Climate Change and Green Growth: A Perspective of the Division of Labor

*Yongsheng Zhang**

Abstract

This paper presents a new research agenda on climate change and green growth from the perspective of the division of labor in classical economics. The paper covers three major dimensions of green growth (i.e. carbon emissions, environmental protection and material resources use) and some related important topics, as well as the fresh policy implications of the new research agenda, Typical marginal analysis in a given structure of the division of labor suggests that "green" action is a burden to economic development. Therefore, climate negotiation has become a burden-sharing game and has reached a stalemate. New thinking is badly needed to rescue these negotiations and to drive a shift to a new "green growth" paradigm. The proposed new research agenda represents an effort to create a new narrative on climate change and green growth. Because the new research agenda can theoretically predict the possibility that a more competitive structure of the division of labor could be triggered by "green" policy, it has promising policy implications for various important challenges facing us in the 21st century.

Key words: climate change, division of labor, green growth, specialization
JEL codes: B52, O13, Q54, Q58

I. Introduction

Since the Industrial Revolution 200 years ago, the relationship between man and nature has entered an era of *Anthropocene*, in which human activities have started to play a dominant role in the evolution of nature. The development paradigm established since the Industrial

*Yongsheng Zhang, Senior Research Fellow, Development Research Center of the State Council of China, Beijing, China. Email: zys@drc.gov.cn. The author is grateful to his co-authors of the joint papers cited in this paper and to the colleagues at the Development Research Center of the State Council of China working on the new research line on climate change and green growth. Invaluable comments and suggestions from a referee, and R. Garnaut, C. Jaeger, Y. K. Ng, J. Sachs, L. G. Song, Van Der Leeuw, S. J. Liu, H. L. Shi, S. T. Yao and D. S. Zhang are deeply appreciated.

Revolution has been based on high carbon emissions, high environmental depletion and high material resource use. Although it has brought unprecedented material affluence to around 40 percent of the world's population, primarily represented by the industrialized and emerging economies, the development paradigm has, unfortunately, caused serious environmental crises. Because the human activities undertaken under this paradigm are driving the Earth system beyond its safe operating space, it cannot bring globally-shared prosperity to the whole population of the planet (see Rockstroem *et al.*, 2009). Furthermore, given the global limits on emissions, resources and environmental services, the continuation of the paradigm will inevitably trigger conflicts between poor and rich countries, especially as nine billion people, mostly in developing countries by 2050, pursue Westernized living, characterized by overconsumption.

To avoid catastrophic consequences and to enable globally-shared prosperity to emerge, the only solution is to shift from the old development paradigm to a green growth paradigm. Although to date no standard definition of green growth has emerged (Huberty *et al.*, 2011), green growth can be considered to comprise three dimensions: low carbon emissions, a low environmental footprint and low material resource use (World Bank/ DRC, 2012). The forthcoming United Nations Sustainable Development Goals (SDG) that will supercede the Millennium Development Goals (MDG) in 2015 precisely reflect the situation. Different from MDG that focus on developing countries, the SDG emphasize the urgency for all countries, including both developed and developing countries, to shift to a sustainable development paradigm (Sachs, 2013).

Nonetheless, conventional studies on climate change and green growth are incapable of providing sufficient theoretical support for solving the current crises and transitioning to green growth. Take climate change as an example. Because most of the existing studies are conducted in a typical marginal analysis framework dealing with resource allocation within a given structure of division of labor, the most exciting story in fighting climate change, that is, that carbon mitigation might trigger organizational changes and drive the local economy to a more competitive division of labor, is missing. Consequently, the tremendous local benefit from mitigation cannot be fully predicted by theory, and the global mitigation negotiations have become a zero-sum game of burden-sharing, sharing the insufficient global carbon space. Without a global transition to green growth, it is unlikely that the world will reach any substantial international agreement on climate change.

Recognizing the inadequacy of conventional analysis, efforts have been made in various ways to show that a shift to green growth could be of self-interest for local economies. For instance, the World Bank (2006), the UNEP (2011) and Hallegatte *et al.* (2012) apply the

natural wealth approach based on Solow's model, Acemoglu *et al*. (2012) the endogenous innovation growth model and Garbaccio *et al*. (2000) the carbon mitigation co-benefits approach.[1] Some very insightful ideas have been presented on green growth, for example, by Garnaut (2011), but have not been formalized in a rigorous manner.

The purpose of this paper is to present a new, alternative research agenda on climate change and green growth from the perspective of the division of labor and specialization, as represented by Smith (1776), Young (1928), Coase (1937), Yang and Ng (1993) and Yang (2001). In addition to the problem of resource allocation that marginal analysis centers on, this agenda focuses on the structural changes in the division of labor that environmental action could trigger, and provides a new theoretical perspective with fresh policy implications. It represents an effort to create a new narrative on climate change and green growth.

The research agenda covers three dimensions of green growth (i.e. carbon emissions, environmental protection and resources use), and a number of relevant important topics. The rest of the paper is organized as follows. Section II, discussing the limitations of the conventional studies on climate change and green growth, shows why a new analytical approach involving the division of labor is necessary. Section III concentrates on climate change and carbon emissions, investigating how carbon emissions reduction could possibly lead to a more competitive economic structure, as well as the associated policy implications. Section IV investigates how strict environmental action could drive the economy from a "lose–lose" division of labor structure to a "win–win" structure. Section V investigates how a paradigm shift towards green growth could substantially reduce material resource use. Section VI explains how green growth could accelerate economic development in poor regions, and investigates the emerging business opportunities in green growth. Section VII concludes.

II. Climate Change and Green Growth: Why a New Analytical Approach Is Needed

1. Limitations of Conventional Marginal Analysis

In typical marginal analyses of climate change, the optimal global emissions reduction is to achieve a balance between the costs and benefits of global emission reduction (e.g.

[1]A comprehensive literature review on different research lines of green growth theories, as well as their theoretical origins and their limitations, can be found in Zhang (2014a).

Nordhaus, 1993; Stern, 2007). The benefit of fighting climate change, or of emission reduction, is defined as the climate change damage that is avoided. This is a problematic definition because it excludes the possibility that mitigation might drive the economy into a more competitive structure with a utility level even higher than in a utility without climate change scenario (see details in Zhang and Shi, 2014).

Because the damage to be avoided by current mitigation is primarily in the future, time discount rates are central to the debate. This is seen, for instance, in the "Stern Review" (2007) itself and in the responses to it. Most of the critiques (some are, indeed, severe) of the "Stern Review" and Nordhaus (2007) are heavily concentrated on the value of the discount rate. For instance, according to Pindyck (2013, p. 860): "These models have crucial flaws that make them close to useless as tools for policy analysis: certain inputs (e.g., the discount rate) are arbitrary, but have huge effects on the social cost of carbon estimates the models produce; the models' descriptions of the impact of climate change are completely ad hoc, with no theoretical or empirical foundation."

From the perspective of the division of labor, although the value of the discount rate is a problem, the limitation of the analytical framework is a more substantial problem, because the most substantial story – that fighting climate change could possibly drive the economy to a more competitive structure – is missing. Consequently, mitigation has become an action that is undertaken to avoid damage or implement burden-sharing, rather than to explore new opportunities. The utility with mitigation, no matter how decisive the action to be taken is, could never be greater than the assumed "utility without the damage of climate change."

The conventional analysis is, to some extent, also misleading in regards to policy. Because the benefits of emission cuts it predicts are primarily globally-shared, while the cost is local, all countries have strong incentives to be free-riders, leading to a large global mitigation coordination problem. Because the global emission space to meet the 2°C target is far from sufficient for the emissions needed in a business-as-usual (BAU) scenario of economic development, it is impossible to reach agreement on how to share the global emission space, unless either the developed or developing countries accept significant retreat.

Therefore, the issue of climate change and green growth is not just a story about how resources shall be reallocated in a given structure of the division of labor, but more about how the structure of the division of labor could change. Otherwise, the most substantial and exciting stories will be missing and the policy suggestions are likely to be misleading. Yet the analytical framework of neoclassical economics is not capable enough of tackling

the structural problem. We need a new analytical framework, and inframarginal analysis provides such a framework (Yang, 2001).

2. Resurgence of the Idea of Division of Labor in a Modern Body

According to Yang (2003), classical economics, represented by William Petty, Anne-Robert-Jacques Turgot and Adam Smith, focuses on the implications of the division of labor for economic development. To some extent, the core of mainstream economics is, in fact, development economics, whose central ideas were developed in Smith's (1776) theorem: the division of labor is the spring of economic growth, and the division of labor is limited by the extent of the market, while the market extent is dependent on transport. In his famous text book the *Principles of Economics*, Marshall (1898, Vol. IV, ch. 8–12) was full of insight into the implications of the division of labor for economic development. Unfortunately, he was not able to formalize his thoughts about the division of labor in a mathematic framework because the mathematical tools for dealing with the division of labor were not available until the 1950s. Therefore, marginal analysis of resource allocation within a given structure of the division of labor became mainstream economics, and, consequently, the role of the structure of the division of labor has been marginalized or is absent in mainstream economics (Stigler, 1976; Yang, 2001).

As Young (1928) further points out, not only the division of labor is limited by market size, but the latter also depends on the division of labor. It is a question of mutual reinforcement between the increase in the division of labor and the expansion of the size of the market, in which economic progress becomes a "natural" phenomenon. This idea is referred to as the Smith–Young theorem (Yang, 2001).

How is the division of labor organized? Through the market or through firms? The firm was a "black box" in neoclassical economics until Coase (1937), in his path-breaking work, employed transaction costs to explore the nature of the firm, and, thus, opened a new door for economic analysis. Applying modern analytical tools, Xiaokai Yang developed a unified new classical economics (NCE) framework to integrate Coase's idea of transaction costs into Smith and Young's insights about the division of labor and specialization (see Yang and Ng, 1993; Yang, 2001).[2] Since that form of analysis is beyond marginal analysis,

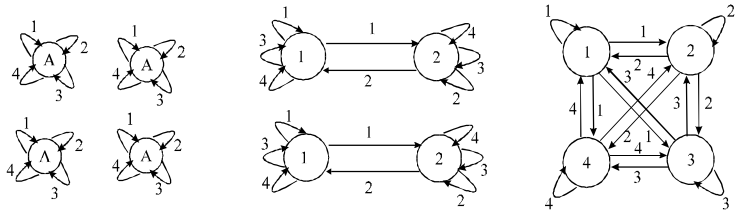
[2]Yang's original contribution to economics is highly recognized by other economists. For instance, in 2002 and 2003, the 1985 Noble laureate James Buchanan nominated Yang for a Nobel Prize. He described Yang's work as among the best economics research in the world. Yang's views can be seen in his advanced text: Yang (2001, in English) and Yang and Ng (1993); a popular edition in Chinese is Yang and Zhang (2000).

technically, the new approach is referred to as *inframarginal analysis*. Therefore, the basic idea of NCE is rooted in classical economics, but its body of work is younger than the neoclassical framework.

In the new framework, there is a trade-off between economies of specialization or division of labor and transaction costs. Due to the increasing returns of specialization, a higher level of specialization and division of labor means increased productivity. Nonetheless, any increase in division of labor incurs more trade and transaction costs. Therefore, transaction efficiency plays an essential role in the trade-off and has implications for the general equilibrium. Figure 1 illustrates how the structure of the division of labor changes with transaction efficiency. There are three different structures of the division of labor: (i) autarky; (ii) incomplete division of labor; and (iii) complete division of labor. When transaction efficiency is sufficiently low, autarky is general equilibrium since the transaction costs of division of labor is greater than the benefits of the division of labor. As transaction efficiency increases to a critical level, an incomplete division of labor becomes general equilibrium, and so forth. Inframarginal analysis does not only comprise a marginal cost–benefit analysis of each kind of structure, but also includes a total cost–benefit analysis to compare the utilities of different division of labor structures. The structure with the highest utility is general equilibrium. Therefore, in the NCE perspective, neoclassical marginal analysis only deals with one special case among all possible structures of the division of labor. In other words, the general equilibrium in the neoclassical economic framework is only a partial equilibrium in the NCE.

Transaction cost, or transaction efficiency, plays an essential role in balancing the trade-off. How then is transaction efficiency improved? There are two types of transaction costs: exogenous and endogenous transaction costs. There are various ways to exogenously improve transaction efficiency, or decrease unit transaction cost (e.g. transport, urbanization and information and communication technology, or {ICT}). Urbanization, in particular, can dramatically increase transaction efficiency through the physical

Figure 1. Evolution of the Division of Labor with Changing Transaction Efficiency



Source: Yang (2001).

concentration of population, and, therefore, increase the division of labor. However, there are also various ways to enhance endogenous transaction efficiency through institutional improvement. For instance, the strict protection of property rights, including intellectual property rights, efficient patent protection, the firm as an institution, free trade policy, the legal system, political stability and certainty of government policy, are all essential for improving transaction efficiency. Some smart business models can also effectively decrease transaction costs. Generally, a functioning market will facilitate transaction.

If a government adopts strict environmental policies, then that has the effect of reducing the coordination costs (transaction cost) across the whole society, and of expanding market size for green products and services. According to Smith–Young–Coase–Yang's idea, such an improvement in transaction efficiency will increase the division of labor, as market expansion and the evolution of the division of labor mutually reinforce each other, pushing towards a situation in which "economic growth becomes a natural phenomena," as Young (1928) points out.

Therefore, coherent climate and environment policy and action will have a big impact on the evolution of the division of labor and on economic development. Since 2010, this perspective on the division of labor has been applied in the field of climate change and green growth by an international research team based at the Development Research Center of the State Council of China and a new research agenda on climate change and green growth has been opened up. Since the inframarginal approach is more powerful in explaining the structural changes of division of labor that may result from fighting climate change, it has more interesting theoretical predictions than marginal analysis, and, therefore, can provide fresh policy impetus for addressing the challenge of climate change and promoting green growth.

III. Climate Change and Economic Development: New Perspective and Implications for Climate Negotiations

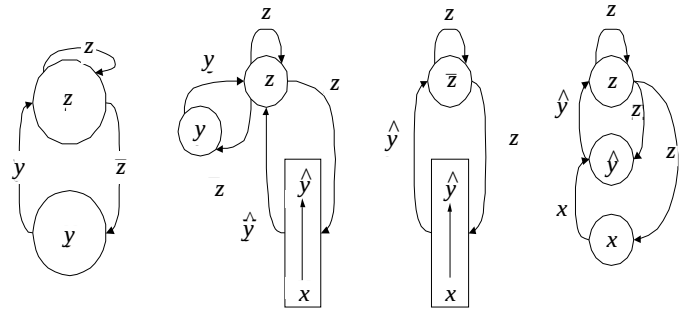
1. How Could the Reduction in Carbon Emissions Promote Economic Development?

In the above framework on the division of labor and transaction costs, Shi and Zhang (2012) develop a theoretical model to show how emission reduction could possibly result in a more productive division of labor, and how stringent emission reduction action could actually be good for economic development.

The argument is about how emission reduction could drive such structural changes. Suppose there are *M* identical economic agents who are both producers and consumers. There is one consumer good, *z*. The utility of each agent is determined by his or her actual consumption of *z*. To produce *z*, energy and labor are required. Energy in this case can be generated by a traditional high carbon technology, *y* (e.g. coal fired power plants), or by a low carbon technology, $\hat{y}$ (e.g. wind power). The difference is that the high carbon technology *y* produces CO_2, while the low carbon technology $\hat{y}$ does not. Labor, *l*, is needed to produce *y*. To produce $\hat{y}$, we may use labor, or both labor and specialized equipment, *x*. Each economic agent may choose autarky or specialize in one product. There will then be many possible options for the division of labor. According to Wen's theorem (see Yang, 2001) based on the Kuhn–Tucker theorem, those options that cannot be optimal are excluded. We only need to consider four structures of the division of labor (see Figure 2). Structure 2.1 is a high carbon structure based on fossil fuel. Structure 2.3 is based on new energy that is produced in an incomplete division of labor. Structure 2.2 is a combination of structures 2.1 and 2.3. Structure 2.4 is entirely low carbon, based on new energy that is produced with complete division of labor.

The role of the government is crucial in the evolution of the division of labor. If the government sets a carbon emission cap (or institutes carbon pricing) and takes strict emission mitigation measures (e.g. regulation), the external emission costs would be largely internalized and become expensive. These factors will drive the cost of traditional fossil fuels up and lower their price competitive edge against new energy. If the government further provides considerable support to new energy, such as regulation of emission standards or subsidies to the new energy sector in its early stage of development, that will help to shape the initial market for new energy and a price competitive edge for new energy

Figure 2. How Carbon Emission Reduction Promote Economic Development



Source: Shi and Zhang (2012).

will emerge.

Once the low carbon process is set in motion, it will become a self-fulfilling process and the division of labor will continue to evolve towards a complete division of labor (Structure 2.4), in which the productivity of $\hat{y}$ is significantly increased due to the enlarged production chain, because market expansion and the increase in the division of labor are mutually reinforcing, as the Smith–Young theorem suggests. The cost of new energy will come down and new energy will become more competitive than fossil fuel (Shi and Zhang, 2012).

A comparison among the utilities of different structures in different variable spaces provides the following results. Without strict emission reduction policies in place, structure 2.1 has the highest utility and is the equilibrium. With a strong emission reduction policy in place, the equilibrium will move towards structure 2.2. As the policy becomes stronger, the equilibrium will shift towards structure 2.3. As the market evolves, a low carbon structure, structure 2.4, with a complete division of labor, will eventually emerge (Shi and Zhang, 2012).

An implication of this research that is substantially different from the conventional analysis is that although the motivation to fight climate change is to avoid the damage of climate change, the benefit of fighting climate change might be much greater than the damage to be avoided. Hence, even if climate change is not caused by human behavior, as is argued by the climate skeptics, fighting climate change is worthwhile because it would lead to higher utility and better quality of life.

2.From Burden-sharing to Opportunity-sharing: New Policy Implications for Climate Negotiations

The Smith–Coase approach predicts discontinuous jumps between economic structures with different utility levels, whereas in traditional marginal analysis the benefits of mitigation are merely a result of a trade-off between climate change damage that is avoided and the cost of doing so within a given structure of the division of labor. Therefore, the new approach has novel policy implications (Zhang and Shi, 2014).

First, because a reduction in carbon emissions could possibly drive the economy towards a structure with an even higher utility, the local benefit of a reduction in carbon emissions might be substantially higher than is suggested by conventional analysis. Emissions reduction would no longer just be a burden, but possibly become an opportunity for economic development. Second, the typical global coordination problem could then also be largely solved. In the new (inframarginal) perspective, because the predicted local cost of emission reduction is much less, while its benefits are substantially higher (in

general, but in particular also locally), the incentive for free-riding is reduced, and global coordination failures can be avoided, when the "new" local benefits dominate local costs. Third, because mitigation could be a new source of growth, developed and developing countries could develop collaborative rather than conflicting relations in exploring the opportunities of green growth, which is the ultimate solution to climate change.

To unlock the stalemate, global climate change negotiations should be shifted from burden-sharing to opportunity-sharing. To achieve this, green growth should be placed at the heart of the post-2020 global climate change regime (Jaeger *et al.*, 2012; Zhang and Shi, 2014).

However, because the jump between different structures is like jumping from a vicious circle to a virtuous one, a "chicken and egg" dilemma needs to be overcome. On the one hand, some people argue that because there is no sufficient evidence for the success of green growth, risk-averse governments and businesses should not take bold action. On the other, the success of green growth is dependent on strong governmental mitigation policies and actions. In its early stages, green growth will still largely exist as a vision, without becoming a commonly-experienced reality. For that reason, governments might be reluctant to take firm action on emission reductions. In turn, without strong action, evidence on the benefits of green growth will be slow to accumulate (Zhang and Shi, 2014).

Hence, the key to breaking this vicious circle is to introduce a risk-aversion and incentive-provision mechanism into the global climate change regime, so that the risk-averse individual countries are willing to take serious mitigation action, and green growth can be realized. In other words, for governments to take serious action, those actions should at least be no-regrets actions.

Because green growth is a self-fulfilling process, the key to breaking the dilemma is to encourage early action. In practice, a new two-track architecture consisting of low legally-binding targets and high voluntary targets might be an effective option. A relatively lower legally-binding target based on principles of "common but differentiated responsibilities" could form a more politically realistic and inclusive basis for participation. A green growth club formed by major emission countries could promote higher voluntary global ambition and accelerate mitigation.[3]

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[3]This idea is further developed based on the Carbon Budget Account Proposal (DRC, 2009) and the country chapter in the report of the BASIC Expert Group (2011), where emission reduction was still traditionally seen as a burden and the basic question was more about how to clearly define the share of each country in the global carbon space.

3. How Unilateral Emission Reduction Actions Could Lead to Multilateral Actions

The situation of climate policy today is very similar to the situation of trade policy 200 years ago, when countries viewed unilateral free trade as harmful to their economies, and the appropriate trade policy in the national interest was believed to be the imposition of tariffs on imported goods. However, when the UK took the first step to unilaterally adopt a free trade policy, its economy greatly benefited. Due to competition and the effect of this demonstration, other countries followed suit to improve their competitiveness. A free trade rationale became widely accepted, and free trade policy gradually spread worldwide (Yang and Zhang, 2001). Of course, the history of trade is complex and has often been charactized by conflict and even violence (O'Rourke, 2000).

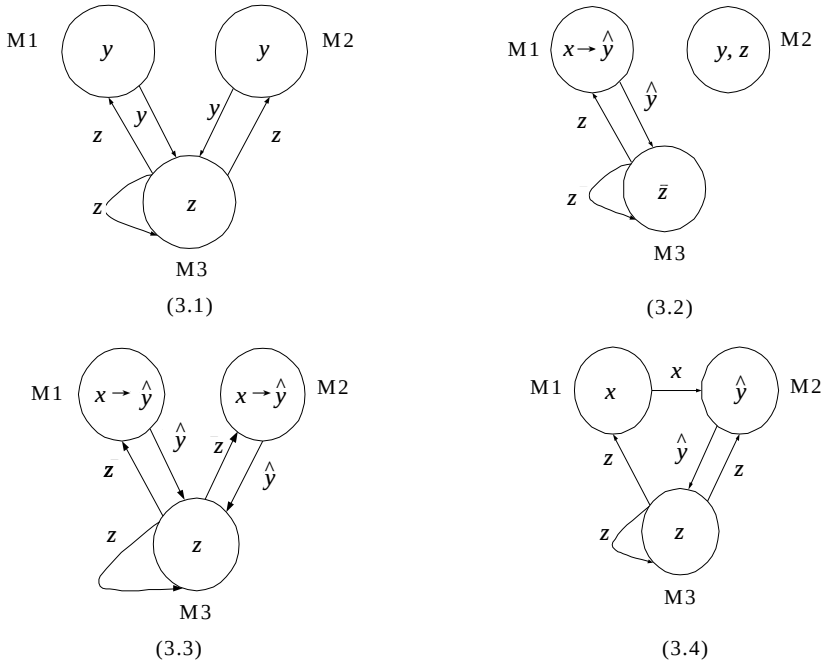
At present, emission reduction is seen by most countries as against their national interest. The history of trade and our research suggest that this might be a strategic misjudgment of their national interest. In contrast, unilateral emission reductions might be the best policy to serve their national interests. If the reduction in carbon emissions could result in an economy having a more competitive structure of its division of labor, then through international competition, unilateral emission reduction actions could lead to multilateral action, repeating the story of trade.

Consider three countries (i.e. countries 1, 2 and 3) in a global economy, represented by *M1*, *M2* and *M3*, respectively. At first, both countries 1 and 2 specialize in producing high carbon intermediate goods, *y* (*y* can seen as traditional fossil energy), while country 3 imports *y* from country 1 and 2, and uses **y** to produce final good *z*. Countries 1 and 2 sell *y* to country 3 and buy *z* from it. This is a global division of labor among the three countries. We will now show how country 1's first move to low carbon will lead to global low carbon (see Figure 3).

In structure 3.1, all three countries are in a high carbon economy. For simplicity, we assume that only countries 1 and 2 emit carbon, while country 3 only has embodied emissions because it imports *y* and uses *y* to produce *z*. Assume further that the leaders in country 1 see the potential high productivity from shifting to new energy and take the first move to use *x* to produce new energy, $\hat{y}$, while country 2 is not able to envisage the potential high productivity.[4] As shown in Shi and Zhang (2012), country 1, with a higher level of division of labor, will have higher productively. Consequently, country 3 only trades with the more competitive country 1 that has cheaper $\hat{y}$, while country 2 is excluded from trade and has

[4]Note that the mechanism by which this move could possibly drive its economy to a more competitively structure is investigated in Shi and Zhang (2012), and, therefore, in Figure 3.2, for simplicity, the roundabout production chain that produces $\hat{y}$ in a structure of complete division of labor is omitted.

Figure 3. How Unilateral Emissions Reduction Leads to Multilateral Action



Source: Zhang *et al.* (2014).

to retreat to a situation of providing both *y* and *z* for itself, in which its productivity is even lower than in structure 3.1 (see structure 3.2 in Figure 3). In this case, country 2 has to follow country 1 to adopt a low carbon economy, and a new division of labor in global trade is formed, in which both countries 1 and 2 use *x* to produce $\hat{y}$ and trade with country 3 (see structure 3.3). Structure 3.4 represents a complete division of labor, in which country 1 is specialized in producing *x*, country 2 is specialized in producing $\hat{y}$, while country 3 imports $\hat{y}$ to produce *z* for all three countries. Eventually, triggered by country 1's first move, all countries' emissions are reduced and productivity is increased. A global low carbon paradigm is shaped. This story has been formalized, with a general equilibrium model, by Zhang *et al.* (2014).

IV. How Could Environmental Protection Promote Economic Development?

1. Three Viewpoints on Environment and Economy

Environment is one of the three dimensions defining green growth. There are three

explanations for the relationship between environmental protection and economic growth. The first is the typical viewpoint that environmental protection conflicts with economic growth, represented by the so-called Kuznets environment curve (1955). It suggests that economic growth can only be achieved by sacrificing the environment, and that the environment can only be cleaned up as the economy develops to an advanced stage. For a long time "grow first or pollute first, clean up later" has widely been accepted as the law of economic development. The second is that economic growth can be achieved without sacrificing the valuable environment (see UNCHE, 1972). The third viewpoint goes further, arguing that environmental protection can actually promote economic development (World Bank, 2006; UNEP, 2011).

A typical approach for the argument that environmental protection can actually promote economic development is represented by the World Bank (2006) and UNEP (2011). The UNEP approach is based on the World Bank's work, a so-called new measure of wealth that treats nature as a form of capital. It introduces natural capital into the Solow growth model, so that natural capital works with human capital, physical capital and technology in growth. Therefore, the change in the stock of renewable and non-renewable natural capital, and the substitution elasticities between natural capital, physic capital and labor have implications for growth. As the stock of natural capital changes, it is likely that the net savings for growth are also changing.[5]

Therefore, not surprisingly, this type of model is able to predict that growth in a green scenario may be higher than that in a BAU scenario, because in the BAU scenario natural capital is depleted and net savings decrease (it is likely to reduce input in production in the BAU scenario), but not because it can model an extra "new green economy" based on a new structure of the division of labor driven by environmental protection.

2. From "Lose–lose" to "Win–win" Structure

The approach based on Smith's idea about the division of labor is substantially different from the approach based on the Solow model.[6] In the former, we analyze how environmental protection could drive the economy to a more competitive structure of the division of labor.

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[5]Quotation from UNEP (2011). The dependence of economic production on the dtraditional' inputs of labor and physical capital, as well as stocks of natural capital in form of resources, such as energy, forest land, soil, fish and water. Growth is thus driven by the accumulation of capital----whether physical, human or natural----through investment, also taking into account depreciation of depletion of capital stocks.

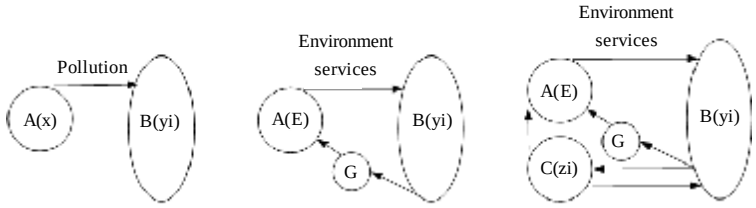
[6]More details about the difference in various theories of green growth, including the theoretic origins, strength and weakness and policy implications, can be found in Zhang (2014a).

Here we start with a familiar conventional scenario where there are externalities within a given structure of division of labor. We assume that agent A is a polluter who does not need to pay for the cost of his or her external pollution. Agent A earns 1 million dollars. We further assume that the cost for agent A to prevent pollution is $200 000. The number of agents B is *M*, and each suffers damage of $1000 because of the pollution by agent A. The total social cost is thus 1000 * *M*. As *M* > 200, the net welfare of the society will improve if its government imposes strict regulations that require agent A to stop pollution.

Because pollution is non-rival, the damage from the same pollution will increase with the population of agents B. Similarly, the benefit of cleaning up the pollution will increase with the population of agents B. Therefore, as long as the net benefit is positive, there is room for Pareto improvement, and strict environmental policy will be good for economic development. Due to the non-rival nature of pollution, this is particularly the case in populous areas. The non-rival nature of environmental cleaning-up is crucial for green growth, because it implies increasing returns from environmental actions.

Nonetheless, the second part of the story is the most exciting. In Figure 4, we further assume that the agents A are farmers providing environmental/ecosystem services in the upstream area, and agents B are specialized in making various products y_i in the downstream area. As shown in Structure 4.1, unlike the production of toys that can easily be traded in a market, the direct trade of environment/ecosystem services with beneficiaries B is not feasible, due to the extremely high transaction cost of precisely identifying the beneficiaries involved and clearly defining their benefits.[7] In this case, the upstream farmers A have a strong incentive to develop high pollution industries or practice deforestation to gain short-term revenue. The pollution of agent A will inevitably affect agent B with a production function $y_i = Af(l)$, where *A* is a coefficient of environmental effect. The value of *A* is $0 < A$

Figure 4. From "Lose–Lose" Structure Jump to "Win–Win" Structure



(4.1) Lose–lose structure

(4.2) Win–win structure with incomplete division of labor

(4.3) Win–win structure with complete division of labor

[7]Because it involves structural changes in division of labor, the idea goes beyond the theories of externalities by Pigou (1920), Coase (1960) and Cheung (1970).

< 1 with pollution, and $A > 1$ with ecosystem services. A "lose–lose" structure between the upstream and downstream areas is then developed (see Structure 4.1).

As shown in Sturcture 4.2, when the government steps in to *roughly* identify and charge the beneficiaries B in the downstream area, and to pay the farmers who are specialized in providing ecosystem services in the upstream area, the transaction efficiency of ecosystem services greatly increases. Because the output of agents B will increase with ecosystem services provided by agents A: $y_i = Af(l)$, where $A > 1$ with ecosystem services, agents B can then share some of their increase in production with A. Both A and B will be better off. Therefore, a lose–lose structure becomes a win–win structure of the division of labor.

In Structure 4.3, in addition to the payment for ecosystem services in the upstream areas,with the increase of transaction efficiency, a variety of businesses, z_i, based on a well-conserved ecosystem and environment can be developed, such as organic agriculture, health industries, recreation, training, sports and tourism. Therefore, once the win–win structure is established, a virtuous circle will accelerate, in which "green" can be turned into "gold." The above story has been formalized by Zhang and Yao employing a model with division of labor.

V. How Resource Use Decreases in the Green Growth Paradigm

1. What Drives High Resource Consumption?

Resource use is the third dimension of green growth. One characteristic of the old development paradigm, established since the Industrial Revolution, is high level use of material resources. This has not only caused tension between people and resources, but most environmental depletion and carbon emission is also related to high levels of material resource use.

Without doubt, consumption of material goods is absolutely necessary for human subsistence and wellbeing. Nonetheless, the overconsumption of material goods in the developed world does not necessarily improve human wellbeing as many believe. According to studies on happiness (see the survey in Ng, 2003), people's level of happiness increases with income level, but only slightly. There is evidence that the more materialistically inclined are less happy. At least, after a certain minimum level, higher incomes do not really make the individual significantly happier.

If that is the case, then how can human society evolve to the existing path of overconsumption? As Smith (1759) points out, people have the illusion that acquiring wealth, possessions and status will make them permanently happy. The productivity of the market economy is driven by this "deception": the misguided belief that wealth brings

happiness. Smith (1759, pp. 263–4) notes that: "it is this deception which rouses and keeps in continual motion the industry of mankind … which have entirely changed the whole face of the globe." A large portion of material consumption is actually commercially created purely for profit, through marketing and advertising, rather than reflecting mankind's genuine need. As Ng (2003) indicates, worse than just creating a consumption bias, a lot of advertising actively creates unhappiness, as a top executive of a large merchandise admits, "it is our job to make women unhappy with what they have," as quoted in Walsh (1990, p. 5).

Therefore, since the Industrial Revolution, human economic development could have taken a path that is very different from the existing material-based one. Above a certain threshold, a substantially different structure of the division of labor from the existing structure, with less consumption of material goods and more consumption of nonmaterial services, would not decrease wellbeing, utility or GDP. Moving from this material path to a more dematerialized structure represents a comprehensive and profound inframarginal structure change in the division of labor. Therefore, the inframarginal approach is particularly helpful in analyzing the paradigm shift of human development.

2. Implications of Dematerialization for Green Growth

In green growth with low resource use, utility, productivity and environmental quality could be improved simulanously.

First, in terms of consumer utility, material goods and non-material services, to a large extent, are substitutive above a certain threshold. For instance, after their basic needs are met, people could choose between two pathways with the same utility level but very different implications for the environment: for instance, bigger houses and cars, or more online entertainment and virtual experiences.

Second, non-rival services can significantly improve productivity, especially if incorporated into manufacturing. Non-rival services are a source of increasing returns, because they can be provided with (almost) zero marginal cost. For instance, a software product can be repeatedly used with almost zero marginal cost. In particular, by taking advantage of ICT, productivity can be dramatically increased. An example is massive online open courses, which can make quality education accessible to people in every corner of the world with zero marginal cost. Through ICT, high quality services for medical care and production, for example, can also be provided online.

Third, a green growth paradigm that is based more on weightless "environment, knowledge, online services and ICT" will overcome the traditional resource constraints, and make globally-shared prosperity possible. In the new development paradigm, the concept of "resources for economic growth" will be changed substantially and some

resources that would not be seen as resources in a material resources-based development model would become valuable in the green growth approach. Inexhaustible resources like human capital, big data creativity, cultural identity, environment and renewable energy will become a vital source of green growth. An example is the 798 Art Zone in Beijing, where abandoned factory buildings now host a thriving artistic community.

VI. Green Growth, Poverty Reduction and Business Opportunities

1. How Green Growth Could Become a Lever for Poverty Reduction

Because the growth paradigm of "pollute first and clean-up later" is no longer feasible, a new green growth paradigm must be established in both developed and developing economies. This means that poor regions have to follow a green growth pathway. Therefore, we must address the question of how green growth can help the development of poor regions.

Existing studies have painted a mixed picture on this issue (see UNEP, 2011; Dercon, 2012; King 2013). For the research that suggests that green growth is a way to eradicate poverty, the narrative goes like this. Poor regions, and the majority of their population, depend directly on natural resources. Their livelihoods are intricately linked with exploiting fragile environments and ecosystems (Barbier, 2005). Therefore, a transition to a green economy can contribute to the eradication of poverty. A number of sectors with green economy potential are particularly important for the poor, such as agriculture, forestry, fishery and water management. Investing in greening these sectors, including through scaling up microfinance, is likely to benefit the poor in terms of not only jobs, but also secure livelihoods that are predominantly based on ecosystem services (UNEP, 2011).

Nonetheless, this is far from enough. If the implication of green growth for poverty eradication is limited to this, then green growth can, at most, lift some poor out of absolute poverty, but cannot bring them prosperity. The implication of green growth for poverty reduction must be more widely investigated in the context of the paradigm shift that we propose.

For poor regions, two emerging historic advantages make it possible for them to take a different green growth path. First, as the industrial countries and emerging economies grew, there was no such concept as "green growth" and the current pattern with high pollution, high carbon emissions and high resource use was the only option available. However, the regions that are currently poor now have the knowledge to avoid the environmentally costly old path. Second, due to their underdevelopment, their ecosystems in general have been better conserved, and vital ecological resources can now be turned

into gold. In particular, by taking advantage of ICT, big data, online shopping, high speed railways and advanced logistic systems, poor regions can be directly connected with the advanced outside market (Adeya, 2001; Sharma and Sturges, 2007; Ofwona *et al*., 2014).

In other words, due to historic progress, some poor regions with vital ecological assets now possess high transaction efficiency and big markets: the two necessary conditions for the evolution of division of labor and economic growth, as the Smith and Young theorem suggests. Therefore, the traditional constraints in poor regions can be overcome. For instance, thanks to ICT, freeways and high-speed railways, and efficient logistics systems, their geographic isolation is no longer a major problem. The narrow local market is no longer a barrier limiting economic growth, because online shopping can connect them to the advanced outside market. Capital is no longer a problem because China has abundant capital and microfinance can be introduced. The human capital problem can be solved through new business models (e.g. franchised business) and by online use of high quality human capital located in big cities. For instance, services for medical care and education can be provided to remote poor regions via ICT. Finally, resource endowment is no longer a problem either, because based on these regions' vital ecological assets, various high value-added businesses can be developed, including organic agriculture, health industries, recreation, training and tourism.

Figure 5 shows how a new division of labor based on "green" resources could be developed in a "big push" by taking the advantage of ICT and other technological advancement. In structure 5.1, the transaction efficiency is sufficiently low and there is no concept of green growth either. The poor region is simply a base providing agricultural products to advanced regions. The farmers (A) in poor areas sell food x to agents B in advanced areas, and buy limited industrial products produced by agents B, while a high division of labor within the society of agents B is developed to produce various industrial products, y_i. In Structure 5.2, as transaction efficiency is sufficiently increased, some industries (z_i) based on "green" resources are developed in a "big push" manner in the

Figure 5. How Green Growth Could Become a Lever to Accelerate Development in Poor Region

(5.1) Low division of labor in poor region with low transaction efficiency

(5.2) High division of labor based on "green" resources in "poor" region with high transaction efficiency

poor region, and a high level of division of labor between the poor region and the advanced region is developed. Green growth accelerates the development of the poor region.

Therefore, a situation in which green growth becomes a lever to accelerate the development of poor regions can be envisioned. By taking advantage of ICT, high-speed railway and freeway systems and convenient logistics systems to connect poor regions with the advanced outside market, a "green" structure of the division of labor, based on these regions' vital ecological and cultural resources, can be developed in a "big push" manner, enabling the poor regions to leapfrog to wealth in a relatively short period of time. If we consider the advanced areas in this story as developed countries, and poor regions as the least developed countries, then green growth could reduce poverty worldwide (Zhang, 2014b).

2. Business Opportunities in Green Growth

The market is the ultimate solution for climate change and green growth. To understand the business opportunities offered by green growth, we need to open the "black box" of the firm to see how firms emerge in the evolution of division of labor, and understand the role the system of firms plays in economic growth (Zhang, 2003).

According to Smith (1776), the spring of economic growth is the division of labor, which is limited by the extent of the market, and the latter is determined by transaction efficiency. But how is the division of labor organized? Through the market or the firm? Coase (1937) argues that the firm is a substitute for the market for saving transaction costs. Cheung (1983) further points out that the firm replaces the market for intermediate goods with the market for labor. If the transaction efficiency of labor is higher than that of intermediate goods, then the division of labor is organized within the firm. Otherwise, it will be organized through the market.

Therefore, transaction efficiency plays an essential role in the evolution of the division of labor, and in how that division of labor is organized. As transaction efficiency increases, especially at a high level of division of labor, the possible ways to organize the division of labor dramatically increase, and so does the potential for improving organizational efficiency.

Thanks to the three major changes outlined below, the possibilities for entrepreneurs to make a fortune through innovation of their business models and products dramatically increase. This is particularly the case as the contents of production and consumption are becoming dematerialized under a green growth paradigm.

First, transaction efficiency is dramatically increased due to the spread of ICT, the availability of big data, and the introduction of new materials and high-speed railways. Specifically, the changes in transaction efficiency are reflected in the following aspects.

Information flow: Information collection and dissemination are growing exponentially in terms of speed and content due to the rapid development of the Internet, ICT, big data and cloud storage.

Population flow: People move much more conveniently and faster than ever before, with the progress of high-speed railways, highways, aviation and the increased popularity of private cars.

Logistic system: The speed of delivery of goods is significantly increased thanks to smart, quick and convenient logistics systems.

Second, the enlargement of production chains for both goods and services significantly increases the potential of division of labor. A higher level of division of labor represents more possibilities for entrepreneurs to find efficient organizational structures.

Third, a key characteristic of green growth is that the economy is becoming more dematerialized. Thanks to big data, human non-material needs can be more easily identified, and the potential for new non-material products to emerge is dramatically increasing. The division of labor and transactions are no longer so limited by physical and material constraints, and the possibility space that entrepreneurs can explore has expanded substantially.

In sum, green growth represents a paradigm shift, and the potential for green growth is much bigger than many think. However, its opportunities cannot be fully understood if green growth is merely thought of in terms of renewable energy and a few cutting-edge high technologies, or if conceived in a perspective of marginal analysis within a given structure of the division of labor.

VII. Concluding Remarks

This paper presents a new research agenda on climate change and green growth from the perspective of the division of labor. It covers three dimensions of green growth, that is, carbon emissions, environment and material resources use, and some of the relevant topics involved, as well as exploring their policy implications.

To achieve green development, there are two very different ways of thinking. One is to produce the same kinds of consumer goods in a greener way, so all people in the world can achieve the same material affluence as the industrialized countries now have. This approach is related to, for instance, production efficiency, energy efficiency, renewable energy, new material and new technology. Its success is largely reliant on the breakthrough of green technology, which is quite uncertain. Another way is to rethink the purpose of development, and the implications for happiness of the existing growth pattern based on materialism and

consumerism, and change people's consumption to follow a more dematerialized direction. Through redirecting the course of human development, green growth then no longer relies as much on the breakthrough of green technology. High productivity can be achieved based on knowledge, services, the environment, big data and ICT.

Green growth represents a paradigm shift, which is like a jump from one structure of the division of labor to another. In a historical perspective, the non-green path our societies have taken since the Industrial Revolution is just one of the possible paths that we could have chosen, and it somehow emerged by chance and has then been reinforced upon path dependence. To solve the problems resulting from the old paradigm, we need to think beyond the old paradigm, to think "outside the box."

Accordingly, the economic analysis of climate change and green growth can be conducted at three levels. The first level is the conventional neoclassical analysis focusing on efficient resources allocation in a given production structure of division of labor. The second level is, in a given set of final consumer goods, to further analyze how to produce them with new green technology or a new green structure of division of labor (see Acemoglu *et al*., 2012; Shi and Zhang, 2012). The third level focuses on the development paradigm shift, analyzing the changes in both consumption and production in the green direction. So far, most of the analyses on climate change and green growth have been conducted at the first and second levels. The new research agenda on division of labor proposed in this paper is not just able to be used for analysis at the second level, but also to analyze the jump across different development paradigms at the third level.

Although we can theoretically predict that there are possibilities for human societies to transition to a more sustainable and productive green growth trajectory, at the moment we are not very sure what exactly the new development paradigm is likely to be. Because green growth represents a new paradigm that is substantially different from the old one, it is, based on the past experience and data, hard to construct econometric models to forecast the future of green growth. A promising direction would be to conduct case studies on green growth.

Since CCGG is an interdisciplinary issue, some interdisciplinary research on economics is also promising. For instance, research in collaboration with historians, jurists and natural scientists is encouraging. An interesting extension of the research would be to explore the wider implications of climate change and green growth, asking such questions as whether overconsumption of material goods in the traditional paradigm really increases human well-being and happiness, or how that overconsumption has driven human societies to the current path leading destruction, and how to change the collective mindset to find a way out of the current predicament.

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