Influence of a Carbon Tax on Low-Carbon Trade Competitiveness of the Paper-Making Industry

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Abstract

Policies to constrain carbon emissions, such as the carbon tax, have made low-carbon trade competitiveness (LCTC) a significant tendency in research concerning industrial international competitiveness. However, few empirical studies have analyzed the influence of a carbon tax on LCTC. We combined the trade competitiveness index and industrial carbon productivity to construct an industrial LCTC index that can analyze carbon emissions performance and international competitiveness. We then used the LCTC index to build a dynamic panel model with its potential factors, which was estimated by system generalized method of moments method based on panel data of 38 countries between 1995 and 2009. We found evidence that a carbon tax exerts an indirect positive influence on the LCTC of the paper-making industry by stimulating technological innovation. The policy implications suggest that, considering the increasingly intensified countermeasures against carbon leakage, governments should strengthen the promotion mechanism of technological innovation to guarantee the positive effects of a carbon tax.

In the post–Kyoto Protocol era, the world has begun to reach a new consensus on carbon reduction. For that reason, the growth in exports sustained by sacrificing resources and the environment as well as by high energy consumption and high carbon emissions is unsustainable, which makes low-carbon trade competitiveness (LCTC) a significant tendency in the field of industrial international competitiveness. LCTC refers to the ability of a country or an industry to gain the ''increment'' of trade competitiveness by means of low-carbon economy. It reflects the industry's carbon-reduction efficiency and the trade competitiveness, which is an extension of the traditional concept of trade competitiveness. Exporters must fully consider the important effects of carbon emissions on international trade competitiveness, particularly if they do not want to risk green barriers to trade.

Many researchers (Zhang and Baranzini 2004, Lozano and Gutiérrez 2008) have studied the influence of such restrictions on the gross volume or intensity of carbon emissions, which can provide examples of carbon reduction induced by a carbon tax. Because of concern that a carbon tax may weaken the international competitiveness of countries levying it, several researchers have studied the influence of such a tax on industrial international competitiveness (Ho et al. 2008, Wang et al. 2010, Aldy and Pizer 2011). However, the problems caused by carbon emissions can be solved only by economic development, and growth in exports is an important driver of such development. Therefore, achievement of the carbon-reduction target and growth in exports should not be separated. We need both reduction in carbon and improvement of international trade competitiveness at the same time. Only in this way can the LCTC of industry be truly reflected and the actual influence of a carbon tax on competitiveness be confirmed. Because of a lack of appropriate indexes to measure industrial LCTC, however, little research has been performed on the influence of a carbon tax.

In view of this, we constructed an industrial LCTC index, based on the trade competitiveness index and carbon productivity, that can reflect both carbon emissions and trade competitiveness and provide an effective foundation for the future studies on LCTC. Furthermore, considering

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the dynamic changing features of LCTC, this study built a dynamic panel model and estimated it with the generalized method of moments (GMM). The empirical results are more scientific and reliable than those produced by the World Bank (2008), Ho et al. (2008), and other scholars, who used static panel models that did not solve for endogenous risk.

Owing to its high energy consumption and high carbon emissions, paper-making has been a major industry constrained by climate change policy, which is also regulated by the Kyoto Protocol. Furthermore, the paper-making industry involves a high degree of globalization in the producing stage and the selling stage. For these reasons, governments and scholars have been very concerned about the influence of a carbon tax on the carbon-reduction and trade competitiveness of the paper-making industry. The conclusions drawn from this study are strongly representative of other, similar energy- and carbon-intensive industries and have practical significance for governments in designing a carbon tax and its supporting measures.

Theoretical Framework

When a carbon tax is levied, a firm can shift part of the cost of that tax onto consumers, and the amount they can shift depends on the price elasticity of supply and demand (Turner et al. 1994). Using the research by Varma (2003) as a reference, we analyzed the economic mechanism through which a carbon tax affects industrial LCTC. Figure 1a shows that without changes in technology, a levy T on carbon emissions will increase a firm's production costs, and the firm will maintain the original equilibrium output at the price $(P_0 + T)$. Thus, the supply curve moves from S_0 to S_1. In actuality, however, firms cannot shift all the added carbon tax onto consumers. The rise in price leads to a reduction in market demand and, thus, forces a decrease in the market price as well as a reduction in supply. Finally, the market equilibrium point moves from E_0 to E_1, and the equilibrium price and equilibrium output change from P_0 and Q_0 to P_1 and Q_1, respectively, with $P_1 > P_0$ and $Q_1 < Q_0$. The part of the carbon tax assumed by consumers is $P_1 - P_0$, and the part assumed by the firm is $T - (P_1 - P_0)$. The carbon tax therefore hurts the profits of resource owners—for example, the laborers and the owners of capital—as well as the welfare of consumers. The carbon tax produces a reduction in gross demand and in the return rate of resource owners, which in turn reduces the supply of laborers, capital, and other factors for the industry. Finally, the situation is reflected by a rise in the unemployment rate and a drop in income. Meanwhile, consumers may increase the import of lower-priced products from countries that do not levy a carbon tax, which causes a reduction in output and weakens the industrial international competitiveness. This process is the central theme of the ''pollution haven hypothesis,'' which is that environmental regulation adds the operating costs of regulated enterprises and weakens their market competitiveness.

A dynamic perspective such as the ''environment hypothesis'' (Porter 1990), however, suggests that an environmental regulation will drive a firm to seek ways to reduce costs and increase income, during which the utility efficiency of resources is increased to reduce waste and the waste can be turned into salable products, as well as to develop low-carbon green products. As Figure 1b shows, a firm's cost reduction, achieved by the firm being stimulated to use innovative techniques, is $2T$—that is to say, when output Q_0 is unchanged, the product price reduces the T to $P_0 - T$ compared with original equilibrium price P_0. The corresponding actual market demand and supply are, respectively, Q_2 and Q_0, and a situation develops in which supply falls short of demand, which leads to a continuous growth in the price. Gradually, reduced demand and increased supply return the market to an equilibrium, with the equilibrium point moving from E_0 to E_1 and the equilibrium price and equilibrium output becoming P_1 and Q_1, respectively, from P_0 and Q_0, in which $P_0 > P_1$ and $Q_0 < Q_1$. The price reduction enjoyed by consumers is $P_0 - P_1$, and the rest enjoyed by the firm is $T - (P_0 - P_1)$. Therefore, a carbon tax not only reduces the product's market price but also encourages domestic industry to increase output, which has a simulative role in promoting industrial international competitiveness.

The process described above imposes an ''innovation offset'' effect on a firm's international competitiveness (Porter and Claas 1995): a carbon tax and other environmental regulation will stimulate enterprises to carry out the process- or product-oriented technological innovation, which has an indirect positive effect on competitiveness. Taking ''process compensation'' as an example, we

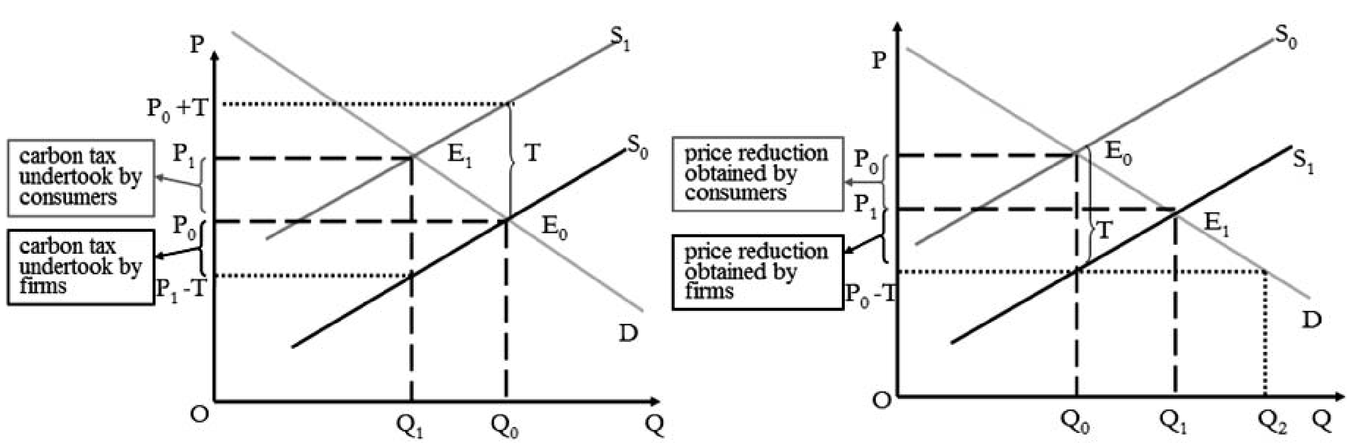

Fig.1a Fig.1b

Figure 1.—Potential effects of a carbon tax on industrial low-carbon trade competitiveness of a firm.

performed an in-depth analysis of the environment hypothesis. The process compensation could be described as a carbon tax that can encourage paper-making enterprises to research and introduce energy-saving equipment or manufacturing technology, which helps a firm to realize high productivity and high carbon efficiency in the producing stage and to make up the operating cost caused by the carbon tax. In Figure 2, we hypothesize that a firm's inputs are divided into two main types: (1) energy and (2) capital and other substitutes. The line of the initial cost is *AB*. According to the environment hypothesis, the carbon tax stimulates a firm to improve efficiency through technological innovation, which in turn decreases the unit cost of the energy factor. Then, the isocost line becomes AB', and the equilibrium point of the firm's maximum profit moves from *a* to *b*. The positive influence of carbon tax on output increases energy input by $X_1'X_1'''$ and reduces the use of capital and other factors by *MN*. A virtual isocost line *FG* is shown, parallel to line AB', to highlight the influence of the actual income change and to make the original isoquant Q_0 tangent to *c*. The substitution effect and the income effect of a carbon tax on industrial output are as follows. First is the substitution effect—that is, technological innovation reduces the unit cost of the energy factor. In the isoquant Q_0, the firm will surely increase the input of the energy factor and reduce the use of capital and other factors. Thus, the equilibrium point of maximum profit will move from *a* to *c* on line Q_0, and the substitution effect will increase the energy input by $X_1'X_1''$. As shown, the reduction in the unit cost of energy factor raises the firm's actual disbursable cost, which promotes the further increase of energy factor as well as cuts down other factors. By now, the equilibrium point has moved from *c* to *b*, with the income effect increasing the energy input by $X_1'X_1'''$. Taking into account the substitution effect and the income effect, the carbon tax helps the firm increase to the higher isoquant Q_1 from Q_0. Thus, a firm meeting the emission-reduction requirement by increasing energy efficiency and carbon emissions efficiency with technological innovation will increase its international competitiveness in a low-carbon economy.

There are several criticisms of the environmental hypothesis. Supporters of the pollution haven hypothesis claim environmental regulation will push technological

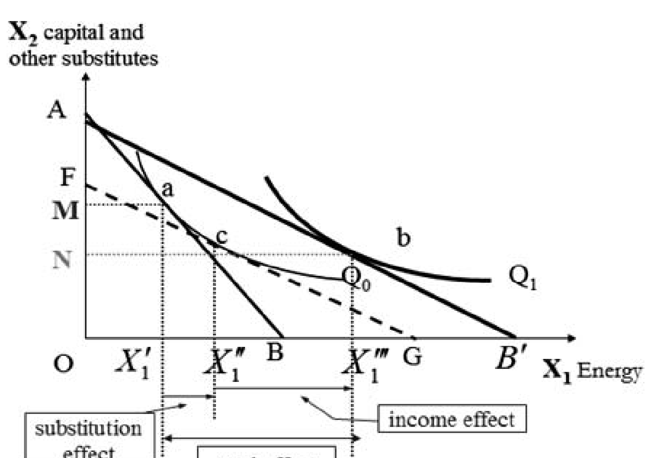

Figure 2.—Potential effects of a carbon tax on industrial output and process offsets.

innovation and reduce costs, but they doubt the validity of the innovation offsets because of the opportunity costs from investment in technological innovation, which could be used for something with much greater production efficiency (Palmer et al. 1995). Porter and Claas (1995) assert that pollution abatement is accompanied by improvement in production efficiency, so the innovation offsets are everywhere. Until now, the focus of the debate between the pollution hypothesis and the environment hypothesis seemingly has been on whether the increase in a firm's operating costs and opportunity costs caused by a carbon tax will be offset, and how long it takes to be offset. Actually, however, the debate centers on whether low-carbon constraints stimulate a firm's technological innovation in time and effectively, and then whether the induced innovation can increase productivity and whether the additional value of products can in time reduce the bad influences of the increased operation cost.

Literature Review

Industrial LCTC measurement index needs to be improved

Researchers have generally used two methods to measure industrial low-carbon competitiveness. One is the single-index measure method, such as foreign trade implicit carbon (Peters and Hertwich 2008), carbon emissions intensity (Nicholson et al. 2011), carbon productivity (Xu et al. 2013), total factor productivity of carbon emissions (Lozano and Gutiérrez 2008), etc. Single-factor measurements are easy to operate, but they only reflect environmental performance and cannot reflect performance in terms of industrial international competitiveness. The other method is to design an assessment indicator system of LCTC. For example, the climate competitiveness index built by the United Nations Environment Programme consists of 26 indicators, whereas the low-carbon competitiveness index built by the Climate Institute consists of 36 indicators. Wang (2013) built an industrial international competitiveness assessment index for the low-carbon economy from five perspectives, i.e., international market competitiveness, low carbon levels, scale efficiency, efficiency competitiveness, and innovation competitiveness. These indicator systems measure the important roles of environmental and economic factors in industrial international competitiveness and are a big improvement over the single-index methods. It is difficult, however, to collect complete industry data cross-country, cross-years, and from multiple indexes. Therefore, we need to build a new LCTC index that can reflect both carbon emissions performance and international trade competitiveness, for example, to measure and make international comparisons of the paper-making industry's LCTC.

Little research on the influence of carbon tax on industrial LCTC

Researchers have simulated the influence of a carbon tax on various industries in different countries at different tax levels, and the main results have been that a carbon tax has a significant positive effect on carbon reduction within manufacturing or niche manufacturing industries (Bruvoll and Larsen 2004, Floros and Vlachou 2005, Johansson 2006, Newcomer et al. 2008, Lu et al. 2012). Some scholars, however, still doubt the intensity of the positive influence of a carbon tax, such as the electric power supply decision function built by Cullen and Mansur (2013), which found that a tax of US$50/ton had little effect on the electric industry's carbon emissions in Texas. In addition, much of the research has studied the positive effect of a carbon tax from the perspective of environmental benefit and neglected its influence on industrial output, benefit, and export value. Realizing the harmony among society, the economy, and the environment, however, is the basic point of designing a climate change policy. Therefore, many scholars have focused on the influence of a carbon tax on industrial international competitiveness. Ho et al. (2008), Ministry of Finance Research Group of China (2009), Wang et al. (2010), Aldy and Pizer (2011), Cai et al. (2012), and Zhao and Fan (2012) found that a carbon tax had significant negative effects, whereas other scholars think a carbon tax will have positive effects on international competitiveness when it is supplemented by a special energy-saving fund (Kasa 2000); a fiscal subsidy, tax deduction, and some type of exemption (Liang et al. 2007, World Bank 2008); and a carbon-emissions trading scheme (Lee et al. 2008). We find that the conclusions of previous researchers about the influence of a carbon tax on the industrial international competitiveness are inconsistent, with a few studies based on observed data but many having simulated results.

In addition, in the post–Kyoto Protocol era, the development of carbon emissions trading scheme makes carbon dioxide an important input or undesirable output of firms. Therefore, a carbon tax will have a positive effect on carbon reduction. It can help an industry reduce operational costs and add some intangible assets, such as the Certified Emissions Reduction. A carbon tax also lays the foundation for increasing the LCTC. Whether reduced costs or increased invisible carbon assets can compensate for the loss caused by reduced output and exports is an important factor in estimating the influence of a carbon tax on LCTC. Currently, however, little research exists regarding the influence of a carbon tax on industrial carbon reduction and international competitiveness (in which carbon reduction and international competitiveness are bundled). Lee et al. (2007) combined an input–output table and a gray forecasting method to prove the effect. They assumed that from 2000 to 2020, the price of the carbon tax rose 2.75 percent every year, and the carbon emissions of European Union chemical materials, plastic materials, artificial fiber, plastic products, and rubber products were reduced by 31.8, 54.8, 38.3, 11.8, and 17.7 percent, respectively. Thus, the gross output value was reduced by 26.4, 13.7, 10.2, 1.4, and 2.4 percent, respectively. The decreasing amplitude of the output was obviously less than the decrease in carbon emissions, which indicates that a carbon tax had a positive effect on industrial carbon-emissions intensity. From that, it can be seen that a carbon tax contributed to strengthening the LCTC, but there may be deviations when the influence of a carbon tax is researched separately. Therefore, an LCTC measurement index needs to be designed that can reflect carbon emissions performance and competitiveness performance to further examine the actual influence of a carbon tax.

Meanwhile, according to the environment hypothesis, a carbon tax can stimulate firms to innovate their process- and product-oriented technologies, which will cause an innovation offset effect on their industrial international competitiveness. However, little empirical research about that effect exists—that is, few research results about the indirect influence of a carbon tax are available. Scholars, such as World Bank (2008) and Zhao and Fan (2012), mainly research the direct influence of a carbon tax on industrial carbon emissions and international competitiveness. Some scholars, however, have paid attention to the indirect influence of a carbon tax. For example, Newcomer et al. (2008) suggested that a carbon tax can encourage power operators to develop new power-generation techniques to promote significant carbon reduction, but they did not provide empirical research about that influence. Although Aghion et al. (2012) provided empirical research to prove that a carbon tax can stimulate the automobile industry to develop clean-technology innovations, such as electric automobiles, hybrid electric vehicles, hydrogen vehicles, and fuel cells, they did not measure the influence of these clean-technology innovations induced by a carbon tax on the LCTC. They only researched the front half of the carbon tax → technology → LCTC pathway, without examining the environment hypothesis completely. Therefore, to fully assess the effect of a carbon tax, research about the effect of the innovation offset of a carbon tax on LCTC needs to be added.

Methods

Structure of the LCTC index

Under the trend of more and more instruments to control carbon emission, the improvement of carbon productivity may help regulated firms reduce production costs and have a positive effect on industrial profits. What is more, if one company has higher carbon-reduction productivity than its competitors, it can garner a competitive advantage. Therefore, carbon emissions should be taken into account when industrial international competitiveness is measured. Currently, however, the available measurement methods and the index of industrial international competitiveness cannot meet this demand in a low-carbon era. In light of this, we considered the adjustment function of carbon productivity to industrial international competitiveness, adjusting the traditional trade competitiveness (TC) index to build a new LCTC measurement index that can conveniently measure industrial LCTC in a low-carbon economy.

The TC index is as follows:

$$\mathrm{TC}_{i,k} = \frac{X_{i,k} - M_{i,k}}{X_{i,k} + M_{i,k}} \tag{1}$$

where $\mathrm{TC}_{i,k}$ is the traditional trade competitiveness index of industry k in country i, $X_{i,k}$ is the total export of industry k in country i, and $M_{i,k}$ is the total import of industry k in country i.

The calculation process of the LCTC index is as follows. Carbon productivity (CP) is expressed by the ratio of the industrial added value to the total carbon emissions—that is $\mathrm{CP}_{i,k} = Y_{i,k}/C_{i,k}$, where $\mathrm{CP}_{i,k}$ refers to carbon productivity of country i's industry k, $Y_{i,k}$ refers to the added value of country i's industry k, and $C_{i,k}$ refers to the carbon emissions of country i's industry k.[1] For the concept of carbon productivity, country i's industry k's imports from country j

[1] To decrease ambiguity, hereafter the subscript will omit the k variable that represents the industry so that it can be expressed concisely—for example, CP_i represents the carbon productivity of an industry in country i.

are represented as $M_{i,j}$, which means that country i reduces the carbon emissions by $M_{i,j}/\mathrm{CP}_i$—that is, country i imports a carbon quota of $M_{i,j}/\mathrm{CP}_i$. The country i's industry k's exports to country j are represented by $X_{i,j}$, which means that country j reduces its carbon quota by $X_{i,j}/\mathrm{CP}_j$, country j imports a carbon quota of $M_{i,j}/\mathrm{CP}_j$, and country i exports a carbon quota of $X_{i,j}/\mathrm{CP}_j$, where CP_j refers to carbon productivity of country j's industry k. From total exports and imports, the total exports of country i's industry k equals its exports carbon quota of $\sum_{j=1}^{n}(X_{i,j}/\mathrm{CP}_j)$, where n refers to the number of export markets of country i's industry k. The total imports of country i's industry k equals its imports a carbon quota of $\sum_{j=1}^{m}(M_{i,j}/\mathrm{CP}_i)$, where m refers to the number of import sources of country i's industry k; therefore,

$$\sum_{j=1}^{m}\frac{M_{i,j}}{\mathrm{CP}_i}=\frac{\sum_{j=1}^{m}M_{i,j}}{\mathrm{CP}_i}=\frac{M_i}{\mathrm{CP}_i}, \qquad M_i=\sum_{j=1}^{m}M_{i,j} \tag{2}$$

where M_i is the total imports of country i from all of country j.

Based on these ideas and learning from the form of the TC index, we can represent the LCTC index of country i's industry k as follows:

$$\begin{aligned}\mathrm{LCTC}_i&=\frac{\sum_{j=1}^{n}\frac{X_{i,j}}{\mathrm{CP}_j}-\frac{M_i}{\mathrm{CP}_i}}{\sum_{j=1}^{n}\frac{X_{i,j}}{\mathrm{CP}_j}+\frac{M_i}{\mathrm{CP}_i}}=1-\frac{2\times\frac{M_i}{\mathrm{CP}_i}}{\sum_{j=1}^{n}\frac{X_{i,j}}{\mathrm{CP}_j}+\frac{M_i}{\mathrm{CP}_i}}\\&=1-\frac{2M_i}{\mathrm{CP}_i\sum_{j=1}^{n}\frac{X_{i,j}}{\mathrm{CP}_j}+M_i}\\&=1-\frac{2M_i}{\mathrm{CP}_i\left(\sum_{j=1}^{n}\frac{\alpha_{ij}}{\mathrm{CP}_j}\right)X_i+M_i}\end{aligned} \tag{3}$$

where $X_{i,}$ is the total number of exports of country i to all of country j and α_{ij} is the proportion of exports to country j accounted for by the total exports of country i. The carbon emissions intensity (CEI) is the ratio of the total carbon emissions to the industrial added value, that is, $1/\mathrm{CP}=C/Y=\mathrm{CEI}$, where CP is carbon productivity, Y is the added value, and C is carbon emissions. We can therefore change $\sum_{j=1}^{n}(\alpha_{i,j}/\mathrm{CP}_j)$ of Equation 3 into $\sum_{j=1}^{n}\alpha_{i,j}(1/\mathrm{CP}_j)=\sum_{j=1}^{n}\alpha_{i,j}\mathrm{CEI}_j=\mathrm{WACEI}_j$, which is the weighted average of carbon emissions intensity (WACEI) of industry k for all of country j. Based on $1/\mathrm{CP}=\mathrm{CEI}$, we can get $1/\mathrm{WACP}_j=\mathrm{WACEI}_j$, where WACP_j is the weighted average of carbon productivity of industry k for all of country j. Thus, we can change Equation 3 as follows:

$$\mathrm{LCTC}_i=1-\frac{2M_i}{\mathrm{CP}_i\left(\sum_{j=1}^{n}\frac{\alpha_{i,j}}{\mathrm{CP}_j}\right)X_i+M_i}=1-\frac{2M_i}{\frac{\mathrm{CP}_i}{\mathrm{WACP}_j}X_i+M_i} \tag{4}$$

The LCTC index reflects both the comparative advantage in trade and the level of relative carbon productivity of the countries in the world. When the imports and exports of country i and the WACP_j remain unchanged, the rise in the domestic carbon productivity of country i will improve its LCTC, whereas the rise of WACP_j will reduce the LCTC of country i. When the WACP_j and the imports remain unchanged, the export increases of country i will improve its LCTC, whereas the import increases of country i will reduce its LCTC.

It can be proven that the LCTC index and the TC index are also between −1 and +1. When the LCTC index is close to 0, it means that the LCTC is closer to average. When the LCTC index is greater than 0, it means that the LCTC is strong, and the closer it is to +1, the greater the competitiveness. When the LCTC is less than 0, the LCTC is weak, and the closer it is to −1, the weaker the competitiveness.

Also, from Equation 1, we can change TC_i into the following equation:

$$\mathrm{TC}_i=\frac{X_i-M_i}{X_i+M_i}=1-\frac{2M_i}{X_i+M_i} \tag{5}$$

Therefore, we can find that the only difference between the LCTC index and the TC index is the difference between $(\mathrm{CP}_i/\mathrm{WACP}_j)X_i$ and X_i. When $\mathrm{CP}_i/\mathrm{WACP}_j>1$, then $\mathrm{LCTC}_i>\mathrm{TC}_i$, and the converse is also true. When $\mathrm{CP}_i=\mathrm{WACP}_j$, then $\mathrm{TC}_i=\mathrm{LCTC}_i$. It can be proven that the traditional TC index is a special case of the LCTC index when $\mathrm{CP}_i=\mathrm{WACP}_j$.

Variable selection

Technology innovation (patent).—The proxy variable for technological innovation frequently used in the literature includes the number of patents (Greenhalgh et al. 1994), the proportion of research and development (R&D) investment to sales revenue (Özçelik and Taymaz 2004), the R&D expenditure and the number of patent applications (Dosi et al. 2014), etc. Patents may only capture a portion of the direct effect of innovation for two reasons: (1) many businesses across a wide swath of industries have trade secrets (i.e., innovations) that are never patented, usually deliberately, and (2) many business practices that are innovative and substantially lower the cost of production are never, or cannot be, patented. Even so, we still selected the number of patent applications, also for two reasons. First, the Patent Cooperation Treaty (PCT) was established and executed by the World Intellectual Property Organization (WIPO), which guarantees consistent and international comparability of statistical caliber of patent data. Second, the number of patent applications can be more directly reflected by the final results of the paper-making industry's R&D activities than an R&D input can, and it reduces the lag effect of technological innovation activities (Greenhalgh et al. 1994).

Carbon tax variables (tax).—Drawing a lesson from the World Bank (2008), we examined the effect of a carbon tax on industrial LCTC by determining whether a carbon tax is levied. *Tax* refers to the virtual variables of whether country i levies a carbon tax in year t. If it levies the carbon tax, it gets a 1; otherwise, it gets a 0. Drawing lessons from Zhang et al. (2014), we designed a cross-term between a carbon tax and the number of patent application ($tax \times patent$) to reflect the effects of the innovation offsets of a carbon tax to examine whether the carbon tax indirectly affects the LCTC of the paper-making industry through technological innovation.

Other variables.—The new factor theory on international trade has expanded the inputs of the production function as capital, unskilled labor, skilled labor (human capital), and knowledge. Human capital is considered to be one of the decisive factors in forming the comparative advantage of a knowledge-intensive commodity. The paper-making industry is a knowledge-intensive industry. Therefore, we chose hours worked by high-skilled and medium-skilled persons engaged as shared total hours worked by all persons engaged to examine the influence of human capital (*skill*; Vernon 1966). We used the forest resource endowment coefficient (*forest*), the labor resource endowment coefficient (*labor*), and physical capital intensity (i.e., the total value of the fixed capital divided by the total employees; *capital*) to analyze the influence of traditional factors (Fu and Li 2010, Yang and Nie 2011). The ''diamond model'' considers a domestic demand scale, and a severe degree of domestic buyers will affect the benefit-of-scale economics, technological innovation, and product innovation investment of domestic firms, which will influence the international competitive advantage of domestic firms. Whether an industry in a country can succeed in international trade competitiveness obviously involves whether it has numerous and competitive support and related industries. The domestic free competition can force domestic firms to try their best to improve management efficiency and quality and to strengthen their innovative ability to create and maintain a competitive advantage (Porter 1990). Therefore, drawing lessons from Liu and Hsu (2009) and from Deng and Liao (2010), we designed a per-gross real domestic product (*rgdp*), a TC index of the paper-making machinery (*machine*), and a marketing degree index (*market*) to analyze the influence that comes from strong domestic demand, from related and supporting industries, and from domestic free-competition status.

Panel data model

The World Bank (2008), Ho et al. (2008), Zhao and Fan (2012), and other researchers have studied the influence of a carbon tax on the international competitiveness of energy-intensive industries with a static panel model. Drawing from their studies, we first built a static panel model as follows (Model 1, Eq. 6):

$$\mathrm{LCTC}_{i,t} = \alpha + \beta tax \times patent_{i,t} + \sigma X_{i,t} + \mu_i + \varepsilon_{i,t} \tag{6}$$

where $\mathrm{LCTC}_{i,t}$ is the paper-making industry's LCTC for country i in year t, α is the intercept term, $tax \times patent_{i,t}$ is the ''innovation offsets'' effect of a carbon tax, β is the parameter of the innovation offsets effect to be estimated, X is the other explanatory variables affecting LCTC, σ is the parameter vector of each variable to be estimated, μ is the individual effect, and ε is the error term.

The new trade theory suggests that a firm's trade behavior has strong sustainability or inertia, which means that previous trade practices will heavily affect trade in the current period. In addition, the effect of inputs such as equipment investment to improve carbon-emissions efficiency is also characterized by sustainability. From the LCTC index of China and other sample countries' paper-making industries, the existence of path dependence is obvious over time; however, the static panel model cannot reflect dynamic attributes (González and Marrero 2012). The ellipsis of lag time in the LCTC index may cause omission errors, which would introduce biased and inconsistent estimated values (Nickell 1981). Drawing on the practice of Marrero (2010) and considering the limited time series of the sample observation, we can add a first-order lag value of the LCTC index into Model 1 to reflect the dynamic change. A dynamic panel Model 2 (Eq. 7) was then built as follows:

$$\mathrm{LCTC}_{i,t} = \alpha + \eta \mathrm{LCTC}_{i,t-1} + \beta tax \times patent_{i,t} + \sigma X_{i,t} + \mu_i + \varepsilon_{i,t} \tag{7}$$

The dynamic panel Model 2 (Eq. 7) does not eliminate unobserved heterogeneity among countries, and endogenous problems may exist in other explanatory variables. A fixed-effect or random-effect model would cause a model-estimation bias. Arellano and Bond (1991) as well as Arellano and Bover (1995) recommend use of the GMM to overcome these problems in a dynamic panel model. Arellano and Bond (1991) described the difference of the GMM method, which has the significant advantage of controlling unobserved time and individual effects with a difference method and of overcoming endogenous problems by using previous explanatory variables and lagged interpreted variables as instrumental variables. Their method, however, cannot estimate the variable coefficients that do not vary over time. In addition, if the explanatory variables have strong sustainability, this will lead to a problem with weak instrumental variables, namely, the lagged value of the level value is no longer an effective instrumental variable for items of difference. To compensate for the abovementioned shortcomings of the difference GMM, Arellano and Bover (1995) as well as Blundell and Bond (1998) introduced the system GMM method (a GMM estimation with a difference equation and a level equation within an equation system) based on the following ideas: (1) adopting a difference equation to erase a fixed effect and horizontal lagged terms for independent variables as instrumental variables of differential terms; (2) adopting lagged differential terms as instrumental variables of the horizontal terms, which increase the number of instrumental variables to solve the problems of weak instrumental variable for the horizontal lagged term; and (3) joining the horizontal equation to the estimate coefficients of the variables that do not change over time.

The effectiveness of the GMM method depends on whether a serial correlation exists in the residuals and whether selection of the instrumental variables is valid. Therefore, we conducted a corresponding test. First, the precondition of using differential GMM is that there is no self-correlation of the disturbance term of the difference equation, which requires an autoregressive (AR) model, where the AR(1) statistic is negative and its P value of AR(1) is <0.05 and its P value of AR(2) is >0.05 to accept the null hypothesis of ''there is no self-correlation of the disturbance term.'' Second, an overidentification test of instrumental variables is required to ensure their effectiveness. A Sargan test should be conducted to examine whether there is an overidentification problem and whether weak instrumental variables exist within the instrumental variables, which require the P value of the Sargan statistic to be >0.05 to accept the null hypothesis of ''selected instrumental variables of model being effective.'' The number of moment conditions, however, increases with growth in the time dimension T in an exponential manner during estimations with the system GMM method (Blundell and Bond 1998), which would reduce the effectiveness of the Sargan test. In addition, when the sample size is limited, excessive identification of instrumental variables will cause model-estimation bias (Roodman 2009). To address this, Roodman (2009) proposed three methods to reduce the number of instrumental variables: (1) using up to q-order of lagged variables as instrumental variables, (2) replacing the matrix of expanding GMM-style instrumental variables with a matrix of collapsing instrumental variables, and (3) using collapsing instrumental variables and restricted lagged order at the same time. In this study, the first and third methods were adopted, with second- and third-order lagged variables used.

Data resources

Import and export data of the paper-making industry, which were required to calculate the TC index and the LCTC index, were taken from the UN Comtrade Trade Statistics database (http://comtrade.un.org/data/). The product codes of the paper-making industry include HS47 (pulp of wood, fibrous cellulosic material, waste, etc.) and HS48 (paper and paperboard, articles of paper pulp, articles of paper, and articles of paperboard), based on the International Convention for Harmonized Commodity Description and Coding System formed in 1992. Import and export data required to calculate the trade competitiveness of the paper-making machinery industry were also taken from the UN Comtrade database, including product codes HS8439 (machinery for making pulp, paper, and paperboard) and HS8441 (other machinery for making paper pulp, paper, and paperboard, including cutting machinery of all kinds); the industrial added value and CO_2 emissions required to calculate the LCTC index, hours worked by high- and medium-skilled persons engaged as shared total hours worked by all persons engaged, gross fixed capital required to calculate the physical capital intensity, and total number of employees all came from the World Input–Output Database (WIOD; Timmer et al. 2015). The number of patent applications for the paper-making industry was the number of patents applied for through the national registration of patent applications by the PCT of the WIPO and from the Organisation for Economic Co-operation and Development (OECD) database (International Patent Classification code, including B31 and D21). The forest area, labor, and the national per-capita GDP required to calculate the forest resource endowment coefficient and the labor resource endowment coefficients were from the World Development Indicators (WDI) database (http://data.worldbank.org/data-catalog/world-development-indicators/), and the market degree index was from the Economic Freedom database of the Economic Freedom of the World project of the Fraser Institute (Miller and Vandome 2011).

The WIOD covers the period from 1995 to 2011, but some important indicators (i.e., hours worked by high- and medium-skilled persons engaged) are only updated to 2009. We still chose the WIOD because of its three advantages: (1) it provides the added value, hours worked by high- and medium-skilled persons engaged, and other indicators that cannot be provided by other databases; (2) the consistent data collection procedures and statistical standards ensure the international comparability among countries and industries; and (3) it provides the sectoral price deflators of 35 departments to avoid the measurement error caused by the differences of price-change trend among different sectors.

The WIOD contains annual time-series data of 40 countries. Therefore, the study samples were initially set to the 40 countries. After sorting the data, we discovered that data for the value of imports and exports of the paper-making industry of Taiwan and Lithuania were missing, so these countries were removed. In addition, some of the remaining 38 countries have implemented Emission Trading Schemes (ETS) since 2005, but other countries have not. To determine the actual effect of a carbon tax on the LCTC of the paper-making industry without the disturbance of the ETS, we made an econometric analysis of the panel data of 38 countries from 1995 to 2004.[2] The carbon tax execution time of the samples was primarily collected from the World Bank (2008) and other relevant research papers and international agency Web sites (e.g., the International Energy Agency, the OECD, the European Economic Areas, and the Seoul Broadcasting System). The 38 countries sampled included those with a traditional power, emerging status, or weak status in the country's paper-making industry, and they accounted for 85 percent of the world's export volume of paper, which guarantees the representativeness of the research sample.

Results

International comparison of paper-making industry LCTCs

Figure 3 shows the changing trends in the TC index and the LCTC index for the paper-making industries of the 38 countries sampled. For the traditional TC index, the international competitiveness of China's paper-making industry showed a characteristic uneven, nonlinear rise from 1995 to 2009; the LCTC index was less than the TC index between 1995 and 2005, which indicates that carbon productivity of China's paper-making industry was lower than the weighted average level of the other 37 countries. However, the LCTC index of China was greater than the TC index since 2006, which indicates the increasing speed of the carbon productivity of China's paper-making industry was faster than the weighted average level of the other 37 countries and lays a solid foundation for a new trend in international competitiveness in the low-carbon economy. The relatively high carbon productivity of the developed countries made their LCTC indexes generally higher than their TC indexes. Some countries' competitive positions have even changed from a competitive disadvantage to a competitive advantage (e.g., Canada, Denmark, Germany, and the

[2] The 38 countries (with carbon tax implementation years in parentheses; no year indicates no carbon tax was levied) included Australia (beginning in 2012 and repealed in 2014), Austria (1996), Belgium, Brazil, Bulgaria, Canada (2007), China, Cyprus, Czech Republic (2010), Denmark (1993), Estonia (2000), Finland (1990), France (1999 only), Germany (1999), Greece, Hungary, India (2010), Indonesia, Ireland (2010), Italy (1998 only), Japan (2007), Latvia (2006), Lithuania, Mexico (2014), Poland (1993), Romania, Russia, Slovakia, South Korea (2015), Malta, The Netherlands (1990), Portugal, Slovenia (1997), Spain (2006), Sweden (1991), Turkey, the United Kingdom (2001), and the United States (1991, carbon composite tax). Countries that levied only a vehicle carbon tax were not included in the study samples.

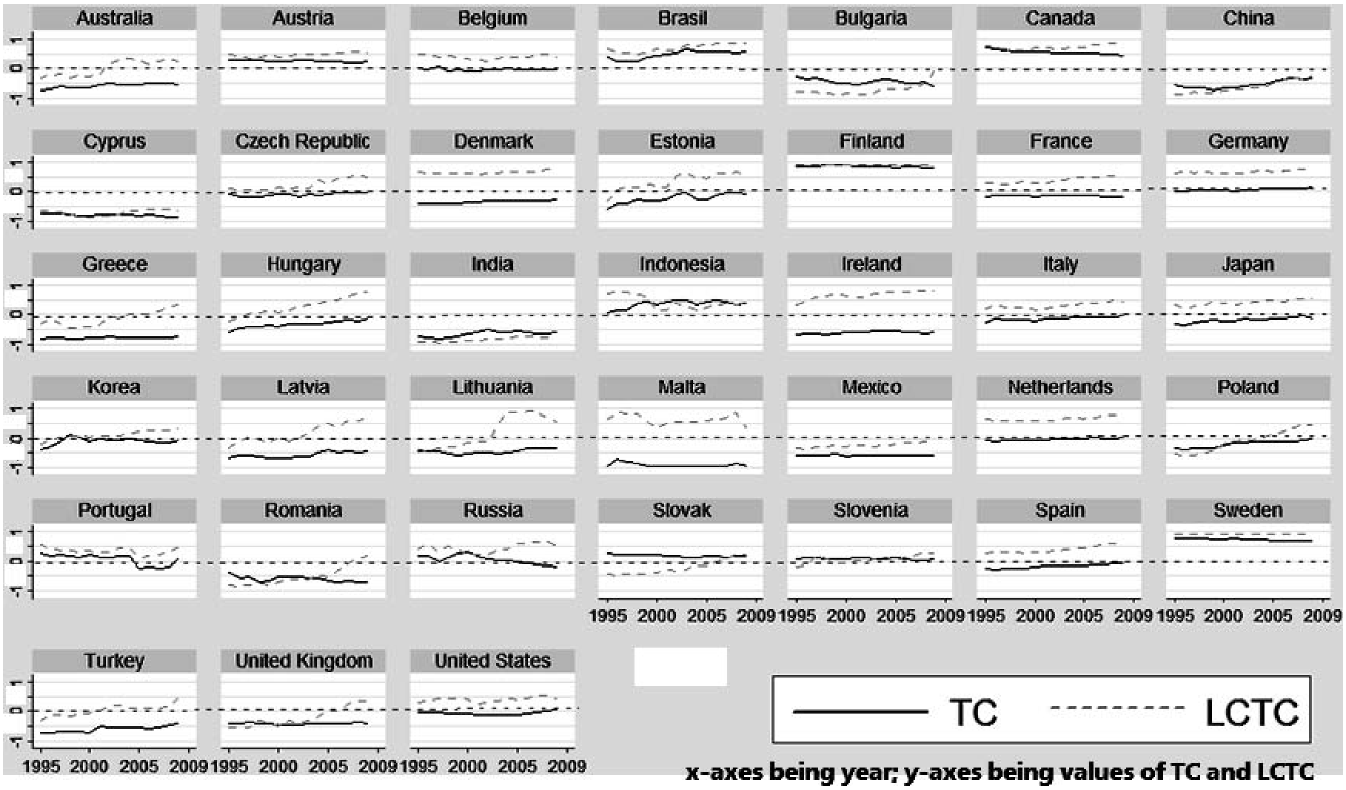

Figure 3.—Changing situations of the traditional trade competitiveness (TC) index and low-carbon trade competitiveness (LCTC) index of the countries sampled.

United States), and some developing countries (e.g., Brazil, Latvia, Russia, and Turkey) have achieved the same effect. However, the situations of some developing countries, such as India, Indonesia, and Slovakia, are similar to that of China, with relatively lower carbon productivity, which has reduced the LCTC of their paper-making industry. Overall, China's paper-making industry is at a competitive disadvantage, and it is necessary to improve its carbon efficiency to promote a low-carbon competitive advantage.

Selection of an econometric model

In our empirical analysis, we were fully aware of the article by Windmeijer (2005) on the problems of the endogenous nature of models, weak instrumental variables, and overidentification.[3] In this study, *forest, labor, rdgp,* and *market* were regarded as strictly exogenous variables. They were instrumental variables in both the level equation and the difference equation. All other explanatory variables were considered weak exogenous variables, and a lagged item for weak exogenous variables was used as an instrument for internal instrumental variables.

Table 1 shows the fitted results of the static panel model and the dynamic panel model, and the result of the variable coefficient estimation varied widely with the different estimation methods. In the static panel model (Column 1 [first column of data]), the coefficient of *tax* × *patent* does not reach significance; in the fixed-effect fitting of the dynamic panel model (Column 2), the coefficient of *tax* × *patent* also does not pass the significance test. The coefficient of LCTC(–1) is significantly negative, which is inconsistent with the actual situation shown in Figure 3, proving the existence of biased estimation results in the model. Columns 3 and 4 show estimation results from the system GMM method in instruments with up to two lags and instruments with up to three lags, respectively, but the P values of the Sargan statistics are <0.05, which denies the null hypothesis and indicates the existence of weak instrumental variables. Column 5 shows the estimation results of collapsing instruments using up to two lags. Although the P value of the Sargan statistic is 0.118 (>0.05), the P value of AR(2) is <0.05, which rejects the null hypothesis and indicates that the selection of instrumental variables is wrong. Column 6 shows the estimation results of collapsing instruments using up to three lags, and the P value of the Sargan statistic is 0.057. AR(1) is negative ($P < 0.05$), and the P value of AR(2) is 0.105, which indicates that the selection of instrumental variables is valid and there are no weak instrumental variables or overidentification problems. All of these situations indicate the model estimation results are valid. Meanwhile, the estimation method proposed by Roodman (2009) significantly reduces the number of instrumental variables in the GMM estimation, from a maximum of 313 to 14. Based on the abovementioned reasons, the estimation results of Column 6 will be discussed below.

[3] Windmeijer (2005, section 4.3) targets the issue that estimated parameter values are vulnerable to being greatly underestimated when the system GMM method system performs estimates from a small sample. The use of STATA's "xtabond2" was developed by Roodman (2006) to address this situation.

Table 1.—Results of estimations from the static panel model and the dynamic panel model.[a]

		Dynamic panel model					
			Instruments		Collapsing instruments		
	Static panel model OLS-FE (1)	OLS-FE (2)	≤2 lags	≤3 lags	≤2 lags	≤3 lags	≤3 lags
LCTC(−1)		−0.066 (0.037)*	1.562 (4.049)	−0.424 (0.168)**	5.582 (1.937)**	0.296 (0.116)**	0.823 (0.074)***
Tax × *patent*	0.0003 (0.0008)	0.0001 (0.001)	0.001 (0.007)	−0.001 (0.001)	0.082 (0.029)**	0.004 (0.002)*	0.002 (0.001)**
Forest	0.054 (0.006)***	0.058 (0.006)***	0.184 (0.363)	0.019 (0.018)	1.205 (0.403)**	0.082 (0.010)***	0.008(0.005)*
Labor	−0.053 (0.010)***	−0.053 (0.009)***	−0.182 (0.068)**	−0.103 (0.022)***	−0.519 (0.165)**	−0.083 (0.012)***	−0.019 (0.006)***
Skill	−0.224 (0.077)***	−0.314 (0.073)***	−1.770 (3.941)	−0.227 (0.139)	−42.870 (15.150)**	−0.007 (0.192)	−0.114 (0.121)
Rgdp	0.014 (0.031)	0.004 (0.029)	−2.748 (6.079)	0.710 (0.371)*	−4.443 (1.540)**	−0.057 (0.023)**	0.004 (0.018)
Capital	0.034 (0.005)***	0.041 (0.005)***	0.425 (0.711)	0.076 (0.013)***	1.318 (0.429)**	0.026 (0.007)***	0.001 (0.003)
Machine	0.559 (0.141)***	0.424 (0.138)***	2.659 (3.807)	0.597 (0.141)***	28.410(9.859)**	0.947 (0.116)***	−0.129 (0.093)
Market	0.152 (0.034)***	0.193 (0.033)***	2.190 (5.949)	−1.014 (0.485)*	4.014 (1.377)**	0.244 (0.021)***	0.031 (0.020)
_Cons	−1.133 (0.206)***	−1.356 (0.208)***	−13.250 (36.040)	5.848 (2.834)*	−9.777 (2.975)***	−1.857 (0.172)***	−0.081 (0.139)
n	380	370	370	370	370	370	532
Instr. matrix *Z*			313	304	15	14	15
AR(1)			−0.51 (0.613)	−2.10 (0.036)	−2.12 (0.034)	−2.86 (0.004)	−3.43 (0.001)
AR(2)				−2.39 (0.017)	2.26 (0.024)	1.62 (0.105)	−1.47 (0.141)
Sargan test			359.01 (0.015)	357.01 (0.007)	8.77 (0.118)	9.19 (0.057)	3.19 (0.670)
Sample time	1995–2004	1995–2004	1995–2004	1995–2004	1995–2004	1995–2004	1995–2009

[a] OLS-FE = fixed-effect model estimated by ordinary least squares; LCTC = low-carbon trade competitiveness. Other variables' implications are as described under ''Variable Selection.'' Values in parentheses are standard errors. *, **, and *** indicate significance at the 10, 5, and 1 percent level, respectively.

Discussion

Column 6 in Table 1 shows the coefficient of LCTC(−1) is 0.296, significantly under the 95% confidence level, which suggests that LCTC has a path dependence in time. The coefficient of *tax* × *patent* is 0.004, significant under the 90 percent confidence level, indicating that a carbon tax exerts an innovation offsets effect on the LCTC of the paper-making industry. This conclusion has been confirmed by the real data samples, in which a carbon tax helped some countries, including Estonia, Spain, and Poland, to improve both their LCTC index and their TC index in the paper-making industry at the same time; helped other countries, such as Sweden, The Netherlands, Finland, Denmark, and the United States, significantly improve their carbon productivity while maintaining a substantially constant TC index; and helped countries such as Canada substantially increase productivity to compensate for the relatively weaker TC index and to enhance its LCTC index.

Our findings suggest a reinterpretation of the broader empirical literature on environmental policy and LCTC. Several studies regarding the impacts of a carbon tax find evidence that the tax does indeed encourage directed carbon reduction (Newcomer et al. 2008, Lu et al. 2012) and trade competitiveness (Liang et al. 2007, Lee et al. 2008, World Bank 2008). In contrast, some studies, like Aldy and Pizer (2011), Cai et al. (2012), and Zhao and Fan (2012), at best unearth evidence of significant negative effects on trade competitiveness. Our results indicate that this discrepancy may be a consequence of the fact that previous studies have not considered the effect of technological innovation induced by a carbon tax and have used static panel models, which could not reflect dynamic attributes of the LCTC and solve for endogenous risk. Extending the results of Aghion et al. (2012), our study completes the latter half of the research on the carbon tax → technological innovation → industrial LCTC pathway and is consistent with the environment hypothesis, indicating that the function of technological innovation induced by a carbon tax can be expressed in a timely manner and can then reduce the negative influences of the increased operation cost caused by the carbon tax.

As mentioned in the ''Theoretical Framework'' section, a carbon tax can stimulate domestic paper-making firms to carry out process- or product-oriented technological innovation and then make an indirect positive effect on international competitiveness. First, regulated enterprises will accelerate the introduction of more energy-efficient technology, energy-saving equipment, carbon capture and storage technology (integrated gasification combined cycle, oxy-fuel, and postcombustion of carbon and oxygen), biomass energy, and other new technology combinations, especially the energy conversion and combined heat and power system, which can help paper-making enterprises to reduce carbon emissions (Calel and Dechezleprêtre 2012). Second, a reasonable carbon tax policy can stimulate paper-making enterprises to enhance the R&D of more green paper and deep processed paper products. In fact, many enterprises establish market competitiveness by building a environment-friendly public image (Porter 1990). Third, a carbon tax and other carbon-emissions control policies will encourage paper-making enterprises to seek ways to reduce both energy consumption and carbon emissions by optimizing their business model and changing their organizational structure, such as through training staff, improving staff skills and energy-saving motives, developing carbon-reduction targets and implementation schedules, auditing energy consumption, integrating processes, implementing energy-saving financing mechanism, etc. (Gulbrandsen and Stenqvist 2013). In addition, knowledge-spillover effects from the regulated paper-making industry itself and from nonregulated industries may increase the low-carbon technology output of the paper-making industry, help them reduce energy consumption and carbon-emissions intensity, and finally, offset the negative effects of higher costs resulting from the carbon tax (Cohen and Miller 2015).

The coefficient of forest resource endowment is significant and positive (0.082), indicating that forest resources remain an important supporting element for the material-dependent paper-making industry. The coefficient of labor resource endowment is significant and negative (–0.083), whereas the physical capital intensity and the TC index of the paper-making machinery are significant and positive (0.026 and 0.947, respectively), indicating that the innovative capability of the machinery is very important for the capital-intensive paper-making industry. However, human capital, which should have been important, does not pass the significance test in the estimation model, possibly because of specialization in the global paper-making industry and employment exchanges between countries that levy a carbon tax and those that do not, causing a ''mismatch'' of the labor market and weakening the function of the human capital factor. The estimated coefficient of per-capita GDP and the market degree index are –0.057 and 0.244, respectively, and both reach the level of significance, indicating that domestic demand is not as important as what Porter (1990) referred to but that the degree of free-market competitiveness does have a positive role.

Stability test

From the conclusions of Lee et al. (2008), we adjusted the study period to between 1995 and 2009—that is, we did not exclude the cross-influence of the ETS first implemented in 2005 so that we could investigate the role of a carbon tax after the introduction of the ETS. Therefore, we built panel data for 38 countries from 1995 to 2009, which resulted in a coefficient of $tax \times patent$ of 0.002, which was significant at the 95% confidence level, using the estimate method of ''collapsing instruments $\leq$ 3 lags.'' This result indicates that in the era of the ETS, although the effect intensity of the carbon tax wakened, the innovation offset effect of the carbon tax still existed, which proves that the indirect promotion of carbon tax is stable.

Remarks, policy implications, and limitations

By combining the TC index and carbon productivity, we built an LCTC index to measure and compare the paper-making industry LCTC of sample countries; we then established a dynamic panel model showing how the carbon tax affects the LCTC of the paper-making industry. Based on panel data from 38 countries between 1995 and 2009, the results using the system GMM method show that a carbon tax exerts an indirect positive influence on the LCTC of the paper-making industry by stimulating technological innovation, which verifies the innovation offset effect proposed by the environment hypothesis, and that positive effect is shown in the current period with no time lag. The United States, the European Union, and other countries that assume carbon-reduction obligations will impose carbon tariffs or border adjustment taxes on energy-intensive goods imported, indicating that the policy coping with ''carbon leakage'' will be growing in intensity. At that time, the paper-making industry in countries not levying a carbon tax will be forced to become a ''taxable entity,'' which ensures that all countries compete equally under low-carbon restrictions, and then the positive effect of a carbon tax might appear.

The policy implications of our findings suggest that governments should strengthen the trigger mechanism of technological innovation to support the positive effect of a carbon tax. The appearance of the innovation offset effect of a carbon tax requires the time and effective technological innovation of paper-making enterprises. Either a country will be proactive and implement a carbon tax, or that country's paper-making enterprise will be forced to become ''taxable entity.'' Government should establish systematic support and operational mechanisms to trigger enterprises' technological innovation. By way of tax cuts, financial subsidies, special energy-saving funds for industry and small firms, interest-subsidized loans, and other similar ways, governments can make use of the carbon tax revenue to compensate firms for the cost resulting from carbon reduction and the opportunity cost of technological innovation, and then encourage and support enterprises to achieve carbon-reduction targets through the technological approach. For example, governments can support the regulated firms and their suppliers of technology and equipment (1) to increase the innovation of low-carbon products and lower energy-consuming equipment and processing techniques; (2) to enhance the innovation of more energy-efficient technologies, carbon capture and storage technologies, pipe-end treating techniques, and other low-carbon technologies; and (3) to enhance the development and utilization of biomass energy, renewable energy, and other similar low-carbon energy. In addition, governments should shift from the direct supervision or policy support to guide firms to initiate low-carbon economic activity as their future strategy, which requires the governments to focus on creating a market environment for low-carbon consumption to ensure that firms can achieve the economic benefit when they reduce their carbon emissions by technological innovation.

This study is not without its limitations. First, owing to the data involving 38 countries spanning 15 years, data collection was difficult, with the result that some indicators that may affect the LCTC of the paper-making industry could not be obtained (e.g., industrial concentration degree, which can reflect the degree of domestic competition in the paper-making industry). Fortunately, the GMM method can solve the endogenous problem caused by omitting variables so as to ensure the accuracy of estimated results. Second, the paper-making sector is characterized by multiple production technologies, different product types, multiple raw materials, and energy as a side product in some of the production technologies (heat recovery with mechanical pulping). For example, chemical pulping technologies are self-sufficient in terms of energy supply, but mechanical pulping technologies require significant external energy. It is therefore difficult to compare the LCTC of paper-making industries internationally and estimate the influence of a carbon tax on LCTC because product mixes and energy supplies differ dramatically among countries. Third, many paper manufacturers have established long-term relationships with suppliers (i.e., the chemical products, electricity, natural gas, and water supply industries, etc.) and distributors of their products. These suppliers and distributors also have patents and trade secrets that can lessen the cost of doing business for the paper manufacturer, improve product quality, and increase carbon productivity, which can enhance the LCTC of the paper-making industry. Consequently, we intend to empirically research the ''indirect effects of innovation'' from the patents and trade secrets of suppliers and distributors for paper manufacturers.

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