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Trade-induced technological change: Analyzing economic and environmental outcomes[☆]

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ABSTRACT

We analyze how changes in trade openness are related to induced technological innovations that are not only GDP increasing but also pollution saving. Our model includes by-products of carbon dioxide and sulfur dioxide emissions. We estimate a directional distance function for 76 countries over the period 1963–2000 to measure exogenous and trade-induced technological change. On average, we find substantial trade-induced technological progress, and its magnitude is about one third of the overall technological change. The trade-induced technological changes, however, are GDP reducing and pollution increasing. Empirically, we find that increased trade openness correlates to increased pollution.

1. Introduction

Technological progress allows standards of living in the world to increase. International trade plays an important role in technological change (e.g., Grossman and Helpman, 1991).[2] This study extends the traditional measures of technological change to take account of the production of undesirable by-products (i.e., environmental pollution), which may lead to decreases in the level of human welfare. Then, we test whether there is significant trade-induced technological progress, and whether international trade is able to encourage the efficient reduction of the negative externalities as well as faster traditional technological progress.

The environmental impact of trade liberalization is one of the most important questions in trade policy in the past 10 years (Copeland and Taylor, 2005). Previous studies have ignored the technological effects induced by trade on the environment. Trade can affect the environment in two ways: *terms of trade effect* and *trade-induced technological effect* (Maria and Smulders, 2004). Several empirical studies on trade and the environment support the pollution haven hypothesis, i.e., that international trade allows developed countries to clean up their environments at the expense of those in developing countries.[3] These studies apply the terms of trade effect argument, i.e., that environmental regulations are relatively weak in developing countries, and these countries specialize in the production (or export) of dirty goods.

However, if production techniques improve because of trade, then a greater share of dirty goods production might be associated with lower pollution levels (Copeland and Taylor, 2005).[4] In the literature, insufficient evidence exists to understand the trade-induced technological effect: there are only a few theoretical studies that deal with

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[2] A number of studies found a positive link between international trade and productivity growth (e.g., Coe et al., 1997; Chaudhari and Hakura, 2000). However, the theoretical and empirical literature is ambiguous about the direction of causality between international trade and productivity growth (e.g., Rodrik, 1988, 1992, 1995; Havrylyshyn, 1990; Tybout, 1992). Given this ambiguity, understanding the effects of trade liberalization on productivity growth requires further empirical investigation.

[3] See Antweiler et al. (2001), Cole and Elliott (2003), Frankel and Rose (2005), and Levinson and Taylor (2008) for recent empirical studies identifying the association between trade liberalization and the environment.

[4] Trade openness may be associated with sectoral shifts in the economy. The sectoral shifts change may cuase change in pollution intensity of GDP and the consequences of certain kinds of technical change.

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endogenous technology and pollution haven effects (e.g., Golombek and Hoel, 2004; Maria and Smulders, 2004). Maria and Smulders (2004) follow the theory of directed technological progress in Acemoglu (2002) and show that trade-induced technological change may reverse (or exacerbate) the pollution haven effect. However, at least to our knowledge, there are no previous empirical studies that test the effects of trade on technological progress that consider both market and environmental factors. Our study contributes to the literature by developing methodologies and empirically examining the effects of trade liberalization on markets and environmental technology, in both developed and developing countries, within the framework of productivity measurement.

Conventionally, productivity is measured using index numbers that require price information. Although price information for marketed commodities is available, those for bad outputs (i.e., pollution) are not available. The use of a distance function may help overcome such problems. (e.g., Färe et al., 2005; Boussemart et al., 2006; Guironnet and Peypoch, 2007; Managi and Jena, 2008.). Distance functions are more general representation of production technology of a firm. They require only quantitative information about inputs and outputs. A general method of measuring total factor productivity (TFP) using the distance function is the Malmquist index (Färe et al., 1994). However, incorporation of bad outputs into the Malmquist index can be problematic. As the Malmquist indexes are radial in nature, firms cannot be credited with the reduction in bad outputs. Therefore, it does not allow for changes in technology that reduce the pollution generated whilst increasing the production of good outputs. In other words, it does not capture "decoupling" of the production of good outputs with bad outputs. If there has been a decoupling of pollution and production, then there may be computational problems associated with using the distance function (Kumar, 2006).

There is a large body of literature measuring productivity in the presence of production of undesirable outputs. Some studies have treated the bad outputs as inputs[5] while others have treated them as synthetic outputs such as pollution abatement (e.g. Gollop and Roberts, 1983). Considering bad outputs as inputs is inconsistent with the material balance approach[6] (Murty and Russell, 2002). Similarly, the treatment of a reduction in bad outputs as good outputs creates a different nonlinear transformation of the original variable in the absence of base-constrained emission rates (Atkinson and Dorfman, 2005). To overcome the problems, Pittman (1983) proposed asymmetric treatment of good and bad outputs. Chung et al. (1997), Färe et al. (2005), and Managi et al. (2005) use the directional distance function to calculate production relationships involving good and bad outputs that treat good and bad outputs asymmetrically. The productivity indicator credits producers for simultaneously increasing good outputs and reducing bad outputs.

We use a directional distance function as a representation of production technology. This function simultaneously seeks to expand good outputs and reduce bad outputs. It is particularly well suited to providing a measure of technical efficiency in the full input–output space, and satisfies all those properties required by conventional representations such as production or profit functions. Using the dual *Hotelling lemma*, one can derive the inverse of input demand and output supply functions from the directional distance function.

The decompositions of TFP into technological change and efficiency change are analogous to the notions of technological innovation and adoption, respectively. Technological change is further decomposed into trade-induced as well as exogenous technological change effects. We also address the dual measures of output and input bias arising from technological change. The estimates of the direction of technological change help us analyzing whether the trade is beneficial for the environment.

The production frontier is constructed based on data for 76 countries for the period 1963–2000. Our data allow for a more thorough assessment of the production processes that generate carbon dioxide (CO_2) and sulfur dioxide (SO_2) emissions from the use of energy where energy consumption is included in the input side. This paper uses the maximum likelihood method to estimate a directional output distance function. We find substantial trade-induced technological progress, and its magnitude is about one third of the overall technological change. The trade-induced technological changes, however, are GDP reducing and pollution increasing. Empirically this corroborates to the fact that increased trade openness correlates to increased pollution.

The remainder of the paper is structured as follows. In Section 2, we provide the model. Section 3 discusses the estimation procedure and data used in the study. The results are analyzed in Section 4. The concluding remarks are provided in Section 5.

2. Model

To measure trade-induced technological progress, we use a directional output distance function. A directional output distance function seeks to expand the vector of desirable output (such as GDP), $y \in \mathfrak{R}_+^{\mathfrak{M}}$, and reduce the vector of bad outputs (such as CO_2 and SO_2 emissions), $b \in \mathfrak{R}_+^{\mathfrak{N}}$, by employing a vector of inputs (such as labor, capital and energy use), $x \in \mathfrak{R}_+ \mathfrak{K}$. The function inherits its properties from the production technology, *P(x)*. The production technology is defined as:

$$P(x) = \{(x, y, b) : x \text{ can produce } (y, b)\}. \tag{1}$$

The production technology may be modeled in alternative ways.[7] Good outputs are assumed to be null-joint with the bad outputs.[8] Formally, the directional output distance function is defined as:

$$D(x, y, b; g) = \max_{\beta} \left\{ \beta : \left(y + \beta \cdot g_y, b - \beta \cdot g_b \right) \in P(x) \right\}. \tag{2}$$

This function requires a simultaneous reduction of bad outputs and expansion of good outputs. The computed value of β (i.e., β^*) provides the maximum expansion of good outputs and reduction of bad outputs if a firm has to operate efficiently given the directional vector g. The vector $g = (g_y, -g_b)$ specifies the direction in which an output vector ($(y,b) \in P(x)$) is scaled so as to reach the boundary of the output set at the point $(y + \beta^* \cdot g_y, b - \beta^* \cdot g_b) \in P(x)$ by expanding the good outputs and reducing the bad outputs, where $\beta^* = D(x,y,b;g)$.

The directional output distance function derives its properties from the output possibility set, *P(x)* (see Färe et al., 2005).[9] These properties include monotonicity conditions on the good and bad outputs, and from its definition a translation property which is the

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[5] See Cropper and Oates (1992), Kopp (1998), Reinhard et al. (1999), and Murty and Kumar (2004).

[6] According to material balance approach, the residuals (pollution) at the end of the materials flow are determined by all materials entering that flow as well as by all transformation processes in production and consumption activities.

[7] The output is strongly or freely disposable if $(y, b) \in P(x)$ and $(y', b') \leq (y, b) \Rightarrow (y', b') \in P(x)$. This implies that if an observed output vector is feasible, then any output vector smaller than that is also feasible. This assumption excludes production processes that generate bad outputs that are costly to dispose of. For example, concerns for pollution reduction imply that these should not be considered to be freely disposable. In such cases, bad outputs are considered as being weakly disposable: $(y, b) \in P(x)$ and $0 \leq \theta \leq 1 \Rightarrow (\theta y, \theta b) \in P(x)$. This implies that pollution is costly to dispose of and that abatement activities would typically divert resources away from the production of desirable outputs, leading to lower good outputs for given inputs.

[8] Null-jointness implies that a firm cannot produce good outputs in the absence of bad outputs, i.e., if $(y,b) \in P(x)$ and $b = 0$ then $y = 0$.

[9] For the properties of directional output distance functions, see Färe et al. (2005).