Is the Structure of Technology Progress in China "Green"?

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Abstract: This paper argues that, considering input–output linkages, microeconomic technology progress may lead to CO2 mitigation of the entire economy. We develop an environmentally extended heterogeneous agents and input-output (EE-HA-IO) model to evaluate CO2 emissions in different technology progress scenarios. We also measure the rate of technology progress in each sector in China between 2002 and 2014, with the aim of showing whether technological progress is compatible with the carbon mitigation of technological progress in each sector. In other words, whether there is an upside down phenomenon between technological progress and CO2 emission reduction. Our main conclusions include: (1) Most industries (except energy sectors) have a negative carbon footprint to technology progress. (2) Technology progress in energy related sectors and in the upstream sectors of industrial chain can be found to have a strong potential of emission increase effect. (3) From 2002 to 2007, the number of mispairing sectors gradually increased, while decreased significantly in 2008-2014. The reason behind it is that China's economic growth mode has changed.

Keywords: Technology Progress; China's Economic Growth Mode

1. Main

In the face of climate change threats.To achieve the development goal, China must take the initiative in reacting to changing technological and economic environment in a flexible and effective way. A classic but worth pondering question is how technological advances affect carbon dioxide emissions (Iyer*et al.*, 2017). Furthermore, does China's technological progress hinder China's goal of carbon neutrality or not?

There are several traditional understandings of this problem. some studies are considered to be the main drivers of green production and consumption structures (Chen *et al.*, 2020). Therefore, technology progress is an effective strategy to achieve the goal of carbon neutrality (Wang and Wei, 2020). On the other hand, a large number of studies have found that the process of technological progress may also produce so-called "rebound effect" (Jevons, 1865). It means lower production costs due to technological advances may lead to larger consumption and production, resulting in increasedCO_2 emissions. In addition to the views mentioned above, a more complex one has received wide attention. This view is also known as the environmental Kuznets curve which means that technology progress is not a simple linear relationship to CO_2 reduction (Grossman and Krueger, 1995; Panayotou, 1993). The early stages of technology progress will increase CO_2 emissions, but after a certain level, technology progress will lead to CO_2 reduction..

Although the impacts of technological advances from individual industries on CO_2 reduction has been studied in depth (Herrero*et al.,* 2016; Machado, Sousa and Hewings, 2016), few studies have addressed the network effects of technology progress on CO_2 reduction within a multi-sectoral framework. The concern about the network effect of technology progress mainly comes from the externality of technology progress as a public product, and the concept of industrial chain which has been fully studied. Technology advances in one industry tends to reduce or increase CO_2 emissions in other industries through production networks. Technological advances in China's steel industry, for example, will lead to changes in CO_2emissions in many industries. Firstly, for the steel industry, technologyprogress will lead to a reduction in the intensity of carbon emissions, which is conducive to thecarbon mitigation in itself. Secondly, technologyprogressof the steel industry will contribute to lower costs, which will bring about increased demand and thus increased CO_2 emissionsfrom downstream industries. Thirdly, technologyprogressof the steel industry will reduce the demand for its upstream products, which will help its upstream industries reducingCO_2 emissions. As a result, technological advances in one sector may lead to changes in carbon emissions throughout the network. More importantly, the position of the supply chain has profoundly affected the carbon footprint of technology progress (Acemoglu, 2015).

Based on the above. Within this framework, we define the carbon footprint effects of technology progress. To illustrate whether China's technology progress matches its carbon mitigation, we also measured the rate of technology progress in China using input-output methods. In this paper, the carbon footprint of technology progress is defined as the impact of technologyprogress at the industry level on the overall CO_2 emissions of the economy. We first usethe EE-HA-IO model to define the concept of the carbon footprint of technology progress. Second, we measure the carbon footprint using counterfactual analysis by calibrating the EE-HA-IO model with WIOT data which includes 56 sectors of 43 countries. Finally, using the same data, we also measured the rate of technology progress in China. We find that:(1) Most industries (except energy sectors) have a negative carbon footprint to technology progress. (2) Technology progress in energy related sectors and in the upstream sectors of industrial chain can be found to have a strong potential of emission increase effect. (3) From 2002 to 2007, the number of mispairing sectors gradually increased, while decreased significantly in 2008-2014. The reason behind it is that China's economic growth mode has changed. Between 2002 and 2007, China's economy was dominated by an extensive, investment-driven economic growth, which did not achieve rapid technological development. As a result, the mispairing sectors are gradually increasing at this stage. After 2008, China's economy steers gradually to intensive and technology-driven economic growth. Accelerating technology progress in various sectors has contributed to a reduction in the number of mispairing sectors. There are two implications of these results:(1) China’s emission reduction policies should focus not only on the energy sectors, but also on some downstream sectors of the production chain. (2) China should pay more attention to technology progress on downstream sectors of supply chain.

The new model defines the carbon footprint of technologyprogress and the corresponding calculation methods contributes to climate change economics. Firstly, this approach can help us assess the potential for direct or indirect carbon mitigation as a result of technologyprogress in different sectors. This will help us more accurately assess the environmental impact of all sectors’technologyprogress. Secondly, this method gives us a new way to measure the carbon footprint from the perspective of production network. This approach is different from the previous one, based onthe produceror consumer approaches.

2. Methods

2.1 Environmentally Extended Heterogeneous Agents and Input-Output.

We develop an environmentally extended heterogeneous agents model to evaluate CO_2 emissions in different technological progress scenarios.. On account of the consistency and comparability of time series, we use the World Input-Output Tables (WIOT), industry-level data on employment and capital stocks in China Emissions Accounts & Datasets (CEADs).

2.2 Measurement of Technology Progress.

To measure technology progress, we use Shestalova(2001)approach.In traditional practices, total factor productivity (TFP) is measured by Solowresidual which meets with lots of puzzles. The measure of Solow residual requires competitive market(Jorgenson and Griliches, 1967; Mohnen and Ten. Raa, 1998) which is difficult to satisfy. As a result, TFP based on Solow residul may not be an effective variable for “clean” technology advances (Mohnen and Ten Raa, 2001). To solve this problem, Ten. Raa and Mohnen (1998) used shadow prices as marginal productivity of labour and capital, and further breaks TFP down into three parts: technology progress, changes in preferences, and terms of trade. In particular, Shestalova(2001) points that a better measure for technologyprogressshould be examined by internalizing the terms of trade. Specifically, we assume a free trade economic environment in which three countries using intermediate goods, labour and capital to produce output. We denote intermediate input by $\mathbf{z_j}$ ($j = 1,2,3$), output by $\mathbf{x_j}$, final demand by $\mathbf{f_j}$ and net export by $\mathbf{nx_j}$, where j represents the country, i denotes the sector. $\mathbf{z_j}$ is an $i \times i$ matrix, while $\mathbf{x_j}$, $\mathbf{f_j}$ and $\mathbf{nx_j}$ are all i -dimensional column vectors. We also define a column vector $\mathbf{e}$, of which entries are 1. We can get the Leontief inverse matrix $\mathbf{B_j} = (\mathbf{I} - \mathbf{A_j})^{-1}$ where $\mathbf{A_j} = \mathbf{z_j}(\widehat{\mathbf{x_j}})^{-1}$ and $\mathbf{I}$ is a diagonal matrix of $\mathbf{e}$.

Measurements of technological advances consist of two steps: Firstly, we construct the following (1) linear optimization model to get the shadow price of labour and capital. Secondly, we caculate the TFP using shadow price and decompose it.

$$\max c\mathbf{e}^{\mathbf{T}} \sum_{\mathbf{j=1}}^{\mathbf{3}} \gamma_j \mathbf{f_j} \tag{1}$$

Subject to

$$\begin{aligned} &(\mathbf{I} - \mathbf{A_j})\mathbf{x_j} \geq c_j \mathbf{f_j} + \mathbf{nx}_j \\ &\sum_{\mathbf{j=1}}^{\mathbf{3}} \mathbf{nx_j} \geq \sum_{\mathbf{j=1}}^{\mathbf{3}} \mathbf{nx_j^0} \\ &\mathbf{k_j^T x_j} \leq K_j, \mathbf{l_j^T x_j} \leq L_j \\ &\mathbf{x_j} \geq 0, j = 1,2,3 \end{aligned} \tag{2}$$

where the expansion factor for three economies are scalar $c_1 = c, c_2 = c\gamma_2, c_3 = c\gamma_3$. By multiplying with the final consumption, we can get the expanded final demands. $\mathbf{nx_j^0}$ are observable net export. $\mathbf{K_j}, \mathbf{L_j}$ are sum of sectors' capital stock and labour. Correspondingly $\mathbf{k_j^T}, \mathbf{l_j^T}$ are all initial input coefficient. In input-output economy, the quantity model is the dual model of the price model. Solve the dual problem, and we can get $\mathbf{p_j}, w_j, r_j$, which are price of all goods, labour and capital.

Another question is how to determine γ_2 and γ_3 .We adopt this rule that require total net exports and surpluses at the equilibrium allocation must be financially feasible. That's (3):

$$\frac{S_1}{S_2} = \frac{S_1^0}{S_2^0}, \frac{S_1}{S_3} = \frac{S_1^0}{S_3^0} \tag{3}$$

where S_j represents the surplus of country j and S_j^0 represents the observable surplus of country j . We adopt a kind of Negishi's adjustment process (Negishi,1960) to get γ_2 and γ_3. Firstly, we can specify any value for $\gamma_2 > 0$ and $\gamma_3 > 0$. Secondly, we conduct the linear optimization and get the S_j .Thirdly, if $S_j > (or <) \frac{S_j^0}{S_1^0} S_1$, we can increase or decrease γ_j a little. After that, we replicate the process from the first step again until meeting with the condition (4).

The solution to the above problem can provide the optimal consumption allocation and shadow prices for a given year. We use the following method (Ten Raa & Mohnen, 1998) to calculate TFP:

$$\dot{\mathbf{TFP}} = \frac{\dot{\mathbf{r}}\mathbf{K} + \dot{\mathbf{w}}\mathbf{L}}{\mathbf{rK} + \mathbf{wL}} \tag{4}$$

where dot denotes derivative with respect to time.

According to Shestalova(2001), we can decompose TFP growth to three parts: technical change effect, final demand change effect and terms of trade effect:

$$\begin{aligned} (dr)\mathbf{K} + (dw)\mathbf{L} &= \mathbf{d}(r\mathbf{K} + w\mathbf{L}) - r\mathbf{dK} - w\mathbf{dL} \\ &= \mathbf{d}[\mathbf{p^T}(\mathbf{I} - \mathbf{A})\mathbf{x}] - r\mathbf{dK} - w\mathbf{dL} \\ &= -(\mathbf{p^T dA} + r\mathbf{dk^T} + w\mathbf{dl^T})\mathbf{x} + (\mathbf{dp^T})c\gamma\mathbf{f} + (\mathbf{dp^T})\mathbf{nx} \end{aligned} \tag{5}$$

The first term can be seen as technical change effect. It can be also also decomposed into sectoral technical change effects as follows:

$$\mathbf{SR} = [-\mathbf{p^T}(\mathbf{dA}) - w(\mathbf{dl^T}) - r(\mathbf{dk^T})](\hat{\mathbf{p}})^{-1} \tag{6}$$

where $\mathbf{SR}$ is $i \times 1$ dimension vector.

2.3 Parameter Calibration for Technology Progress Calculation.

All parameters except capital stock and labour are from WIOT. The capital stock and labour data are straightly drawn from SEA. Capital stock and labour are adjusted by annual average exchange rate.

3. Date Description

For raw data, We mainly follows the following procedure: (1) Sectors adjustments. Since carbon emissions data from CEADs (Shan *et al.*, 2018) do not match sectors in the WIOT, we must adjust the carbon emissions sectors. The WIOD we use in this study refers to 56sectors and 43countries. HoweverCEADs has only 44 sectors. We use the classification of the WIOT as the standard. The comparison between CEADs and WIOT is in the appendix. On the other hand, because our focus is on carbon emission sectors, we some services sector which empirically has little CO_2 emissions. At last, we get 33 sectors. Particularly, we should ignore two sectors: repair and motor vehicles because they are missed in I-O table published from National Bureau of Statistics of China. (2) Price adjustment. We use data from 2000 to 2014, for which price adjustments must be made to exclude price implication. We use adjust the total output price, the intermediate input price index, and the value-added price index in SEA to adjust raw data to constant prices and base year is 2010. In addition, the labour and capital stock is adjusted to dollars using the average annual exchange rate. (3) Countries selection. We choose China, the United States, and Japan as target. This is mainly due to the fact that the three countries account for a large global share of trade and that the three countries are easier to calculate.

4. Results

4.1 Sector linkages for CO_2 Footprint of Technology Progress

Technologyprogress in one sector will have an impact on carbon dioxide emissions in all other sectors through production networks (Fig.1).From the perspective of carbon emission mitigation, we establish that most industries (except Mining, Petroleum, Chemical, Basic Metal and Electricity) have a negative carbon footprint to technology progress. We can also see that technology progress in the trailing end of supply chain, such as the direct consumer goods industries which are usually downstream of supply chain and Construction, has a greater potential of CO_2 mitigation by technology progress.From the heat map, a 1-percentage-point increase in technology progress in Agriculturecan reduce 15.11Mt of CO_2 emissions fromElectricity. Technological advances of 1% in light industries such as Food, Textiles, Wood, Paperwill reduce CO_2 emissions from Electricity, Basic Metals by 72.59 Mt and 34.59Mt.While other manufacturing industries (such as Medical, Rubber, Nonmetal Products, Computer, Machinery and Vehicles) will lead to CO_2 reduction in Basic Metals and Electricity. Especially, A 1-percent-point increase in technologyprogress in Construction will lead to a reduction of 30.74Mt in Electricity and 13.96Mt in Basic Metals .

From the perspective of CO_2 increase, technologyprogress in energy related sectors and in the upstream sectors of industrial chain can be found to have a strong potential of emission increase effect. Specifically, technology progress in Mining, Petroleum, Basic Metals, Electricity plays an important role in increasing CO_2 emissions from Basic Metals and Electricity. Especially, 1% technology progress inMining, Petroleum andElectricitywill separately leads to emissions of Basic Metals increasing by 1.56Mt, 21.45Mt, 9.22Mt, and lead to Electricity increasing by 19.34 Mt, 29.45 Mt and 86.35Mt. Every 1% increase in Basic Metals will result in an additional 54.75Mt carbon emission of Electricity. In addition, we have also established that technologyprogress in one sector will lead to increased carbon emissions fromitself, particularly in Basic Metals and Electricity. Those results show that the concentration of technology progress for CO_2mitigation should be shifted from energy sectors to sectors located in the downstream of supply chain.

One explanation for this phenomenon is that different sectors have different positions in the supply chain, which contributes to different effects of technology progress through production links. First, technology progress in a sector may have two very different effects. On the one hand, they will lead to more use of cleaner technology, thereby reducing the carbon intensity of itself. On the other hand, technology progress will also lead to more competitive prices of its products, resulting in increased demand for products, and thereby increasing carbon emissions from itself. Because China's economic development is fast, the demand effect is more obvious, which means that the sector's technology progress may lead to more CO_2 emission. Second, technology advances in the upstream sector will lead to lower production costs for their products. Consequently the downstream sector will use more upstream products and increase emissions. Third, technologyprogress in the downstream sector will lead to greater use of its own products in production, thereby reducing demand for the upstream sector. It may help CO_2 mitigation. Finally, advances in sectoral technologies will reduce CO_2 emissions from competing sectors, because technologyprogress will lower the price of the sector's products and crowd competitorsout.

4.2 footprint of Technology Progress in 2014.

This study also reveals total CO_2 emission effect to the whole country affected by one sector’s technology progress. Firstly, We find that the sectors having the most increasedemission of technology progress are the Electricity, Petroleum, and Basic Metal. All of them are in upstream of the supply chain. As mentioned earlier, technology advances in these sectors will lead to a greater use of their products by downstream sectors, contributing to an overall increased CO_2 emission in the economy. Secondly, the most obvious CO_2 mitigation sectors are Construction, Textiles, Food and Vehicles. Most of these sectors are of downstream sectors in supply chain. Technological advances contributes to the replacement to upstream products, thereby reducing carbon emissions. Thirdly, from the view of time trend, technologyprogress in most sectors leads to CO_2emission reductions in the overall economy, except of a few upstream and energy sectors (such as Mining, Petroleum, Base Metaland Electricity). This result also suggest that emission reduction policies should focus not only on the energy sectors (Yang Mian *et al.*, 2018), but also on some downstream sectors of the production chain.

4.3 China's Technology Progress from 2000 to 2014

Since 2000, a large number of literatures have confirmed that China's accession to the WTO in 2001 and the 2008 financial crisis are both important landmarks of China's economic development(Xu *et al.*, 2020).To this end, we present the results of technology progress in three segments: 2000-2002, 2002-2007 and 2008-2014. It can be found that between 2000 and 2002, most industries have made technological progress. During the period 2002-2007, the scope of technology progress in the industries narrowed significantly. After the 2008 financial crisis, technology progress of Agriculture, Food, Petroleum, Chemical and other industries significantly accelerated. The above results we found are consistent with those literatures on sectoral TFP (Xu *et al.*, 2020). Because our technological growth is the result of excluding terms of trade and changes of preferences, some of our results are smaller than those in related literatures (mainly in Agriculture, Mining, but some studies support our result)(Dzonzi-Undi*et al.*, 2016). However, our results can still be useful because it has a tendency to be consistent with other results.

The change of technology progress may be due to the change of China’s economic development mode(Cai, 2013; Tong *et al.*, 2020).The access to WTO has greatly promoted China's economic growth (Tuan, Chyau et al., 2009). At the same time, the capital accumulation rate rose rapidly (Fang *et al.*, 2011).In other words, during 2002-2007 China’s economic growth was a result of large investment which mainly relied on factor-driven rather than technology-driven.As a result, most industries have achieved rapid capital investment instead of technology progress at this stage.

After financial crisis, China's imports and exports suffered a big shock. Chinese government launched a 400 billion yuan plan to stimulate economy, focusing on infrastructure improvements, agricultural water conservancy and independent innovation. Advances in agricultural infrastructure to some extent explain progress of technology in Agriculture. In addition, the setback of foreign trade led to the shift from extensive to intensive growth(Zhang Chengsi, 2016). At this stage, China's enterprises began to spend larger on research and development expenses.(Cai Fang, 2013)As a result, technological progress in most industrial sectorsbegan to improve.

4.4 Mispairing between Technology Progress and Carbon Emissions

Here we define the mispairing scenario as: (i) CO_2emission effect is positive with positive technology progress; (ii) CO_2emission effect is negativewith negative technology progress. It's easier to show that both situation will inhibit CO_2 mitigation. By combining results of technology progress with accompanying carbon footprint, we establish the following results (Fig. 3).

Between 2002 and 2007, we find a rapid increase in the number of mispairing sectors.After 2008, with the transformation of China's economy and the increased investment in research and development, there is a decline in the number of mispairing sectors.

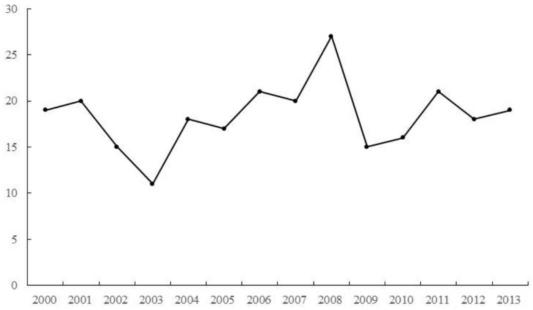

Figure 1. The Number of Mispairing Sectors during 2000-2013.

From 2002 to 2007, the upside-down sectors were light industry (such as Textiles, Food, Paper), Basic Metals, Chemicals, Rubber, Electricity and other sectors. The slow rate of technological advances caused by investment-driven economic growth is the main reason for this. After 2008, the transformation of the mode of economic development contributes to an increase in the rate of technology progress, which transfer the Agricultural sector, the light industry sector, and Chemicals from mispairing to non-mispairing. But we also found that this effect fluctuated. This may show that China is on the road of economic transformation. And to achieve established environmental goals, China should pay more attention to technology progress on downstream sectors of supply chain..

5. Conclusion and Discussion

This study provides a new perspective on China's carbon neutrality by defining the CO_2 footprint of technology progress. Different from the traditional accounting methods from the producer's and consumer's perspective, this new concept evaluates the CO_2 mitigation potential from the perspective of technology progress. In addition, we have adopted a shadow price based method to measure the technology progress. This could help identify the most productive industries of CO_2 mitigation in the production network by technology progress. It is crucial for ChinaCO_2 mitigation policy decisions and achieving carbon neutrality.

First, sectors located in downstream of the supply chain will have greater potential to reduce CO2 emissions. Since CO_2 comes directly from the energy sector (e.g. Mining, Petroleum, Electricity etc), related studies focus more on reducing emissions in the energy sector (Yang Mian *et al.*, 2018). However, our research shows that technological advances in the energy sector has a strong rebound effect, which will lead to an increase in carbon emissions. In contrast, technology progress in sectors at the end of the supply chain tends to lower carbon emissions from sectors such as the energy sector and Basic Metal. We provide an explanation that technological advances in the downstream sector lead to using less products of energy sectors and thus result in emission reductions in the upstream energy sector.

Second, we find that with the transformation of economic development, the mispairing sectors are gradually decreasing. From 2002 to 2007, the mispairing sectors gradually increased, while decreased significantlyin 2008-2014.The reason behind it is that China's economic growth mode has changed. Between 2002 and 2007, China's economy was dominated by an extensive, investment-driven economic growth, which did not achieve rapid technological development. As a result, the mispairing sectors are gradually increasing at this stage. After 2008, China's foreign trade suffered and economic growth of investment-driven is unsustainable. Chinese government implements 400 billion yuan plans to significantly improve infrastructure and increase independent innovation. Companies began to invest more in research and development. As a result, China's economy steers gradually to intensive and technology-driven economic growth. Accelerating technology progress in various sectors has also contributed to a reduction in the number of mispairing sectors. Transforming of the mode of economic development, improving the quality of economic growth and promoting technological progress will be a strong power for carbon-neutrality in the future.

Furthermore, energy sectors are major direct emitters of CO_2 emissions and crucial for CO_2 mitigation by technology progress. Assessing the footprint of energy biased technology progress is vital for further understanding the mechanism of CO_2 mitigation through technology progress. Thus, this can be an interesting direction for future research.

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