstract

With double-digit economic growth, mounting consumer demand and being roused industry potentialities, China's ascendancy has been marked "the start of a new age in the history of energy." Understanding the impacts of technological change and diffusion in a large carbon-intensive country like China is essential for getting acquainted with the future trajectory of global energy demand. In this paper, we examine the evolution of long-run energy demand owing to directed technological change (DTC) and predict the future behaviour of the energy demand in China by setting up a theoretical model of DTC with two inputs, energy and labour, and interactional factor-augmenting knowledge, then simulating the model with data about China since 1980. The modelling of knowledge stocks help us to acquire a new understanding of the interaction among energy, technological change and economic growth.

Key words:

China, energy demand, forecast, factor-augmenting knowledge, relative price of energy, DTC, endogenous growth

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1 Introduction

1.1 Background

China has experienced a spectacular economic development since the national economic reform in 1979. Its gross domestic product (GDP) and GDP per capita has increased annually at 10,5% and 9,3% respectively over the past thirty years. Industry and manufacturing grew at even faster rate, more than 11% in the 1980s and 2000s, more than 13% in the 1990s (World Development Indicators, 2011). But it is noticeable that the energy consumption increased by only 4,5% over the same period (China Energy Statistical Yearbook, CESY).

However, as Fatih Birol, the head of the IEA, announced that China's new status is the world's number one energy consumer, China has become the world's largest energy consumer in 2009 (International Energy Agency, IEA). China has set targets to reduce energy consumption per unit of economic output by 20% in 2010 compared with 2005, meanwhile to reduce emissions of greenhouse gases per unit of economic output by 40 to 45% in 2020 from its 2005 levels. But actually it is tough to meet these targets due to its booming economy and its improving life quality. As a matter of fact, residential and commercial buildings are being constructed at a rapid pace in urban areas, malls are under construction throughout Chinese metropolises; the sale of household appliances have more than doubled in the past years in rural areas since government has been subsidizing peasants to consume modern life conveniences for a long time. Moreover, China's auto sales increased by 48% in 2009 and are escalating.

As a result of China's soaring GDP, the increasing energy demand in China occasionally lower the efficiency of energy-use, which makes the stated goals difficult to achieve. It was reported that the efficiency of energy-use in China declined by 3.2% in the first quarter of 2010 along with its economy shifting away from light industries for export and toward energy intensive industries. China uses three times as much energy per dollar of output as the European Union (Institute for Energy Research, IER).

There are many studies that focus on the long-term dramatic decline in energy intensity in China, and it can be seen from these papers that energy intensity in China has fallen continuously since 1980, see for instance, Hang (2006), Ma (2007), Yu (2012). Many of them, for instance, Huang (1993), Garbaccio (1999), Crompton (2004), find that the key factor is technological change while the structural change, a shift in the mix of industries, has played a minor role in reducing energy intensity. Structural change actually increased energy intensity during the period from 1987 to 1992. Technological change constantly contributed to decrease energy intensity in China during most of the economic reform period, while a clear picture regarding the contribution of structural change has not emerged.

Karen, in 2006, states that “Technological change tends to reflect the resource scarcities of the country supplying energy. Either internal or imported, technological change exhibits an energy-saving bias”. Many previous studies argued that the firm's in-house activities concerning technological change are important for creating the absorptive capacity required for the successful diffusion of imported technology.

1.2 Aim

The aim of our study is to examine the interaction among energy, technological change and economic growth. The objective is to predict long-run energy demand, involving both prices and quantities.

Considering the scenarios discussed in section 1.1, it is worthwhile to predict the future of China's energy demand for policy formulation. However, delineations for China's energy demand typically stretch 25 years into the future. The deficiency of theoretical models connecting technological change with energy prices and demand plus the dearth of empirical evidence to support the existing model with inadequate corroborations lead to an unconvincing prediction about future. Our study makes a small contribution towards enhancing the capability of forecasting the growth path of China's energy demand.

1.3 Literature review

There are a large variety of energy demand prediction approaches used by different authors. Five commonly used approaches suit long term work. Econometric approaches are based on the economic theories and endeavour to validate the economic rules empirically (Griffin, 1993; Harvey, 1997; Dahl and Erdogan, 2000; Adeyemi and Hunt, 2007; Adams and Shachmurove, 2008). End-use approaches or engineering-economy approaches attempt to establish accounting coherence using detailed engineering representation of the energy system. It focuses on end-uses or final needs at a disaggregated level (Wilson and Swisher, 1993; Worrel et al, 2004). Input-output approach provides a consistent framework of analysis and can capture the contribution of related activities through inter-industry linkages in the economy, where makes itself an interesting analytical tool (Wei et al, 2006; Tiwari, 2000; Liang et al, 2007). Scenario approach has been widely used in climate change and energy efficiency policy making (Ghanadan and Koomey, 2005). Hybrid approaches relies on a combination of two or more methods mentioned above with the objective of exploring the future in a better way. It attempt to reduce the methodological divergence between the econometric and engineering models by combining the features of the two traditions (Koopmans and te Velde, 2001; Bataille et al, 2006).

Now, we take a look at the study concerning energy demand prediction at aggregate level. In the studies of aggregate energy demand prediction, Hunt and Manning (1989) analysed the aggregate energy demand in the UK.

Pesaran et al (1998) was a major study that analysed energy demand in 11 Asian developing countries using Autoregressive Distributed Lag Model to co-integrate both at the aggregate and sector levels. However, such studies usually lack explanatory power due to aggregation across fuels, sectors and countries, besides, they scarcely analyse the role of technology. In the studies of sector or fuel-level aggregate energy demand prediction, Chan and Lee (1997) have analysed coal demand in China using three alternative specifications, namely Engle-Granger's error correction model, Hendry's error correction model and Hendry's general-to-specific approach. Similarly, Moosa (2002) analyses oil demand in developing countries to find the correct specification and importance of oil price in the demand relation. Their main result can be concluded as the long-run price and income elasticity of energy demand estimates for countries analysed with more advanced statistical approaches, hence these studies may somewhat contribute to policy-making in developing countries. However, most of these studies find that price does not play a significant role in influencing energy demand in developing countries where income drives the demand, thus these papers may not help the price-based policies. Moreover, these studies do not take traditional energies, informal economic activities and technological diversity in developing countries into account.

One of the recent foremost contributions to the theory of directed technological change is developed by Acemoglu (2002). In order to do some further investigation with respect to energy market, Smulders and de Nooij (2003) adjust the Acemoglu (1998, 2002) model of directed technological change. The long-run factor shares of energy and labour in the model that they formed are constant. Considering the fact that the factor shares may vary when input quantities vary in the short run, they afterwards assume that the economy starts with unbalanced growth, particularly they suppose that the relative level of energy-augmenting knowledge is below its balanced growth path level. This level hence rises over time, which causes the factor share of energy to fall.

The models that endogenize DTC explicitly can be found in two papers of André and Smulders (2004) and Grimaud and Rouge (2008). Both of them are set up upon the demand aspect of Smulders and de Nooij (2003)'s model and deepen the research to different directions; A simple model in regards to resource supply is built by André and Smulders (2004). A study concerning the problem of optimal regulation involve a model with pollution externality was done by Grimaud and Rouge (2008). Broadly, these literatures largely argue that the modelling of decentralized markets with knowledge spillovers is probably vital to comprehend these observations. However, the breadth of such models in the DTC literature is highly insufficient and the models are very specific.

This paper adopt the model from a study of Hart (2010) and Stigzelius (2012). The former aim to build a general model of this type and then to work out specified models which can be applied to policy analysis and empirical studies, thus the results concerning the response of long-run energy demand to exogenous changes such as shifts in relative quantities of the factors can be derived. The latter model 'limited state dependence' rather than 'extreme state dependence' to use the terminology of Acemoglu (2002) and focuses on predicting the evolution of energy markets given different price scenarios. They set up a theoretical model of DTC and calibrate it to U.S. data since 1970, then derive results concerning how long-run demand will respond to exogenous changes such as shifts in relative quantities of the factors. They argued that a model of energy supply to the demand model should be added further. "The supply model should include the possibility of obtaining energy from different sources, these sources would then be substitutes in the overall function for the supply of energy services, by contrast to energy and labour in the production function, which are complements" (Stigzelius, 2012). However, a more detailed account of the long run properties of the model is not presented in their the paper.

The chosen model starts from the work of Smulders and de Nooij (2003), whereas it focus explicitly on predicting the growth of energy demand by given disparate price scenarios. The intrinsic distinction between them is that factor-augmenting technological change in the chosen model is endogenous and it is designed to examine how sector specific stocks of knowledge evolve each other.

2 Theoretical model of directed technological change

2.1 Purpose and assumptions

The purpose of the theoretical analysis is to predict evolution demand function for energy as a result of firm investment in technology, which is in turn driven by firms expectation about future prices. Put simply, if a firm expects high energy prices, it will invest in energy efficient technology.

We begin by specifying the model, it is often useful to set a number of assumptions on the structure of the production functions, these assumptions give rise to various properties that will be addressed below.

Output is generated through a production function by using two inputs, energy and labour, we choose the form as the constant elasticity of substitution (CES) type which is used widely in empirical analysis. This states that output has a functional relationship in a particular form to the quantities of the two inputs that are used. Each output level satisfying the production function is the maximum attainable output for given quantities of the inputs, where implies that inputs are used in a technically efficient way.

We shall assume that the production function exhibits constant returns to scale (CRS) which implies that average and marginal returns to each factor depend only on the factor ratio, more generally, it means that if both inputs are increased by the same factor, output rises by that factor as well. For a mathematical point of view the concept of returns to scale is closely related to that of the degree of homogeneity of a function.

Additionally we assume that knowledge spills over between sectors. Knowledge is brought into the production function through energy and labour, which implies that knowledge in the economy translates into skill at the micro level of the firm and thus augments labour productivity. Growth of per capita output is due entirely to endogenous technological progress in this model.

Furthermore, we assume that an economy includes a large amount of firms producing various products, each of which is characterized by a production function. There is a balanced growth path. One of the stylized facts of growth is the tendency for factor shares to remain fairly constant over time even for an arbitrary production function. Besides, perfect information and discrete time are also assumptions, these are very convenient mathematically because it makes the derivation easier.

2.2 The basic model

Production functions are central to the theory of economic growth since they provide a mathematical representation of the progress of transforming inputs to production such as labour or physical capital into goods and services. The production is Y_t. There are two physical inputs, A and B, here we define input A as energy and input B as labour. Moreover, the firm owns capital, like human capital, machines and so on, with specific technology which augments the two inputs respectively.

We defined the production function of a representative firm in period *t* to be

$$Y_t=[\alpha(k_{at}q_{at})^{\beta}+(1-\alpha)(k_{bt}q_{bt})^{\beta}]^{1/\beta} \tag{1}$$

where q_{at} and q_{bt} are quantities of input A with price p_{at} and input B with price p_{bt} respectively, k_{at} and k_{bt} are the firm-specific levels of input-augmenting knowledge. α and β are parameters, β captures the elasticity of substitution and is assumed to be less than 0, which indicate that the inputs are complements with an elasticity of substitution less than 1.

The firm’s production functions for knowledge are

$$k_{at} = K_{at-1}^{1-\gamma/2} K_{bt-1}^{\gamma/2} I_{at}^{\delta} \tag{2}$$

$$k_{bt} = K_{bt-1}^{1-\gamma/2} K_{at-1}^{\gamma/2} I_{bt}^{\delta} \tag{3}$$

where K_{at} and K_{bt} are levels of general knowledge, the subscript -1 denotes one period in the past, I_{at} and I_{bt} are inputs of an investment good with price p_I, δ and γ are parameters between zero and one, where δ captures the elasticity of knowledge to investments, which implies that there may exist decreasing returns to scale in investments in this model, although it is a theoretical possibility, it often seems less plausible in reality.

The functions indicate that a firm's knowledge augmenting the corresponding input depends on not only the present general knowledge augmenting that input but also the general knowledge augmenting the other input. $\gamma < 1$ tells that the elasticity of the general knowledge that augments the related input is greater than the elasticity of the general knowledge that augments the other input.

In the model, each firm's knowledge is a public good, that is to say, all other firms in the economy can obtain it without any cost. Consequently, it is doable to find general knowledge K_{at} in terms of the representative firm's knowledge k_{at} in any given period and to express the relationship in a equation for economy-wide knowledge by aggregating through all firms.

General knowledge is a CES production function of a firm's knowledge levels:

$$K_{at} = \left(\int_0^1 k_{ai}^{\varepsilon} di\right)^{1/\varepsilon} \tag{4}$$

where ε is a parameter between one and zero. This conveys that firms improve their own knowledges based on general knowledge each period, where can simplify the dynamics and the balanced growth path will not be affected simultaneously; $K_{at} = k_{at}$ in any given period due to the assumption that the firms are symmetric. It can be derived from the expression that $\frac{dK_a}{dk_{ai}}=0$ and $\frac{dk_{a,t+1}}{dk_{at}}=0$.

The firms wish to maximize their profits, the price per unit of output is P_{Yt} , the profit Π is given by the function

$$\Pi=P_{Yt}Y_t-p_{at}q_{at}-p_{bt}q_{bt}-p_{It}(I_{at}+I_{bt})\,. \qquad (5)$$

The constrained maximization problem can be expressed as

max Π subject to equation (2) and (3).

Put all this together, given perfect information and a per-period discount factor η , the Lagrangian of the representative firm is

$$\mathcal{L}=\sum_{t=0}^{\infty}\eta^t[\Pi-\lambda_{at}(k_{at}-K_{at-1}^{1-\gamma/2}K_{bt-1}^{\gamma/2}I_{at}^{\delta})-\lambda_{bt}(k_{bt}-K_{bt-1}^{1-\gamma/2}K_{at-1}^{\gamma/2}I_{bt}^{\delta})] \quad (6)$$

where the λ is the Lagrange multiplier.

Take first-order conditions, differentiate $\mathcal{L}$ w.r.t, $q_{at}, q_{bt}, k_{at}, k_{bt}, I_{at}, I_{bt}$, and equate the partial derivatives to zero. Then define $\frac{k_{at}}{k_{bt}}=K_t$, $\frac{q_{at}}{q_{bt}}=Q_t$, $\frac{p_{at}}{p_{bt}}=P_t$ and $\frac{I_{at}}{I_{bt}}=I_t$ so as to simplify notations. The first-order conditions in q_{at} and q_{bt} yield the ratios of input prices P_t and factor shares $S=\frac{p_a q_a}{p_b q_b}$, the key processing is

$$\frac{1}{\eta^t}\cdot\frac{\partial L}{\partial q_{at}}=\frac{\partial P_{Yt}}{\partial Y_t}\frac{\partial Y_t}{\partial q_{at}}Y_t+P_{Yt}\frac{\partial Y_t}{\partial q_{at}}-P_{at}=0$$

$$\frac{\partial Y_t}{\partial q_{at}}=\frac{1}{\beta}[\alpha(k_{at}q_{at})^{\beta}+(1-\alpha)(k_{bt}q_{bt})^{\beta}]^{\frac{1-\beta}{\beta}}\beta\frac{\alpha(k_{at}q_{at})^{\beta}}{q_{at}}=(\frac{Y_t}{k_{at}q_{at}})^{1-\beta}\cdot\alpha\cdot k_{at}$$

$$p_{at}=\left(P_{Yt}+\frac{\partial P_{Yt}}{\partial Y_t}\cdot Y_t\right)\cdot\frac{\partial Y_t}{\partial q_{at}}=\alpha\frac{Y_t^{1-\beta}\cdot(k_{at}q_{at})^{\beta}}{q_{at}} \tag{7}$$

$$p_{bt}=\left(P_{Yt}+\frac{\partial P_{Yt}}{\partial Y_t}\cdot Y_t\right)\left(\frac{Y_t}{k_{bt}q_{bt}}\right)^{1-\beta}\cdot(1-\alpha)\cdot k_{bt}=(1-\alpha)Y_t^{1-\beta}\frac{(k_{bt}q_{bt})^{\beta}}{q_{bt}} \tag{8}$$

$$P_t=\left(\frac{k_{bt}q_{bt}}{k_{at}q_{at}}\right)^{1-\beta}\cdot\frac{\alpha}{1-\alpha}\cdot\frac{k_{at}}{k_{bt}}=\frac{\alpha}{1-\alpha}\left(\frac{k_{at}q_{at}}{k_{bt}q_{bt}}\right)^{\beta}/\frac{q_{at}}{q_{bt}}=\frac{\alpha}{1-\alpha}(K_tQ_t)^{\beta}/Q_t \tag{9}$$

$$Q_t=\left[\frac{\alpha}{1-\alpha}\cdot\left(\frac{K_t^{\beta}}{P_t}\right)\right]^{1/(1-\beta)} \tag{10}$$

$$S_t=\left[\frac{\alpha}{1-\alpha}\cdot\left(\frac{K_t}{P_t}\right)^{\beta}\right]^{1/(1-\beta)} \tag{11}$$

The expression of factor shares is our first interest, since it tells that when factor share of energy costs rise in price of energy, there will be a fall in energy-augmenting knowledge.

Take first-order conditions in k_a and k_b to find the ratio of the shadow prices of knowledge

$$\frac{1}{\eta^t}\cdot\frac{\partial L}{\partial k_{at}}=\frac{\partial P_{Yt}}{\partial Y_t}\cdot\frac{\partial Y_t}{\partial k_{at}}\cdot Y_t+P_{Yt}\frac{\partial Y_t}{\partial k_{at}}-\lambda_{at}=0$$

$$\frac{\partial Y_t}{\partial k_{at}}=\left(\frac{Y_t}{k_{at}}q_{at}\right)^{1-\beta}\cdot\alpha\cdot q_{at}$$

$$\frac{\lambda_{at}}{\lambda_{bt}}=\frac{\frac{\alpha}{1-\alpha}\cdot(K_tQ_t)^{\beta}}{K_t} \tag{12}$$

This expression is our second interest, it shows that when the value of energy-augmenting knowledge rise in price of energy, energy-augmenting knowledge will fall. Compare equation 11 and 12, we find that the share of value of energy-augmenting knowledges equals to the share of energy costs.

The first-order conditions in I_a and I_b yield, where p_I is eliminated

$$\frac{1}{\eta^t}\cdot\frac{\partial L}{\partial I_{at}}=-p_{It}+\lambda_{at}\cdot\delta\cdot\frac{k_{at}}{I_{at}}=0$$

$$I_{at}\,p_{It}=\lambda_{at}\delta\,k_{at}$$

$$I_{bt}\,p_{It}=\lambda_{bt}\delta\,k_{bt}$$

$$\frac{\lambda_{at}}{\lambda_{bt}}=\frac{I_t}{K_t}\,. \tag{13}$$

Combine equation 10 and 12 to yield the investment ratio

$$I_t=\frac{\alpha}{1-\alpha}\cdot(K_t Q_t)^{\beta}\,. \tag{14}$$

Insert equation 10 in equation 14 to eliminate Q_t yield

$$I_t=\left[\frac{\alpha}{1-\alpha}\cdot\left(\frac{K_t}{P_t}\right)^{\beta}\right]^{1/(1-\beta)}=S_t\,. \tag{15}$$

This shows that the investment ratio is proportional to the factor shares derived from the model in the same period.

Finally, substitute equation 14 into equation 2 and 3 and using $k_a=K_a$ and $k_b=K_b$ to solve the dynamics and then yield

$$\hat{K}_t=\frac{\hat{k}_{at}}{\hat{k}_{bt}}=\frac{I_{t+1}^{\delta}}{K_t^{\gamma}}\,. \tag{16}$$

Here, define variable's growth factor with a hat as $\frac{K_{t+1}}{K_t}=\hat{K}_t$.

From equation 14 and $\frac{K_{t+1}}{K_t}=\hat{K}_t$ we can write

$$I_{t+1}=\frac{\alpha}{1-\alpha}\cdot(K_{t+1}Q_{t+1})^{\beta}=\frac{\alpha}{1-\alpha}\cdot(\hat{K}_t K_t Q_{t+1})^{\beta}.$$

Substitute this equation into equation 16 yield

$$\hat{K}_t^{1-\beta\delta}=\frac{(\frac{\alpha}{1-\alpha})^{\delta}\cdot(K_t Q_{t+1})^{\beta\delta}}{K_t^{\gamma}}, \tag{17}$$

it can be rewritten as

$$\hat{K}_t=[(\frac{\alpha}{1-\alpha})^{\delta}\frac{(K_t Q_{t+1})^{\beta\delta}}{K_t^{\gamma}}]^{1/(1-\beta\delta)} \tag{18}$$

where the relative knowledge levels, K_{t+1}, is determined in equation 18 when the values of initial relative knowledge K_t and factor quantities Q_{t+1} are known.

The basic model of DTC is depicted in detail so far, it plainly exhibit how the ratio of factor prices evolve when factor quantities are given. Relative factor prices P_{t+1} can be deduced from equation 9 and 18.

2.3 The model of price expectation

It is mentionable that the assumption of perfect information is implausible in reality, this is a issue that need to be dealt with in this section. Perfect information implies that firms have already known the coming prices of the two inputs when they decide the investment for next period. In other words, an unexpected fall of energy price, p_a, in period t + 1 denotes that firms expected a higher price when they determined the knowledge levels in period t + 1 but they will afterwards regret to spend such high level on energy-augmenting technology. This may lead to a fall in energy consumption in period t + 1, comparing period t , when the rise in *K* outweigh the fall in *P*.

Now, we go back to the investment problem, take the first-order conditions in investment to account for the issue

$$\frac{I_t}{K_t}=E_{t-1}[\frac{\lambda_{at}}{\lambda_{bt}}] \tag{19}$$

where $E_{t-1}[\cdot]$ denotes the expectations at the end of period t −1 or in the beginning of period t (see equation 13), investment I_t is determined in the beginning of period *t.* Thus, we reset the assumption that prices in period t are unknown when firms decide investments. Then we get (see equation 14)

$$I_t=\{(\frac{\alpha}{1-\alpha})(\frac{K_t}{E_{t-1}[P_t]})^{\beta}\}^{1/(1-\beta)} \tag{20}$$

From equation 18 and along these lines we can write

$$\hat{K}_t=\{(\frac{\alpha}{1-\alpha})^{\delta/(1-\beta)}(\frac{K_t}{E_t[P_{t+1}]})^{\beta\delta/(1-\beta)}/K_t^{\gamma}\}^{(1-\beta)/[1-\beta(1+\delta)]}\ . \tag{21}$$

We suppose that firms expect the price in period t +1 to reflect the price trend in the past in the simulation and thus define a simple model of adaptive expectations, the expressions for expected price are written as the current price times the change in expected price, $E_t[P_{t+1}]=P_t E_t[\hat{P}_t]$, or

$$E_t[P_{t+1}]=P_t[\hat{P}_{t-1}+\theta\hat{P}_{t-2}+\theta^2\hat{P}_{t-3}+\cdots+\frac{\theta}{(1-\theta)}\hat{P}_1](1-\theta) \tag{22}$$

where $\hat{P}_t=\frac{P_{t+1}}{P_t}$ is the change in prices from period t to period t +1; the weight parameter $\theta\in[0,1]$ determines the extent of the effect of past on the forming of expectations.

Equation 7, 8, 10, 11, 21 and 22 are derived for the simulation.

2.4 Theoretical results

By now, we have been able to draw some significant results from the theoretical model. For example, how variables grow in the long run when the trends of exogenous variables are stable and such issues concerning balanced growth can be revealed. Now we focus on the long run balanced growth and examine a simplified model under perfect information.

In order to find the balanced growth path with constant factor ratio Q, we set $\hat{K}=1$ and Q constant, then take them into equation 18 we get

$$K=[(\frac{\alpha}{1-\alpha})^{\delta} Q^{\beta\delta}]^{1/(\gamma-\beta\delta)} . \tag{23}$$

From equations 10, 14 and 15, we have $S=(\frac{\alpha}{1-\alpha})(KQ)^{\beta}$, with this equation we can show the status on balanced growth path

$$S=[(\frac{\alpha}{1-\alpha})^{\gamma} Q^{\gamma\beta}]^{1/(\gamma-\beta\delta)} \tag{24}$$

$$P=[(\frac{\alpha}{1-\alpha})^{\gamma} Q^{\beta\delta-\gamma(1-\beta)}]^{1/(\gamma-\beta\delta)} . \tag{25}$$

We can find that the economy will move to a new balanced growth path with higher energy price factor share when the economy is on a balanced growth path and the relative quantity of energy inputs falls, this follows because the parameter β is negative. Besides, the model tells that the level of relative investments will rise when the relative quantity of energy inputs fall.

Intuitively, we can find a coherent economic story as to why the growth rate of production per worker is increasing in the time spent investing in education by learning skills that can be used productively later on.

Since decision makers at the level of the firm take no account of the impact of their investment decisions on knowledge available throughout the economy, there is a difference between the optimal amount of investment from the perspective of firms and from the perspective of the economy as a whole. There are actions available that would make everyone better off without harming anyone. The reason they are not chosen is because firms fail to recognize an aspect of the decision process that is only properly internalized in the decision once we adopt the perspective of social planners.

3 Data

3.1 Data resource

The model is simulated by using the annual data on real total GDP, total quantity of primary energy consumption, consumer price index of energy, total quantity of paid employment and wages in China from year 1980 to 2008, the example of raw data is shown in Table 1. The sample size is small, which is 29.

The resource of the data on real total GDP is from World Bank national accounts data and Organisation for Economic Co-operation and Development (OECD) national accounts data files (World Bank, 2012, internet source). Data are in current U.S. dollars. Dollar figures for GDP are converted from domestic currencies using single year official exchange rates.

Total quantity of primary energy consumption includes the consumption of petroleum (crude oil and natural gas plant liquids), dry natural gas, coal, net generation of hydroelectric, nuclear, geothermal, solar, wind, wood and waste electricity, also includes net electricity imports. The unit is quadrillion british thermal unit (Btu). The reported data were constructed from the International energy statistics updated on 1st August, 2010 (EIA, 2010, internet source).

The adopted data of consumer price index[1] of energy was constructed from International Labour Office database operated by the Department of Statistics of International Labour Organization (ILO) Tables 7D (ILO, 2010, internet source). The general and the group indices in the tables refer to annual averages. As the original base periods of the national series vary, a uniform

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[1] A consumer price index is usually estimated as a series of summary measures of the period-to-period proportional change in the prices of a fixed set of consumer goods and services of constant quantity and characteristics, acquired, used or paid for by the reference population.

base period (1990) has been adopted for the presentation of the data.

The data concerning wages or in the other word, 'price of labour', was constructed from ILO database Table 5A (ILO, 2010, internet source). Wages are expressed in national currency, the unit is Yuan[2] per month. The data cover, in principle, all major divisions or categories of economic activity.

The data on paid employment or labour inputs with the unit thousands cover all available series of paid employment which should relate solely to employees (wage earners and salaried employees) in employment and preferably be derived from an establishment survey, which is from ILO database Table 2E (ILO, 2010, internet source). The paid employment refer to persons who 'at work' and 'with a job but not at work'.

Table 1. The extracted historical data used in the simulation.

	GDP *(Billions US$)*	Energy input *(quadrillion Btu)*	Price index of energy *(year1990 =100)*	Labour input *(Thousands)*	Wage *(Yuan)*
1980	189	17	54	104437	67
1987	270	25	63	132141	122
1994	559	34	193	148490	378
2001	1325	38	228	107920	906
2008	4522	84	345	115154	2436

3.2 Data assessment

The selected databases are essential tools for supporting critical management decisions and providing key statistical information for economic operational activities. The application of internationally accepted standards and norms results in a consistent, reliable source of information, thus, these data

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[2] Yuan (CNY) is the base unit of a number of modern Chinese currencies. 100 CNY≈ 109 SEK or 12 EUR, according to the average exchange rate in June 2012.

work and products are ensured to be the highest quality by using standards, methodologies, sources, definitions and classifications that are internationally accepted.

GDP at purchaser's prices is the sum of gross value added by all resident producers in the economy plus any product taxes and minus any subsidies not included in the value of the products. It is calculated without making deductions for depreciation of fabricated assets or for depletion and degradation of natural resources.

Energy use refers to the use of primary energy before transformation to other end-use fuels, which is equal to domestic production plus imports and stock changes, minus exports and fuels supplied to ships and aircraft engaged in international transport.

Energy prices are the official list prices for state-owned establishments and free market (fair trade) prices, which refer the State Statistical Bureau and China Statistical Publishing House, Statistical Yearbook of China published in October of the year following the reference year. The weights for calculating the general index are the actual value of sales and purchases based on the different prices.

Employment and wages statistics are based on enterprises' reports. The data aim at drawing up employment plans at the macro level and to measure increases and changes that have occurred in employees' wages. The data on employment are counted as all Chinese persons employed in all types and sizes of enterprises, including employees, self-employed persons and Chinese workers sent abroad, excluding foreign personnel working in China.

4 Simulations

4.1 Hypothesis

From equation 25 in the theoretical model, we can speculate that the quantity of energy will increase at a faster rate than the rise in labour inputs in the long run when the relative price of energy decrease comparatively to labour and the quantity of labour increase at the same time. From equation 10, we can conjecture that a decline in the relative investments and a decline in the relative knowledge stock are caused one lag behind by a diminution of relative prices, this consequentially leads to a positive effect on the relative quantities and leads to enlarge the expected rise in demand.

Since the technological change is endogenous in the model, the technological change will develop in the direction of energy-augmenting knowledge for all the historical observations if $\hat{K}$ would be measured to be larger than 1 in the model. Moreover, since energy price falls relative to labour, we expect energy-augmenting knowledge will fall relative to labour-augmenting knowledge, and energy quantities will rise relative to labour quantities.

4.2 Simulations of price expectations

We use the model of price expectations defined in Section 2.3 to calculate the quantity of energy with the given price and the relative investment levels in the respective factor-augmenting technologies. The price of energy p_a, wage p_b and the quantity of labour q_b are the exogenous inputs in the model. The key equation for simulation model are 21 and 22. Using equation 22, we can predict next-period price from historical observations. This price is then putted into equation 21 to predict growth in relative knowledge stocks K. The resulting value of K, together with actual price determines resource demand q_{at}.

The problem of building the simulation model is to find parameter values in equations 21 and 22 which give the best fit of quantities predicted by the model compared to observed quantities. The problem is easier simulated each parameter with restricted to the limited range of values; for instance, β is negative implies that inputs are complements.

We use Monte Carlo simulations [3] to draw 20000 alternative sets of parameter values, for each set we run model and compare predicted and observed quantities, parameter values are chosen freely within range. In order that the energy demand derived by the model well match the observed energy demand, non-linear least squares [4] is used to decide the best fit value of parameters. The set which gives the best fit according to least squares estimation is chosen. The best fit in the least-squares sense minimizes the sum of squared residuals, a residual is the difference between an observed value and the fitted value provided by a model. It is worth mentioning that there is no closed-form solution to a non-linear least squares problem, numerical algorithms are used to find the value of the parameters which minimize the objective. Most algorithms involve choosing initial values for the parameters and then the parameters are refined iteratively, namely, the values are obtained by successive approximation. The resulting parameter values are shown in Table 2.

The purpose of the Monte Carlo simulation and non-linear least squares are to find the parameters which give the best fit of the model to the empirical data, not to test the model or find out whether parameters are significantly different from zero.

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[3] Its core idea is to use random samples of parameters or inputs to explore the behaviour of a complex system or process. Specifically, using a model of the situation, system, or process being looked at, a random sample of each uncertain input is taken. Next the model is recalculated and the key results is saved. This is done repeatedly and the results saved each time. Once complete the range and shape of the results can be examined visually and numerically.

[4] Non-linear least squares is the form of least squares analysis which is used to fit a set of m observations with a model that is non-linear in n unknown parameters, where $m > n$. The basis of the method is to approximate the model by a linear one and to refine the parameters by successive iterations.

Table 2. The values of parameters drawn by Monte Carlo simulations in Excel spreadsheet.

Parameter	Range	Value
α	(0 , 1)	0.23
β	(-∞ , 0)	−1.6
γ	[0 , 1)	0.25
δ	[0 , 1)	0.02
θ	[0 , 1]	0.12

From equation 1 in section 2.2, we know that β captures the elasticity of substitution, the value of β indicates that the short run demand of energy is inelastic, which implies that the substitution occurs mainly through technological change or investment and the energy costs would rise drastically if the price increase unexpectedly.

The value of γ shows that there exists a link between energy-augmenting knowledge and labour-augmenting knowledge. $\gamma > 0$ is confirmed by the value, which suggest that it is important to take the inter-sector technology spillovers into account. (see equation 2 and 3)

δ captures the elasticity of knowledge to investment as we show in equation 2 and 3, the value of δ as the returns to investment is lower than the common reported value in other literatures. It tells that a rise of investment in a given period leads to a rapid diminishing returns in augmented firm-level knowledge, firm's capability for rapidly boosting their knowledge levels through extra investment is hence limited, this is due to the model specification in which firms reinvest knowledge each period.

The value of θ implies that weight for historical prices is low since θ is close to zero. This can be seen from equation 22, we set θ=0 then we have $E_t[P_{t+1}]=P_t[\frac{P_t}{P_{t-1}}]$, which indicate that firms only use the current price

P_t and the current trend $\frac{P_t}{P_{t-1}}$ when predicting period t+1, older prices make no difference.

The simulation results are shown in the following figures, where 'obs' and 'mod' refer to the quantities observed in the given data and the quantities predicted by the model respectively. All figures are displayed on numerical scale.

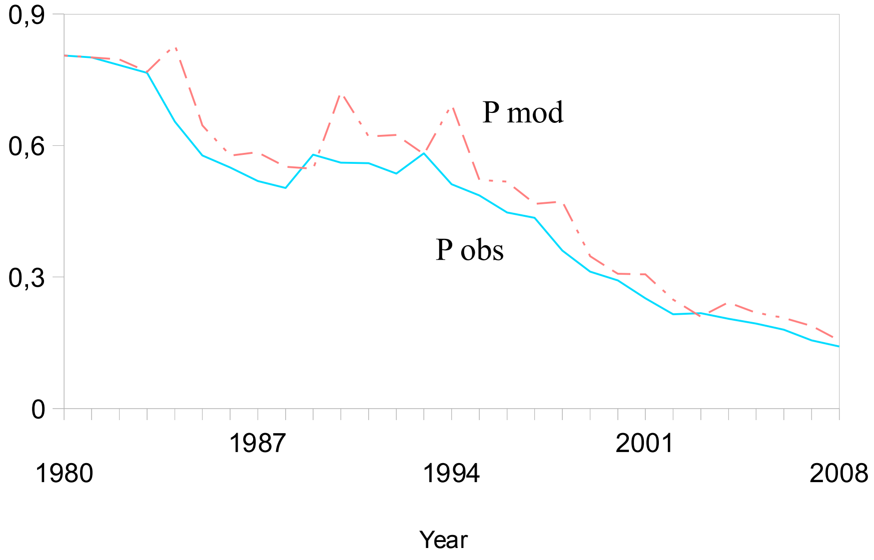

Figure 1. Trends in the price of energy relative to the price of labour along with the expected relative price deriving from the model.

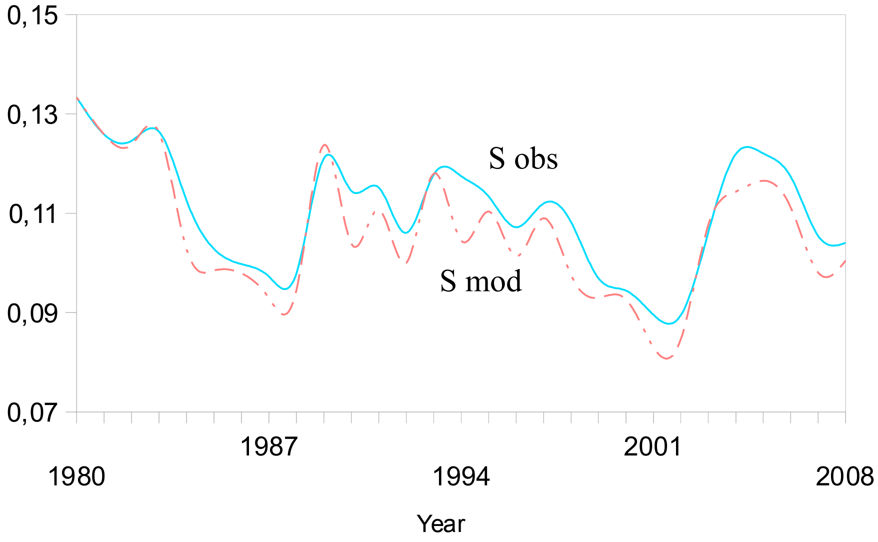

Figure 2. Illustration of how the observed and predicted factor share of energy develop over time in China.

As we can see, the trends generated by the model well match the observed trends. It is shown in Figure 1 that the economy begins at a point with high relative prices of energy and labour and then fall continuously. The reason why the level of energy-augmenting knowledge keeps on increasing in the next two periods in spite of the current decreasing relative prices is that the impact of this initial high relative prices is not reflected in the level of energy-augmenting knowledge at present. The model results have higher peaks in relative prices of energy and labour (P mod) than the observations, this because price of labour grows at rate of productivity growth, however, price of energy is typically rather constant.

4.3 Simulations of energy demand

Giving observed trends of energy prices, labour quantities and wages (labour price), we are ready to examine the evolution of energy demand in China from 1980 to 2008 by the model. The reason why the data are selected is concerning the methodology of constructing, the data of quantity represent the total energy demand in all sectors and a great variety of energy sources, the data of price index is the total expenditure divided by the demand in which technology and demographic parameters are exogenous variables.

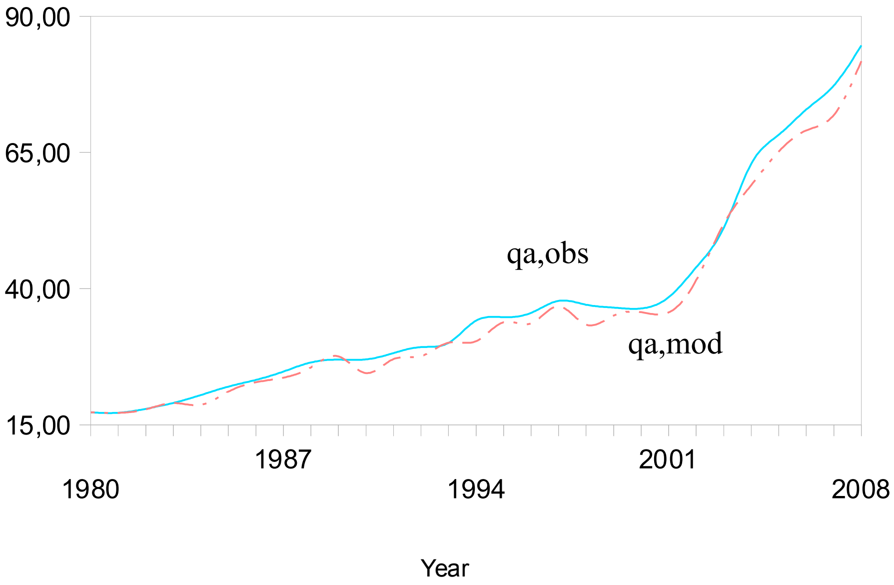

Figure 3. The energy quantities observed in the data comparing to the energy quantities predicted by the model.

It can be seen that the energy quantities predicted by the model are very close to the observed quantities in the selected data. The high relative prices discussed in section 4.2 also have an impact on energy consumption, as shown in Figure 3, the energy consumption slowly increase initially.

Having simulated a model in primary energy demand, we are able to evaluate the future energy consumption scenarios for China. The official forecasts of energy demand are found in International Energy Outlook 2011, published by EIA [5]. EIA is forecasting that world energy demand will grow by 53% between 2008 and 2035, while energy demand in China is expected to

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[5] EIA is the abbreviation of Energy Information Administration, which is the statistical and analytical agency within the U.S. Department of Energy. EIA collects, analyzes, and disseminates independent and impartial energy information to promote sound. policymaking, efficient markets, and public understanding of energy and its interaction with the economy and the environment.

increase by 68 % during the same period. Confronting this forecast with our simulated model, in the reference scenario energy demand is projected under the specific assumptions concerning the GDP growth rate and the energy price development. Real Chinese GDP is assumed to grow 5,7% per year on average from 2008 to 2035, and energy prices are assumed to rise 5,4% annually. With the assumptions from the official energy scenario we are now able to calculate total energy demand until 2035.

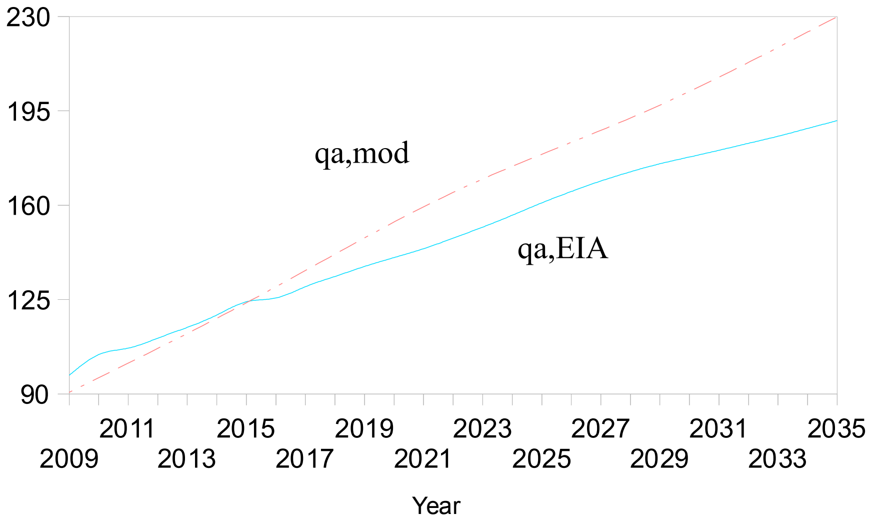

Figure 4. The comparison of predicted energy demand by the model and the forecast energy demand from EIA in China.

5 Discussions

5.1 Results and analysis

It is shown in Figure 1 that in the modelled economy, the relative price of energy to labour falls increasingly from a start point with high level. Comparing Figure 1 to 3, we notice that the relative price of energy declines and labour inputs increase simultaneously, a steep rise in energy demand is predictable as expectation. There is a time lag between energy prices and the energy-augmenting knowledge, energy-augmenting knowledge does not reflect the effect of high price in the current period, actually, the price rises subsequently for two periods even though the current relative price falls, which can explain that energy demand increase gradually at first in the simulations.

As illustrated in Figure 4, the model predicts a steeper increase in energy demand than the prediction of EIA. The different approaches may cause this result. The model that we use is highly aggregated and there are only two inputs, energy and labour, to model a single production process. However, the National Energy Modeling System (NEMS) of EIA consist of a variety of parts. For example, there are elements of various energy sources on the supply and their end use on the demand. Moreover, the electricity market, the petroleum market, the international energy markets and macroeconomic activity are taken into elements as well. The determination of prices and quantities are partially influenced by the interplay of these elements in an integrated system. Another major reason is that technological change is endogenous in our model, while technological change is exogenous in the EIA model.

Implicitly, we find that long-run energy demand is more sensitive to energy prices in the simulation than in the EIA prediction, the trend in energy demand is only marginally influenced by the radical differences in the development of prices. The mechanism behind this is how the model formulate changes in technology. Less price increase would result in even more growth in energy consumption.

Since the chief interest of this paper is total energy demand, the heterogeneity in supply and demand is not taken into account, which might be a flaw.

5.2 Alternative solution for simulations

While we do an empirical study, a research problem such that the dependent variable of the structural model can hardly be directly observed is most likely to arise. A typical case is that the actual value of the variables is possible to be observed within partial time and its observable condition depends on its actual value or other variables' values. Meanwhile, our primary goal of the study is producing a model to predict an economy's future behaviour, a behaviour of a sector in the economy, or a behaviour of an individual firm. A common approach to this problem is the structural model method which can be used in TSP[6].

There are usually three major steps in producing a forecast by TSP. Firstly, define a model with one or more equations, describe the variables of interest properly over a recent time period. Secondly, choose a prediction period and make some reasonable assumptions for the behaviour of the exogenous variables in the model over the period. At last, use the chosen model, projected values of exogenous variables and one of TSP's prediction or simulation procedures to compute the endogenous variables of the model one period at a time. [7]

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[6] TSP is a general-purpose computer language for econometric and statistical data processing and estimation. The program can be used for any of the following tasks: Applied econometrics, Macroeconomic research and forecasting, Sales forecasting, Financial analysis, Cost analysis and forecasting, Monte Carlo simulation, Estimation and simulation of economic models.

[7] Lagged endogenous variables may be determined from either the previous forecasts (dynamic simulation) or may be actual realizations of the variable (static or historical simulation).

We may use one of the procedures described below, running by TSP software, to estimate such DTC model.

1. Full information maximum likelihood (FIML) operates on the model as a whole, however, it requires that the model must be complete, it must have as many equations as endogenous variables. [8]

2. Three-stage least squares (3SLS) [9]. 3SLS does not require the model to be completely specified, that is to say, the estimates for the equations and parameters can be consistent even if the exact form of the rest of the model is unknown. This is a significant advantage over FIML. [10]

Subsequently, we may need to test some hypotheses about the estimated parameters of the model. For example, sometimes we need to test whether the parameters satisfy some nonlinear constraints.

1. Quasi-likelihood ratio test can be used for hypothesis testing in a nonlinear model estimated by 3SLS.

2. Lagrange Multiplier test is generally based on the magnitude of the derivatives of the likelihood function with respect to the constraints evaluated at the constrained estimates. The test is easy to compute even if the alternative hypothesis is not well specified.

Furthermore, we may encounter a task such as to check the statistical properties of a simulation model or to compute bootstrap standard errors when

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[8] In addition to the behavioural equations containing unknown parameters, FIML must be supplied with any identities that involve the endogenous variables. Identities provide a convenient way of entering repeated functions of endogenous variables into several equations.

[9] This is an instrumental variable method for estimating a system of simultaneous equations where there may be endogenous variables on the right-hand side as well as contemporaneous correlation of the disturbances.

[10] For example, we may have a set of equations describing the quantities demanded of energy as a function of the prices of energy. Prices may be determined as part of a larger economy that we do not wish to model explicitly. With the choice of suitable instruments, we could estimate the demand equations consistently without specifying the complete model.

analytic formulas are unavailable. Random variables are handy in such a variety of situations. This type of procedure is often referred to as Monte Carlo analysis, most Monte Carlo analysis involves making a large loop and accumulating statistics on functions of random variables. It is easily programmed in TSP too.

5.3 Further developments of the model

There are two worthwhile steps that could be added to make the model more constructive.

1. Technological innovation is regarded as the engine of economic growth. The discoveries of new route or production process represent even a small part of the driving force behind technological progress can push forward the boundaries of human knowledge. Innovation functions through entrepreneurs who implement these discoveries and bring them successfully to the market.

The notion that innovation as the outcome of purposeful economic activity is ultimately the engine of economic growth can be traced back to the work of Joseph Schumpeter[11]. Schumpeter's basic insight is that new techniques push out old ones to be formalized in an endogenous growth model.

Schumpeterian element is introduced by modelling the determinants of the rate of technological progress as a function of innovative activities,

$$x=\lambda\sigma q$$

where λ is the probability of that each unit spent on research an development yields a successful innovation, σ is the extend to which each innovation raises the productivity parameter, and q is intensity of research and development.

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[11] Joseph Alois Schumpeter (8 February 1883 – 8 January 1950) was an Austrian-Hungarian economist.

Compare the function of Schumpeterian element with our model, it can be seen that q is equivalent to I^{δ} and σ is equivalent to K (see equation 2 and 3). Now we simply analyse λ, which is not included in our model. A rise in λ leads to an improvement in the returns to innovation, which in turn prompts research and development activity through innovation, namely research and development becomes more fruitful. Consequently, q will rise, which raise the rate of technological progress and the economy adjusts to a new balanced growth equilibrium.

2. It will be useful to make some general observations on the role of the model of a economic theory in connection with policy analysis. The economic models used to analyse sustainability issues are generally abstract analytical constructs. There are two economic concepts of sustainability:

Ⅰ A sustainable state is one in which utility/consumption is non-declining through time. (Pezzey, 1992)

Ⅱ A sustainable state is one in which resources are managed so as to maintain production opportunities for the future. (Page, 1977)

We notice that our model does not concern capital unlike most of other endogenous growth models, but ideally, we would include capital and let it make some difference. Production potential at any time point depends on the stock of productive assets available for use. The basic issues of sustainability can be explored by a framework of the simple optimal growth model where production uses a non-renewable resource, the welfare function is,

$$W=\int_{t=0}^{t=\infty} U(C_t)e^{-\rho t}\,dt$$

to be maximised subject to the constraints,

$$\frac{dK(t)}{dt}=Y_t-C_t$$

$$\frac{dS(t)}{dt}=-R_t$$

$$\bar{S} = \int_{t=0}^{t=\infty} R_t \, dt$$

where U denotes utility, C_t is consumption, e is natural exponent, K is human-made capital (the sum of physical, human capital and technology), Y_t is the production function, S is resource and R_t is resource extraction.

6 Conclusions

The factor-augmenting knowledge spills over over time not only between enterprises in the same sector but also between sectors in the modelling economy, which conform the reality in China. Thus, knowledge which augments labour may spill over and promote the accumulation of energy-augmenting knowledge. Enterprise's expectation on the relative price in the future is decisive on their investment of new knowledge. It can be found that the stock of energy-augmenting knowledge is smaller than the stock of labour-augmenting knowledge, which is held not only in the past periods but also in the future periods as well.

Generally, the critical prediction derived from the model can be concluded that the factor share of energy in GDP will decline continuously as long as energy inputs keep going on to increase at a faster rate than labour inputs; on the contrary, the factor share of energy in GDP rise when energy inputs grow at a slower rate than labour inputs. These results are in accordance with the existing theoretical results in some previous studies (e.x. Acemoglu and Hart), but have a dissimilarity to those who predict constant long-run factor shares regardless of quantities and constant quantities as well (e.x. Smulders and de Nooij). In addition, energy price will go up at a faster rate than the sum of the increased rates of labour inputs and the price of labour when energy use in the economy diminish. Besides, less price increase would result in even more growth in energy consumption.

We compare the predicted energy demand with the demand projections of EIA in the same scenarios, the assumed trends which come from EIA's scenarios cover the period 2009-2035. It is mentionable that the NEMS of EIA is disaggregated, they does not integrate prices and quantities due to using a variety of energy sources, sectors and regions on both supply and demand. The main interest of this paper is total energy demand. It is doable to compare the results from our model and EIA model because it is feasible to translate the EIA projection into a measure of total energy consumption irrespective of the blend of energy sources and different end users. Our results suggest that the existing forecasts, such as those of the EIA, may, to some extent, underestimate China's future energy demand given energy price trends. A more sensitive long-run energy demand to energy prices in the simulation compared to the EIA prediction can be seen as a sign to show the power of directed technological change.

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