How Carbon Emission Mitigation Promotes Economic Development - A Theoretical Framework[1]

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April, 2011

(Early draft version, comments are welcome)

Abstract: The substance of fighting global climate change is to decrease the dependence on fossil fuel and to shift to a low-carbon economy which leads to industrial structure transformation, probably the most substantial change since the Industrial Revolution. Nonetheless, the conventional marginal analysis which focuses on non-topological nature of resource allocation is not able to analyse the topological structure changes through specialization and division of labour, an insight dating to Adam Smith. Consequently, marginal analysis usually concludes that mitigation policy will inevitably affect economic development in a negative manner, which is misleading in theory and contributes to the failure of international negotiation conventions. By employing an inframarginal general equilibrium model, this paper shows that unilateral mitigation policy could actually stimulate the emergence and development of new industries associated with low carbon technologies, analogous to the unilateral tariff cutting in the Great Britain leading to economic growth two hundred years ago. The earlier adopter of stringent mitigation policy would enjoy the first-mover advantages in specialization and higher productivity, consequently, international competitiveness. The other countries have to follow and adopt similar stringent mitigation policies so as to maintain and improve their competitiveness, leading to a multilateral carbon reduction policy changes. Moreover, there is a probability that the developing countries could leapfrog to a more competitive low carbon economy since they have lower transition cost than the developed countries which have been locked into high carbon technologies.

Key Words: climate change, greenhouse gas emission mitigation, economic development, low-carbon economy

I.Introduction

[1] This paper is one of the outcomes of “Fighting Climate Change” project of the Development Research Center of the State Council, P.R. China. The authors appreciate the valuable opinions of the whole project team and Zhang Dingsheng, as well as Wu Jiang for his time-consuming calculations in some of the model. The authors are responsible for any remaining errors in the paper. Contact: Yongsheng Zhang: zys@drc.gov.cn, He-ling Shi: he-ling.shi@monash.edu

Climate change is one of the greatest challenges for humankind. The essence of response to the climate change is to gradually break away from the dependence on the traditional fossil fuels. The growth mode of modern economy since the Industrial Revolution is built on the fossil fuels, which will one day be exhausted. Humankind has to step towards the renewable energy-based low carbon economy to achieve sustainable development. The global campaign against the climate change accelerates transformation towards the low carbon economy. Under the global climate crisis, not only it is hard for developing countries to follow the traditional industrialization of developed countries featured by high emissions, developed countries also have to fundamentally change their development mode and way of living. Although there exist controversies over whether greenhouse gas emissions from human activities is the decisive factor of global climate change, the consensus is that developing the low carbon economy is the way to go. The response to climate change represents the most fundamental transformation of economic development mode since the Industrial Revolution and is imposing comprehensive and profoundchanges on human production and lifestyle. In this sense, it is no big deal whether climate change makes scientific sense or not.

According to the mainstream neoclassical marginal analysis, there is a trade-off between emissions reduction and economic growth. Indeed, under the current technical conditions and economic structure, economic development will lead to emissions, which means emissions basically are the side product of development. For an economy, emission reduction, to a large extent, means sacrifices in economic development. In addition, emission exhibits externalities. An economy bears the cost for emission reduction while the benefits are shared across the world. Therefore, on global emission reduction, each country hopes to do less and wishes other countries do more. This makes global fighting for climate change a tougher issue.

However, the idea that emission reduction and economic growth is contradictory is somehow misleading. Although low carbon economy has not become universal, the success stories are spreading across the world. In recent years, rapid development of renewable energy and low carbon industry shows that the above-mentioned idea is having its shortcoming. Consequently, we need to reveal the inherent relationship between emission reduction and economic growth from the theoretical point of view and how the low carbon economy emerges in a way that is different from our conventional way of production and living.

A simple case might illustrate this point. About two hundred years ago, when it was generally believed that unilateral free trade would harm a country’s own interest, the Great Britain was the first to implement the unilateral free trade policy. The free trade brought about market expansion, which greatly enhanced the improvement of division of labour and economic growth in the UK. Finally, free trade became a global trend. From tariff barrier to free trade, different policies responded to different structures of division of labour which represented varied levels of prosperity. However, unless the benefits of free trade are visible, for people living in the tariff barriers, free trade means more risks and losses other than opportunities. Only when the benefits of free trade become reality in the pioneering countries, the others will follow.

In terms of the emission reduction policy, the evolution of trade policies in history has some implications: first, the current economic model that we experience might be just one of many potential models. If not by chance, the world might be totally different. The more efficient division of labour that doesn't exist in reality resides in the minds of visionary politicians and brave entrepreneurs. It is that people are not aware of it before it becomes reality and take it as a risk. This idea in turn hampers the emergence of better division of labour. This can be compared to the new business models. Only when they are created by the innovative entrepreneurs, people are aware of them. We are now living in an economic model which relies on emissions. Before low carbon economic model practiced and demonstrated by pioneers, it is still considered a risk by many people. Second, once the low carbon economy is proved to be a better and more feasible economic structure than the current high carbon economy, all countries have to follow the low carbon path as people did in the tide of free trade. Otherwise, they will the losers in international competition.

This paper is to develop a theory to show that emission reduction could become the driver for economic development and transformation rather than hamper economic development as generally believed. In the next section, the authors reveal the inherent relationship between emission reduction and economic growth with Smith - Young growth theory to discuss how the cost of renewable energies could be continuously brought down in market, and to investigate the mechanism of developing new energy sector. In section III, the authors use an inframarginal general equilibrium model to illustrate that those countries that adopt stricter emission reduction measures earlier will take the lead in international competition by transforming from high carbon model based on the traditional fossil fuels to the more competitive low carbon model based on renewable energies. Section IV discusses some relevant issues in the development of green low carbon economy. Section V demonstrates the implications of analysis in this paper for international climate change negotiations and resolving global climate change issues. The final section concludes the paper.

II. Emission reduction and division of labour: Smith-Young growth model

In a given technical level and division of labour structure, emission reduction to a large extent means output reduction. Therefore, the cost of emission reduction includes two parts: (i) direct cost of emission reduction, and (ii) output decrease due to emission reduction. The benefit of emission reduction for the whole world is that it will bring down the losses. In the framework of neoclassical marginal analysis, the optimal emission reduction level is the compromise between the benefits of emission reduction and reduction cost, i.e. marginal cost equals marginal revenue. However, if emission reduction leads to the non-continuous jump to a more efficient low carbon division of labour model, the result will be different. In this case, emission reduction will promote instead of hamper the economic development. This means emission reduction not only brings down the losses, but also creates a new more competitive structure and more benefits.

These are two different approaches to analyze the issue. The former approach follows neoclassical marginal analysis represented by Marshall, focusing on resources allocation in a given technical level and division of labour structure（Marshall,1890）. The latter approach follows Smith and Young’s classical general equilibrium and inframarginal development which selects the optimal division of labour from the multiple alternatives. According to Smith (1776) and Young (1928), technical level, economic growth and industrial structure will undergo non-continuous change in the evolution of division of labour. This process is similar to what Schumpeter called creative destruction in the economic development.

Examples are given to illustrate the implications of the two different development approaches. According to Samuelson (1948), international trade would lead to factor price equalization and, consequently, American labour wage would be decreased even without free flow of cross-border labour. His analysis leads to protectionism. He failed to predict that international trade brought about big adjustment to global division of labour. With the emergence of new industries and technologies, free trade has become a driver for global economic growth. However, before the emergence of the new division of labour, trade liberalization was considered a risk.

Another example is McDonald's business model. It was generally believed that as the catering industry became crowded, the marginal returns of investment in catering industry would definitely decrease. Thus, it was not a good investment following the traditional marginal analysis approach. However, McDonald's business model creates a new division of labour model. The headquarters only provides the intangible trademark and operating manual, while the franchise retailing stores provide the tangible service, supported by a huge division of labour system. This model can greatly enhance productivity and create a new more competitive division of labour model.

Similarly, suppose humankind is free to choose two different potential economic models. One is the high carbon model, in which industrial structure, production and living are based on traditional fossil fuels. Under this model, due to the high cost, the new energy industry cannot compete with the traditional energy, and remains as the demonstration projects. Another model is the low carbon model, which is based on renewable energies (such as nuclear power, wind power, solar power, and ocean wave power). Under this model, the production cost of the new energy is lower than that in the high carbon model. Division of labour network of related industries is well developed. Compared with the high carbon model, the low carbon model is more competitive and sustainable.

However, if unfortunately, we are living in a high carbon economic model, how can we transform to the low carbon economic model? In the current high carbon model, high cost of the new energy makes it impossible to compete against the traditional fossil fuels. These are the difficulties we face in developing low carbon economy. Does it mean the high carbon economic model cannot transform to the low carbon economic model? The answer is no. The high cost of new energies is due to low productivity. For instance, wind power generation requires investment in wind mill, which involves a long production chain. If the price of the wind mill comes down, so will the price of the wind power. The wind power will not suffer from a price disadvantage compared with the thermal power. Then how to bring down the cost of wind power generation? According to Mises (1927), any product in its early appearance is a luxury. With the enlargement of the production chain and expansion of the division of labour, the productivity of the luxury will keep improving until ultimately becomes an affordable product. Wind power, if considered as the luxury now, will gradually become an affordable product for the general public.

Then how to make the luxurious new product an affordable one under the market force? To illustrate the point, we use an example on car manufacturing. Suppose the car market is very small at the beginning. In its early emergence, only a few people can afford it. This market created by a few becomes a threshold of the car industry, the so-called Smith theorem for division of labour – that is, the division of labour is limited by the extent of the market (Smith, 1776). Suppose the car is Z. To manufacture Z, several parts $y1$,$y2$,$y3$….are needed. Take $y1$ for example. There are two ways of manufacturing $y1$. One is through roundabout production, i.e. using more specialized equipment $x1$; the other is through non-roundabout production, i.e. the production of car z does not use the specialized equipment $x1$. According to Smith , when the market is not big enough, it does not make economic sense to invest in purchasing of $x1$ to manufacture $y1$. In Allen Young's words (1928), it would be wasteful to make a hammer to drive a single nail. Therefore, at the beginning, car manufacturers can only self-produce all or some of the parts by themselves. However, with the emergence of car parts manufacturers as the result of the division of labour, productivity will be greatly enhanced and in turn further expand the car market. Apparently, manufacturing $y1$ using specialized equipment of $x1$ can significantly enhance productivity. As a result, $y1$ will see better quality due to more specialized manufacturing process and lower cost for enhanced productivity. The changes in quality and price of the car parts will be reflected in the quality and price of cars. As a result, the whole car will be of lower price and better quality, which will attract more buyers. The same story will happen to $x2$. The car price will continue to decrease and the market will further expand. This phenomenon is not limited to such tangible products as cars, but also true to intangible products such as software. For instance, some software contains multiple small software packages, which are produced by professionals. As Mises (1927) predicted, any new product in its early appearance is a luxury. Its price will decrease in the process of industrialization, which is the process of increasing returns as a result of interactions between market expansion and division of labour. It is this increasing return that drives economic growth. Therefore, Young（1928） pointed out that, not only the size of the market determines the division of labour, but vice versa."Once the economic growth occurs, it will become a natural phenomenon". It will not stop before the potential of division of labour is exhausted.

We call this type of growth the Smith-Young growth model. Classical mainstream economists represented by William Petty, A.R.J.Turgot and Smith focus on the implications of division of labour on economic development. To a certain extent, the core of classical mainstream economics is economic development, represented by Smith theorem, that is, the division of labour is the source of economic growth; division of labour depends on the size of the market; and the size of market in turn depends on the transport conditions（Yang，2001，p.1）.However, since the evolution of division of labour could not be dealt in the framework of marginal analysis, these visionary insights were overwhelmed by the marginal theory that was much easier to be formalized - which became the mainstream economics.

Theoretically, the reason of cost reduction in new energy and other related sectors is the same as the cost reduction of cars. In the above example, if we replace cars with new energy and related sectors, we may find the mechanism of cost reduction in new energy and related sectors. With the market expansion of new energy and related sectors, the division of labour system in producing new energy generation equipment will be improving – which increases the productivity in the new energy sector and decreases production cost. As a result, the market for new energy will become larger and the cost of new energy will become lower until it is competitive enough against the traditional fossil fuels. Production activities will eventually no longer depend on the traditional fossil fuels. This interaction between the division of labour and the extent of market leads to continuous improvement of new energy productivity and reduction of costs.

However, if we are already in a high carbon structure and the mining cost of traditional fossil fuels is sufficiently lower than the cost of the emerging new energy at the early stage, it is difficult for the new energy industries to develop in the competition against the traditional fossil fuels. Under such circumstances, the role of the government is crucial. If the government sets carbon emission quota (or carbon price) and takes stricter emission mitigation measures, emission would be expensive and the cost will increase with the continuous decrease of global emission space. Meanwhile, with the fossil fuels become scarcer, the mining cost will go up. These factors will drive the cost of traditional fossil fuels up and lower its price competitive edge against the new energy. If the government provides considerable support to the development of new energy, such as subsidies to the new energy sector in its early stage of development, it will help shaping the initial market for the new energy and the price competitive edge of the new energy will emerge. This is also true for the development of industries related to the new energy (such as electric car industry). The chain of division of labour will take shape at an earlier date if the government provides strong support at its initial stage of development.

Therefore, if the government increases efforts in emission reduction, the cost of production based on fossil fuels will increase since new cost for emissions occurs. Meanwhile, if the government uses the revenue from emission fees to subsidize the new energy producer, the new energy will become lucrative. However, the new energy sector at this moment is small and has to rely on government subsidies to survive in the market competition. It is more of a new demonstration project that shows the direction for future development. High carbon structure based on the traditional fossil fuels and low carbon structure based on the new energy coexist for some time. With the market expansion for the new energy, the cost will come down, making low carbon structure more competitive against the high carbon structure until transformation from high carbon to low carbon. The low carbon economy therefore will follow the evolution path from high carbon structure to the coexistence of high carbon and low carbon demonstration projects to low carbon structure. In the process of the evolution, government's emission reduction policy and institutional reforms play the key role.

III. Model

We can formalize the above stories using a model based on Shi and Yang model (1995, hereafter Shi-Yang model). Shi-Yang model is an inframarginal model (see Yang, 2000) of industrialization with intermediate products, a manifestation of Smith-Young's perception of expanding the industrial chain. With the inframarginal model, Shi and Yang attempted to explain how the new intermediate products replace the old intermediate products to manufacture the consumer products, and to explain the Industrial Revolution at the end of the 19^{th} century in the UK when the steam engine replaced the manual spinning. If the old intermediate product is considered the traditional energy, the new intermediate product is considered a new energy; the enlargement of production chain of new energy will improve the productivity of consumergoods. As a result, the new energy-based low carbon production structure will replace the traditional energy-based high carbon production structure.

However, for the following two reasons, the new energy and related industries cannot emerge spontaneously with the market force itself. First, in the Shi-Yang model, producers can arbitrarily emit without any cost. If the old intermediate product is taken as the old energy, the old energy will not withdraw from the market voluntarily when it is not exhausted and there is the absence of emission reduction policy to combat climate change. Therefore, we need the government to impose emission cost through emission reduction policy. Secondly, different from the Shi-Yang model, CO_2 emission that the new model deals with is a global public bad. Although everyone has realized that CO_2 is the cause for global warming and has negative impact on economy, geography and humanity, the pubic attribute of CO2 refrains everyone from taking actions by themselves. Since the emission right is not clearly defined, the Coase Theorem (Coase, 1960)is not applicable. Thus, it is necessary to define the emission right and set up the pricing mechanism. Therefore, we need to introduce the functions of public sector in the model, which is responsible for CO2 pricing (auction of emission right, charges or carbon tax) and allocation of carbon emission right revenue in the general equilibrium framework. To introduce the constraint of “public budget balance” makes our model more challenging than the Shi-Yang model（1995）.

Suppose there are M identical economic agents who are both producers and consumers. There is one consumer good called z. The utility of each agent is determined by the actual consumption of z. To produce z, energy and labour are required. Energy in this case can be generated by the traditional high carbon technology y (e.g. thermal power) or the low carbon technology$\hat{y}$(e.g. wind power）. The difference is the high carbon technology y produces CO_2, while the low carbon technology $\hat{y}$ does not. Suppose β is CO_2 emission coefficient to produce y per unit, $\beta y$is the CO_2 emissions to produce y. l for labour is needed to produce y. To produce$\hat{y}$, we may use labour, or x for specialized equipment or both.

Each economic agent may choose the following professions. According to Wen theorem(see Yang,2000), those options that cannot be optimal are excluded.

(i) Professional(y/z) or ($\hat{y}$/z): specializing in the production of consumer good z. Purchase y or $\hat{y}$ to produce z, sell some of z to buy y or $\hat{y}$.

(ii) Professional(z/y): use the traditional high carbon technology to produce y, and sell y to purchase z

(iii) Professional(z/$\hat{y}$x): use the low carbon technology to produce $\hat{y}$ in an partially-specialized manner. Use the labour to produce x and then use x and labour to produce$\hat{y}$, sell$\hat{y}$ to purchase z.

(iv) Professional(xz/$\hat{y}$): specialize in producing $\hat{y}$ with the low carbon technology. Purchase x to produce$\hat{y}$, sell$\hat{y}$ to purchase z.

(v) Professional(z/x)：specialize in production of equipment x for generating$\hat{y}$, sell x and purchase z.

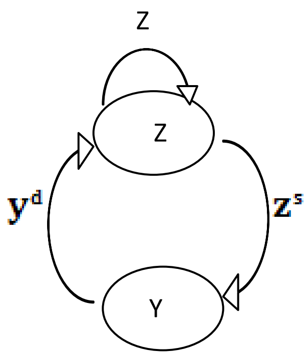
All economic agents may choose the above professions at their own will and engage in production and exchange in the social system of division of labour. The following structures of division of labour may occur in the marketplace:

Structure A：High carbon structure with full division of labour
Structure B：Low carbon structure with partial division of labour
Structure C：Combination of A and B
Structure D：Low carbon structure with full division of labour

In addition, self-sufficiency is also a possible economic structure. Since this paper focuses on studies of low carbon economy in the modern economic system, the self-sufficiency structure is neglected. We only consider the division of labour structure with exchanges.

In each of the above structures, there is an equilibrium(called corner equilibrium). The general equilibrium in the inframarginal analysis is the most efficient structure of division of labour among all corner equilibriums. Each corner equilibrium is equivalent to the general equilibrium in the neoclassical marginal analysis. Therefore, the general equilibrium in the neoclassical marginal analysis is the corner equilibrium in the inframarginal analysis rather than the general equilibrium. Hence, the result of general equilibrium in the neoclassical marginal analysis might be misleading. The following is the calculation of equilibrium in each division of labour structure. The utility is compared in order to find out the general equilibrium in different conditions.

<u>Structure A</u>: Structure A is illustrated in the following figure:



M economic agents may choose two professions in the marketplace. Type 1 professionals (y/z) produce the consumer good z partly for their own use (z) and partly for sale (z^s). The total output of z is $z+z^s$. Labour l_z and energy y are needed to produce z. y can be purchased from type 2 professionals (y^d). Market transactions involve transaction cost. We use $0 \leq k \leq 1$ to represent transaction efficiency. Production function is set to $z+z^s=(ky^d)^{0.5} \cdot l_z$ where ky^d is the actual y in the production process, while its index of $1.5 \geq 1$ highlights the specialized economy.Type2 professionals(z/y) use their own labourl_y to produce y and then sell y to buy z for consumption, i.e.z^d. Due to the transaction cost, the actual consumption is kz^d.

Type 1 professionals have the following decision-making system without considering the negative impact of CO2 on utility.

<u>Type 1 professionals(y/z):</u>

Max: $u_{(y/z)}=z$ (utility function）
s.t. $z+z^s=(ky^d)^{0.5} \cdot l_z$ (Production function）

$l_z=1$ (labourconstraints）

$p_y \cdot y^d = z^s$ (budget constraints）

Where p_y is the price of y. z is the numeraire and its price is1.

To solve the above decision problem, we have the demand function and indirect utility function:

$$y^d=\frac{k}{4p_y^2}$$

$$u_{(y/z)}=\frac{k}{4P_y}$$

<u>Type 2 professionals(z/y):</u>

Max: $u_{(z/y)}=kz^d$

s.t. $y^s = l_y$ (Production function)

$l_y = 1$ (Labour constraint)

$z^d=p_y \cdot y^s$ (Budget constraint)

Solve the problem, we have,

$$u_{(z/y)}=kp_y y^s= kp_y$$

Free choice of professions means the utility equalization of different professions, i.e.$u_{(y/z)}= u_{(z/y)}$, , hence:

$$\frac{k}{4P_y}= kP_y$$

And we have:

$$p_y = \frac{1}{2}$$

$$y^d = k$$

$$u_{(y/z)}= u_{(z/y)}= kP_y = \frac{1}{2}k$$

Market clearing condition:

$$M_1y^d = M_2y^s$$

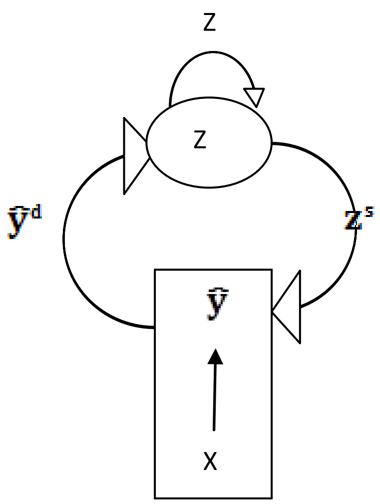
where , M_1 is the number of type 1 professionals (y/z),who buy y; M_2 is the number of type 2 professionals (z/y), who are suppliers of y. Numbers of professionals in the equilibrium of Structure Aare:

$$M_1=\frac{1}{k+1}M,\ M_2 = \frac{k}{k+1}M$$

Now we consider the CO_2 emissions. Suppose production of y per unit produces CO2 emission β, the total CO_2emissions in this structure is $\beta M_2y^s=\beta\frac{k}{k+1}M$.

<u>Structure B</u>:

Now we consider structure B - low carbon structure with partial division of labour. Different from structure A, the consumer good z is produced using the new energy $\hat{y}$ generated through the low carbon technology (for instance, wind power). Suppose $\hat{y}$ is generated without producing CO_2 emissions, y and $\hat{y}$ are undifferentiated products for the energy users. It makes no difference for users whether the electricity is generated by the fossil fuels or the wind power. However, y and $\hat{y}$ are produced in different ways, which leads to different emissions. Labour is needed to produce y, while x, an intermediate product, is required to produce $\hat{y}$. For instance, nuclear power generation and wind power generation both involve a long industrial chain. The structure is shown below, called structure B.



The decision-making conditions for type 1 professionals ($\hat{y}$/z)in structure B is the same as that in Structure A, but for type 2 professionals, they need to consider x and $\hat{y}$ as follows:

Max: $u(z/\hat{y}x)=kz^d$(Utility function）

s.t. $\hat{y}^s = x^{\frac{1}{2}} l_{\hat{y}}$, $x=l_x$ (Production function)

$l_x + l_{\hat{y}} = 1$ (Labourconstraints)

$z^d = p_{\hat{y}} \cdot \hat{y}^s$ (Budget constraints）

To solve the decision problem, we have

$l_x = \frac{1}{3}$, $l_{\hat{y}} = \frac{2}{3}$

$$u(z/\hat{y}x)= kp_{\hat{y}} \frac{\left(\frac{1}{2}\right)^{\frac{1}{2}}}{\left(\frac{3}{2}\right)^{\frac{3}{2}}}$$

Utility equalization condition:

$$\mathrm{kp}_{\hat{y}} \frac{\left(\frac{1}{2}\right)^{\frac{1}{2}}}{\left(\frac{3}{2}\right)^{\frac{3}{2}}} = \frac{\mathrm{k}}{4\mathrm{P}_{\hat{y}}}$$

And we have:

$$\mathrm{p}_{\hat{y}} = \left(\frac{1}{2}\right)^{\frac{3}{4}} \left(\frac{3}{2}\right)^{\frac{3}{4}}$$

$$\mathrm{u_B} = \left(\frac{1}{2}\right)^{\frac{5}{4}} \left(\frac{3}{2}\right)^{-\frac{3}{4}} \mathrm{k}$$

Similarly, the market clearing condition： $M_1 y^d = M_2 y^s$

The following preliminary conclusion can be drawn from the equilibrium in Structure A and Structure B:

Proposition1：If an economic entity neglects the negative impact of global climate change on utility due to the public good nature of CO_2, the market itself will not voluntarily adopt the low carbon technology $\hat{y}$, but will continue to use the high carbon technology y which will generate CO_2 emissions.

Proof: compare the utility of Structure A and Structure B, we have

$$\mathrm{u}_A - u_B \approx 0.2\mathrm{k}$$

Since the climate change induced by carbon emission affects all, is it possible that everyone takes action to reduce emissions? Suppose in the global campaign against the climate change, every economic agent has sufficient information about the negative impact of CO_2 on individual utility. Emissions by any single agent in every corner of the world will affect all due to the fluidity of CO_2.

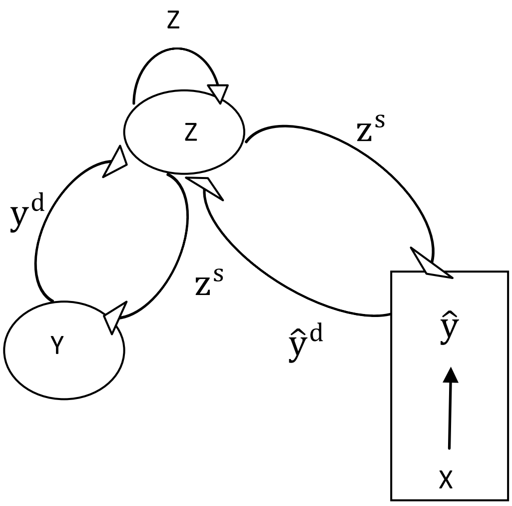
However, due to the public attribute of CO_2, the single agent that takes action to reduce emissions has to bear the cost on its own while the benefits are shared by all.

Hence, the single entity in Structure B has to pay the cost of $\mathrm{u}_A - u_B$

Therefore, although it is an optimal choice for the whole society that all take emission reduction measures to transform to the low carbon economy, the limit of individual pursuit of utility maximization will impede the whole society to achieve the rational targets.

Now that the market cannot take unanimous actions to reduce emissions, the government has to adopt emission reduction policies to reach the emission reduction targets through carbon pricing to artificially raise the cost of carbon emissions. That is to say, professionals that produce y have to pay the price for emissions. Pricing can be realized through emission charges, emission permits auctions or carbon tax. The public revenue from pricing can subsidize producers of low carbon energy to reduce the cost of low carbon technology$\hat{y}$. Hence, we have structure C,a combination of structure A and structure B (as shown below).

Structure C： Combination of A and B



To simplify the model, we assume a fiscal balance scenario, where all the revenue from carbon pricing is to subsidize the production of low-carbon technologies rather than directly introduce a public sector in the model.

For type 1 professionals (y/z) who produce consumer good, the decision problem remains unchanged, while for type 2 professionals (z/y) who produce energy with high carbon technology, the decision problem changes into:

Max:	$u_{(z/y)} = kz^d$	(Utility function)
s.t.	$y^s = l_y$	(Production function)
	$l_y = 1$	(Labour constraint)
	$z^d = p_y y^s - t\beta y^s$	(Budget constraint)

Note that the budget constraints for type 2 professionals is changed. We assume *t* is the unit price of carbon emission, the cost that each professional pays for the carbon emission is $t\beta y^s$

For type 3 professionals, i.e. professionals ($z/\hat{y}x$)who use the low carbon technology to produce energy, the decision problem turns to:

Max: $u_{(z/\hat{y}x)} = kz^d$ (Utility function）

$s.t. \hat{y}^s = x^{\frac{1}{2}} l_{\hat{y}}, x = l_x$ (Production function）

$$l_x + l_{\hat{y}} = 1 \qquad \text{(Labourconstraints)}$$

$$z^d = p_{\hat{y}}\hat{y}^s + sy^s \qquad \text{(Budget constraints)}$$

Note that the budget constraints for type 3 professionals is changed. We assume *s* is the fiscal subsidy rate, so the subsidy each economic agent gets from the public sector is s$\hat{y}$

To solve the problems, we have

$$u_{(y/z)} = \frac{1}{4}\frac{k}{p_y}$$

$$u_{(z/y)} = k(p_y - t\beta)$$

$$u_{(z/\hat{y}x)} = k(p_y + s)\frac{\left(\frac{1}{2}\right)^{\frac{1}{2}}}{(\frac{3}{2})^{\frac{3}{2}}}$$

And utility equalization condition：

$$k(p_y + s)\frac{\left(\frac{1}{2}\right)^{\frac{1}{2}}}{(\frac{3}{2})^{\frac{3}{2}}} = k(p_y - t\beta)$$

$$\frac{1}{4}\frac{k}{p_y} = k(p_y - t\beta)$$

Market clearing condition：

$$M_1 y^d = M_2 y^s + M_3 \hat{y}^s$$

That is:

$$M_1 k = M_2 + M_3 \frac{\left(\frac{1}{2}\right)^{\frac{1}{2}}}{(\frac{3}{2})^{\frac{3}{2}}}$$

Public finance balance condition:

$$t\beta y^s M_2 = s\hat{y}^s M_3$$

That is :

$$t\beta M_2 = s\frac{\left(\frac{1}{2}\right)^{\frac{1}{2}}}{(\frac{3}{2})^{\frac{3}{2}}}M_3$$

Combine the above equations, and note that

$$M_1 = M - M_2 - M_3$$

we can figure out p_y, M_1, M_2,M_3 and s . The others are parameters. Since our focus is the carbon emission, *M2* is the key variable of our analysis. We have

$$p_y = \frac{1}{2}(t\beta + \sqrt{1+t^2\beta^2})$$

$$s = \frac{1}{4}(-2t\beta - 3t\beta - 2\sqrt{1+t^2\beta^2} + 3\sqrt{3}\sqrt{1+t^2\beta^2})$$

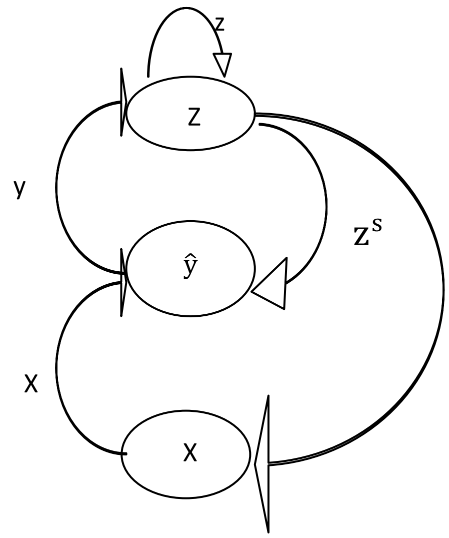
$$M_2 = \frac{2k\frac{1}{4}(-2t\beta - 3t\beta - 2\sqrt{1+t^2\beta^2} + 3\sqrt{3}\sqrt{1+t^2\beta^2})}{4k\frac{1}{4}(-2t\beta - 3t\beta - 2\sqrt{1+t^2\beta^2} + 3\sqrt{3}\sqrt{1+t^2\beta^2}) + 2t\beta + 3\sqrt{3}t\beta k}M$$

Note that in structure A, $M_2 = \frac{k}{k+1}M$. Our numerical simulations show that within the parameter range we set, that is $0 \le k < 1$, for any $0<t<1$, $\beta > 0$, M_2 in structure C is smaller than that in structure A. Therefore, we may draw the following conclusion:

Proposition2：If a country introduces the carbon pricing/subsidy policy, some high carbon producers will adopt the low carbon technology to reduce carbon emissions in the context of public finance balance.

In structure B and C, the economic agents that produce $\hat{y}$ with low carbon technology is not complete division of labour. In other words, generation of new energy $\hat{y}$ remains a demonstration project, which is not marketized. However, if transaction efficiency *k* is high enough, the complete structure of division of labour will occur. Therefore, next we will discuss conditions under which low carbon technology $\hat{y}$ will stand out in the marketplace with the evolution of division of labour to replace the current technology y so that the economy will fully transform to the low carbon economy.

Structure D： production of $\hat{y}$ with completedivision of labour, as shown below:



Decision problem for type 1 professionals(*y/z*) is:

Max: $u=z$ (Utility function）

s.t. $z+z^s=(k\hat{y}^d)^{\frac{1}{2}}\cdot l_z$, $l_z=1$ (Production and endowment constraints）

$z^s=p_y\cdot\hat{y}^d$ (Budget constraints）

Solve the problem, we have:

$$u_{(\hat{y}/z)}=\frac{1}{4}\frac{k}{P_y},\qquad y^d=\frac{k}{4p_y^2}$$

Decision problem for type 2 professionals (*xz/ŷ)* producing low carbon energy is:

Max: $u=kz^d$

s.t. $\hat{y}^s=(kx^d)^{\frac{1}{2}}l_y$, $l_y=1$

$p_y\hat{y}^s=z_1^d+p_x x^d$

Solve the problem, we have:

$$x^d=(\frac{1}{2}\frac{P_y}{P_x}k^{\frac{1}{2}})^2,$$

$$u_{(xz/\hat{y})}=\frac{1}{4}k^2\frac{{P_y}^2}{P_x}$$

Decision problem for type 3 professionals (z/x) who manufacture specialized equipment *x* to produce the low carbon energy:

Max: $u=kz^d$ (utility function)

s.t. $x^s=l_x=1$ (production function)

$z_2^d=p_x x^s$ (budget constraint)

Solve the problem, we have:

$$u_{(z/x)=}\ kz^{d} = kp_{x}$$

In accordance with the requirements of utility equalization, equilibrium price and utility are:

$$p_{y} = \left(\frac{1}{2}\right)^{\frac{1}{2}} k^{-\frac{1}{4}}$$

$$p_{x}=\left(\frac{1}{2}\right)^{\frac{3}{2}} k^{\frac{1}{4}}$$

$$u_{D}=kp_{x}=\left(\frac{1}{2}\right)^{\frac{3}{2}} k^{\frac{5}{4}}$$

Compared with structure A, we have

When $k \geq k_{0} \equiv \frac{1}{2}$, $u_{D} \geq u_{A}$, the following conclusion is drawn:

Proposition3: When transaction efficiency is high enough, the production chain of low carbon energy and related industries will occur in the marketplace to replace the traditional high carbon energy with CO_2 , emissions.

Based on Proposition 1,2 and 3, we make the following statement:

In the absence of the uniform emissions reduction policy at the national level, no single agent would take voluntary emission reduction action. If the government takes measures to reduce emissions, sets the price of the carbon emissions and subsidizes the low carbon technology, some will turn to the low carbon technology, which will create a scenario where high carbon and low carbon technologies coexist. With the market expansion and transaction efficiency improvement through institutional reforms, a more efficient low carbon division of labour will substitute the high carbon division of labour. The economies that take tough emission reduction measures and establish the sound system will be the forerunners to transform to the more competitive low carbon economy.

IV. Discussions

1. Emission Reduction Cost and Returns: partial equilibrium v.s. general equilibrium

Most analyses on emission reduction policy focus on benefit/cost of emission reduction in a given economic structure (for instance, Nordhaus,1993; Stern, 2007). The above model shows that the general equilibrium in the neoclassical marginal analysis is in a given division of labour structure and remains a “partial equilibrium analysis” in the framework of inframarginal analysis - therefore might be misleading.

In the neoclassical marginal analysis, in a given technology and division of labour structure, emission reduction to a large extent means output reduction. The cost of global emission reduction includes two parts: (i) direct cost of reducing emission, and (ii) output reduction due to emission reduction. The benefit of emission reduction for the whole world is mainly that it will reduce the damages associated with climate change. In the framework of neoclassical marginal analysis, the optimal emission reduction level is the compromise between the benefits of emission reduction and reduction cost, i.e. marginal cost equals marginal revenue. Global emission reduction is considered a burden on each country. Global emission reduction becomes an issue of burden-sharing among all countries. If the policy on emission reduction is too strict (suppose it becomes a reality), emission reduction will not make economic sense since the emission reduction cost exceeds the benefits.

However, if emission reduction can lead to a more efficient division of labour structure with low carbon technology, the conclusion will be very different. Emission reduction will promote rather than hamper the economic growth. Firstly, in terms of cost, although emission reduction has direct cost, the cost will promote growth of low carbon economy. Emission reduction, which results in transformation from high carbon to low carbon economic structure, does not necessarily lead to output (as well as employment) reduction. Secondly, in terms of emission reduction benefits, emission reduction will not only reduce losses associated with climate change, but also bring a new more competitive and more efficient structure. In a nutshell, our model demonstrates that the benefits of emission reduction might significantly exceed that in the conclusions of neoclassical marginal analysis. Consequently, countries that take the lead in adopting strict emission reduction measures will have the first mover advantage in transforming to the more competitive low carbon economy and play a dominant role in the new international competition platform.

2.Market-oriented emission reduction mechanism and low carbon economy development

In our model, market-oriented emission reduction mechanism is the implicit requirement that emission reduction can promote economic development. Whether strict emission reduction measures can make an economy transform to the more competitive low carbon economy depends on whether emission reduction adopts market mechanism. If energy conservation and emission reduction rely too much on administrative measures, they will go against economic growth and become a burden. If a long-term market-oriented mechanism can be established, emission reduction can be a self-interested behaviour and be a strong driver to promote technological innovation and new economic growth.

Currently, the biggest problem with emission mitigation in China is lack of market-oriented long-term mechanism. The fact that emission reduction targets in the 11^{th}five-year plan are hard to reach and power cutoff occur in some localities is not because the emission targets are too high, but mainly because there were no flexible options available to reach the targets.

To establish the new market-oriented emission reduction mechanism can efficiently reach the emission reduction target and create new impetus for technological innovation and economic growth. The new impetus is reflected in two aspects: 1) regions and enterprises can flexibly choose the most efficient emission reduction approach; allocation of emission reduction resources can be optimized across the country; emission reduction therefore does not have to sacrifice economic growth; 2) the new emission reduction mechanism will promote the development of the green low carbon economy. Once the flexible implementation to achieve emission reduction targets is available, enterprises can sell emission quota surplus or reduce purchase of the quota when they reduce their emissions. Emissions reduction then becomes a self-interested behaviour for the enterprises, which will encourage them to develop new technologies for energy conservation and emission reduction. As a matter of fact, emission reduction can bring many new investment opportunities. The new green low carbon industry will become new economic growth pole. Those regions that take the lead in adopting emission reduction measures will be the first to transform to the more competitive green low carbon economy.

3.Transformation cost and late-development advantage for developing countries

In the above analysis, we simply compare the utilities of different division of labour structures to get the general equilibrium—— the most efficient corner equilibrium is the general equilibrium. There is no explicit consideration of the transformation cost from one structure to another. However, if an economy has already been (or locked) in a certain division of labour structure, and the chain of intermediate products has taken shape, the transformation from one structure to a more efficient structure will involve cost (sunk cost). Specifically, developed countries, whose fossil fuel supply capacity and traditional industrial system have been in good shape, have to eliminate the traditional capacity to develop the low carbon industrial system, while for developing countries, whose traditional industrial system has not taken shape, elimination of traditional high carbon industry is not a prominent issue. This means that the transformation cost to the green low carbon economy for developing countries is relatively lower, thus enjoying a potential late-development advantage over the developed countries.

However, the potential advantage of leapfrog transformation to the low carbon economy for developing countries is not necessarily translated into reality. Proposition 3 shows that in addition to the tougher national policy on emission reduction, an economy that intends to transform from high carbon structure to the more competitive low carbon structure depends on transaction efficiency, which is determined by a country’s institution. Eventually, the new round of global competition in green low carbon economy is the competition of institutions of different countries. Tough emission reduction policy and competitive institution are the prerequisites for a country to transform to the more competitive low carbon economy.

4.Technical issue or economic issue

It is generally believed that the biggest problem for the development of the low carbon industry is its high cost. This argument does make sense. However, it is more of an argument from the technical point of view, not an argument in the economics. For instance, car was a luxury product ten years ago in China, but with rapid market expansion, the price has significantly been reduced. The price reduction is not because of technical breakthroughs, but because the industrial chain of Chinese automotive industry has expanded, which resulted in productivity enhancement and cost reduction. The same story will happen to the new energy and related sectors. With the market expansion and development of the industrial chain, the high cost of the new energy and related products will decrease at a pace much faster than people expect. Hence, the new energy and related sectors will enjoy a price advantage compared with their traditional peers. If this expanding process is further accompanied by technological breakthroughs, the low carbon industry will grow even faster.

Currently, many new energy technologies and related industries seem too costly to be marketized. It is not the case. Their development depends on the size of the network of division of labour. It can be compared to the chicken-and-egg paradox. The high cost is due to lack of division of labour network. The absence of the division of labour network is resulting from high cost. If the government can provide stimulus and support to promote the development of the new energy and related sectors, the chicken-and-egg paradox will be resolved. A virtuous cycle will occur. This is called the increasing returns in economic growth. Once the virtuous cycle starts, economic growth will become a natural phenomenon（Young, 1928）.

5. Forerunner's risks and action

If the low carbon economy is theoretically feasible, but not has not yet become reality, it will be considered a risk and avoided, the so-called forerunner's risk. Only when the low carbon economy is proved feasible in reality, other people will follow. However, the concern over the so-called forerunner's risk is unnecessary. To promote low carbon economy does not mean the government shall play a dominant role in investment. The transformation will be completed in the competition of the decentralized market players. For instance, the US has the highest rate of bankruptcy, but it also has the strongest innovation capability. It is the forerunner's risks that keep creating new technologies and business models.

Although the low carbon model will bring dramatic changes to human development mode and way of living, this does not mean we need to introduce dramatic policies to make it happen. As illustrated in the paper, the fundamental factors for transformation from high carbon to low carbon economy are improvement of market economic system and competitiveness of the system in addition to the tough emission reduction measures. New technologies occur because the new invention can make money. This requires sound property right, patent and enterprise systems. The late-development advantages of developing countries will be brought into full play when there are 1)expectations of stable emission reduction policy, 2)inherent market stimulus mechanism, and 3)strong government support. Given that developing countries donot have sound institutions in place and are vulnerable to risks, developed countries should play a leading role in developing low carbon economy.

6.Future low carbon industrial chain

Our notion illustrates that, as a result of government policy and market competition, new final goods will continue to emerge, new intermediate products will appear, the industrial chain will keep enlarging and the old industries will withdraw. This is what Schumpeter described as creative destruction. These changes may happen separately or simultaneously. For instance, in terms of the final good, traditional gasoline internal combustion engine is replaced by motor to make electric car. In the intermediate products, the use of wind power, nuclear power and CO_2 capture and storage technologies has reduced CO_2 emissions in power generation per unit. The application of a new technology will inevitably bring about changes to the whole industrial chain. The motor industrial chain is different from that of the gasoline internal combustion engine. The industrial chain of wind power and nuclear power generation differs from that of the coal burning power generation.

This means that the continuous development and expansion of the low carbon industry will become strong drivers for economic growth. With the development of low carbon industry from an infant industry, a future low carbon industrieswill emerge, which will lead to fundamental changes to the development mode of human society and way of living. The low carbon industries include the following:

- Low-carbon energy: (i) new &renewable energy: wind, solar, hydropower, biomass, nuclear energy, ocean energy, etc.(ii) low carbon fossil fuel: shale-gas, LNG and etc; (iii) cleanization of high carbon fossil fuel.
- Upstream industries and services of low carbon energy: a variety of low-carbon energy generation equipment and services.
- Downstream industries: including renewable energy-based industries (such as electric vehicles and its industrial chain).
- De-carbonization of traditional high carbon industrie and modernization of agriculture: new technologies and business models (such as carbon asset management).
- Low-carbon urban planning, infrastructure, and transportation system
- Low-carbon consumption patterns and lifestyles: this will further expand the market of the low carbon products if the consumer are willing to pay a relatively higher price for the low carbon products.

V. Implications for global climate negotiations and resolution of climate change

The theory in this paper is of interesting implications to analyze prospect of global climate negotiations and address global climate change issues. According to our analysis, the prospect of global climate negotiations is not optimistic, but not the case for addressing global climate issues.

1. Prospect of global climate negotiations not optimistic

In accordance with the Copenhagen Accord, global warming shall be limited to 2 degrees centigradeover pre-industrial times. The target means the world can emit as little as 750Gt CO2-e（Meinshausen et al，2009）between 2010 and 2050. Based on the current global annual emission of 30 Gt CO2-e in 2008, there are 25 years to go. This means with the current technology and economic growth model, it is very hard to reach the target unless developed countries or developing countries make significant concessions to reach the global emission reduction agreement. Therefore, international climate negotiations is not likely to achieve significant progress in the foreseeable future

2.More optimistic in addressing global climate issues

Despite the gloomy prospect of international negotiations, the prospect of addressing global climate issues is quite optimistic. As our model shows, those forerunners that introduce tough emission reduction policies will be the first to achieve transformation from traditional fossil fuel-based high carbon mode to the more competitive renewable energy based low carbon green development mode and will take the lead in the future international competition. This will propel other countries to follow suit by adopting strict policies on emission reduction. Thus, the global climate change issue will be ultimately addressed.

3.Top-down vs. Bottom-up global solutions

The current negotiation adopts the top-down approach to address the issue, which first sets the global temperature control target, and then distribute the corresponding global carbon emission space allocation/or reduction tasks among countries. This approach is legitimate. However, due to lack of an efficient international governance, it encounters great difficulties in international politics (for instance, the US, whose overseas policy is influenced by its domestic politics, will not accept the deep emission reduction target). Therefore, some people have lost confidence in the top-down approach and advocated the bottom-up approach to address the issue, which requires each country to set their own target for emission reduction（for instance, Howes, 2010）.

As our model shows the forerunners will be the first to transform to the more competitive green low-carbon development model. The other countries have to follow, or they will be the losers in the international competition. The bottom-up approach will ultimately address the global climate issue. However, this does not mean the top-down approach should be abandoned in the international negotiation. Without the top-down approach to press all countries to reduce emissions, no country would voluntarily adopt strict emission reduction measures for the benefits of the world. Before the low carbon model is proved competitive and feasible, it is considered a risk. Although the paper has proved the advantages for developing countries to move towards the low carbon model, they cannot take risks to introduce tough emission reduction measures, which might sacrifice the economic growth, since their eager to get out of poverty and aversion to risks are stronger than that of the developed countries. Developed countries, without pressure from the top-down negotiations, will not voluntarily adopt strict measures either. Therefore, the bottom-up approach to address the global climate issue depends heavily on the top-down international climate negotiations. This is the dilemma of global climate change talks and global emission reduction.

VI. Conclusions

The essence of response to climate change is to break away from dependence on the traditional fossil fuels and move from the high carbon to the low carbon economy. The transformation is the most fundamental change since the Industrial Revolution in the history of human society. However, the traditional neoclassical marginal analysis can only deal with the non-topological changes such as the optimal resource allocation in a given division of labour structure and is unable to reveal the topological changes in division of labour resulting from emission reduction. In the perspective of marginal analysis, greenhouse gas emission reduction will have a negative impact on the economic development. This conclusion is misleading in terms of theory and policy.

By employing an inframarginal general equilibrium model of industrialization, this paper illustrate that emission reduction can be a driver for economic development. Those countries that take a lead in introducing strict emission reduction measures and sound market mechanism will be the first to transform from high carbon development to the green low carbon development which is based on renewable energies and enjoys more competitiveness, and become leaders in the international competition. This will force other countries to follow their steps by introducing tougher measures to reduce emissions to increase competitiveness and finally resolve the global climate change. In the transformation to low carbon economy, developing countries bear a relatively lower transition cost and enjoy more advantages over the developed countries. It is possible for the developing countries to have a leapfrog transformation into the more competitive green low carbon economy.

However, the potential advantage of leapfrogging to the low carbon economy for developing countries is not necessarily translated into reality. Our study shows that in addition to the tough national policy on emission reduction, an economy that intends to transform from high carbon structure to the more competitive low carbon structure depends on transaction efficiency, which is determined by their institutions. Eventually, the new round of global competition in low carbon economy is the competition of institutions. Tough emission reduction policy and competitive institution together are the prerequisites for a country to transform to the more competitive low carbon economy.

In words, if dealt properly, climate crisis could be turned into an important historic opportunity for development, economic restructuring and transformation to low carbon model. When some politicians are arguing to shirk their responsibilities for emission reduction, the visionary politicians and entrepreneurs have recognized the huge historic opportunities in emission reduction and started to take action.

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