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A sequential Malmquist–Luenberger productivity index: Environmentally sensitive productivity growth considering the progressive nature of technology

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ABSTRACT

This study proposes an index for measuring environmentally sensitive productivity growth which appropriately considers the nature of technical change. The rationale of this methodology is to exclude a spurious technical regress from the macroeconomic perspective. In order to incorporate this in developing the index, a directional distance function and the concept of the successive sequential production possibility set are combined. With this combination, the conventional Malmquist–Luenberger productivity index is modified to give the sequential Malmquist–Luenberger productivity index. This index is employed in measuring environmentally sensitive productivity growth and its decomposed components of 26 OECD countries for the period 1970–2003.We distinguish two main empirical findings. First, even though the components of the conventional Malmquist–Luenberger productivity index and the proposed index are different, the trends of rates of average productivity growth are similar. Second, unlike in previous studies, the efficiency change is the main contributor to the earlier study period, whereas the effect of technical change has prevailed over time.

1. Introduction

In recent decades extensive studies have been made to measure environmentally sensitive productivity growth and its decomposed sources. The expansive development of this research area is in the line with increasing international concerns about climate change and sustainable economic growth. These concerns, in turn, have induced global cooperation in environmental regulations, such as the Kyoto Protocol and the Intergovernmental Panel on Climate Change (IPCC). These international mutual assistance systems for environmental change basically require the assessment of emissions of environmentally harmful by-products through the simultaneous consideration of the environmental, economic as well as technical points of view. This means that the enviro-economic policies, especially those related to climate change, should be made with a multi-facet assessment regarding the features of environmentally harmful by-products.

In order to meet the above prerequisite for the assessment of enviro-economic policies, research with different foci has been demanded to empirically measure the impact of emissions of by-products. This research includes not only theoretical approaches but also empirical studies. Among the range of methodologies in this area, the Malmquist–Luenberger productivity index (hereafter, ML index) has long been widely employed in applied research. Since it only requires the quantities on the input/output bundles without demanding information on costs of inputs/outputs, it has been widely used in applied studies, especially for measuring environmentally sensitive productivity growth in the field of energy and environmental economics. Another favorable aspect is that the ML index does not require any functional form assumptions on the production function. Moreover, the ML index enables environmentally sensitive productivity growth to be decomposed into several components, such as efficiency change and technical change. Thanks to the above methodological merits, the ML index has been frequently utilized not only in micro-level but also in macro-level studies.

With regards to the micro-level, Chung et al. (1997) is the first one. They analyze productivity growth and its decomposed sources of Swedish paper and pulp mills for the period 1986–1990. Their empirical results suggest that technical change is the main contributor

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to productivity growth. Weber and Domazlicky (2001) apply the same methodology to investigate productivity growth in the US manufacturing sector for the period 1988–1994 in order to incorporate toxic release into the productivity analysis. Arocena and Waddams Price (2002) employ the ML index to measure productivity differences of Spanish electricity generators between private and public sectors for the period 1984–1997. Nakano and Managi (2008) measure productivity in Japanese steam power-generation sector to examine the effects of industrial reforms on the productivity for the period 1978–2003. Barros (2008) employs the ML index to examine the productivity growth and its components of the hydroelectric energy generating plants in Portugal. Yu et al. (2008) examine the productivity growth of Taiwan's airport sector by studying the 1995–1999 operations of four airports.

The ML index is also employed in measuring environmentally sensitive productivity growth at the macro-level. Yörük and Zaim (2005) employ both the Malmquist index and the ML index in order to analyze productivity growth and its decomposed sources in OECD countries for the period between 1985 and 1998. They found that Ireland and Norway were the best performers and that technical change was the main contributor to productivity growth. Färe et al. (2001) employ the ML index to account for both marketed output and the pollution abatement activities in US state manufacturing sectors from 1974 to 1986. Kumar (2006) employs the ML index to analyze the environmentally sensitive productivity growth of 41 countries for the period between 1973 and 1992. In his study, Kumar found that the productivity growth of Annex-I countries are higher than that of Non-Annex-I countries, and that technical change was the main contributor to productivity growth. Zhou et al. (2010) employ the ML index to examine CO_2 emission performance of 18 top CO_2 emission countries from 1997 to 2004. Kortelainen (2008) examines environmental performance of 20 EU member states by employing the ML index.

In spite of its wide use, the conventional ML index has a weak point in that it does not appropriately consider the nature of technology. That is, although in general the technology always progresses or at least remains unchanged from the macroeconomic perspective, the conventional ML index often yield long-run technical deterioration when measuring environmentally sensitive productivity growth. Needless to say, as noted by Shestalova (2003), when we consider the features of technology at the industry level, it is not uncommon to observe technical regress in some industrial branches such as the mining sector. Except for those particular branches, it is quite undeniable that in general the technology at least remains unchanged in most industrial sectors. For example, the ratio of CO_2 emissions to energy productions continuously decreases for the period between 1965 and 2005, which reflects that environmental technology progresses or *at least* remains unchanged.[2] Hence, the technology of an economy, being the aggregate of all industrial sectors, should be considered as being in the state of progress or at least as remained unchanged. Especially for the developed countries such as OECD member countries, which will be empirically examined in this study, it is fairly rational to assume that technology progresses or remains unchanged. If we employ the conventional ML index in analyzing data of those countries, it is very frequent to observe technical regress. In Kumar (2006) the half of sample countries showed technical regress, and in Zhou et al. (2010) rates of technical change is negative in almost half of the studied period. Therefore, it is important to adjust the underlying assumptions in the conventional ML index in order to consider the progressive feature of technology.

Recall the necessity of the multi-facet assessment of emissions of by-products. If we employ the conventional ML index in assessing environmentally sensitive productivity growth index, it is obvious that the technical aspect of the three dimensions is left out. Conversely, this means that the feature of technical change is not properly considered in the conventional ML index. Hence, it is necessary to be cautious when assessing the empirical results of the ML index, especially in developing environmental policies. This means that the empirical results obtained by the conventional ML index inherit a likelihood of being biased. Hence, in order to eliminate this dormant bias in the technical change, the conventional ML index needs to be revised.

In this study, we propose an environmentally sensitive productivity growth index which is free from the aforementioned spurious technical regress. We provide this index by augmenting the basic assumptions in the conventional ML index. This measure not only properly reflects the progressive nature of technology but also accordingly yields an unbiased productivity growth index. In developing our methodology, we combine the concept of the successive sequential reference production sets of Tulkens and Vanden Eeckaut (1995) and the concept of the directional distance function (DDF) of Luenberger (1992). We employ the DDF in order to properly deal with environmentally harmful by-products (Färe et al., 2007a). The combination of these two concepts enables us to develop a sequential directional distance function. Our environmentally sensitive productivity growth measure utilizes this sequential directional distance function. We name this environmentally sensitive productivity measure the sequential Malmquist–Luenberger productivity index (hereafter, SML index). Like the conventional ML index, the SML index can also be decomposed into underlying components of productivity growth.[3] It should be noted that, if undesirable outputs are not included in the SML index, the SML index is equivalent to the SM index of Shestalova (2003) and Thirtle et al. (2003). The advantages of using the sequential production possibility sets in calculating the M index are discussed in Shestalova (2003) and Thirtle et al. (2003).

The proposed index is employed in measuring the environmentally sensitive productivity growth, efficiency change and technical change of 26 OECD member countries over the period 1970–2003. Empirical results show that the efficiency change is the main contributor during the earlier part of our study period, whereas technical change is the main contributor during the later part of the study period. Interestingly, this finding is somewhat different from those of the previous studies, in which technical change is the main contributor to productivity growth. Another finding is that the Nordic countries have a higher level of productivity growth among OECD member countries for the study period. For comparison purposes, the result of our methodology is compared with that of the conventional ML index. The result of this comparison

[2] The ratio of CO_2 emissions to energy productions of OECD member countries is as follows: 10.86 kt/ktoe (1965–1975), 7.29 kt/ktoe (1976–1985), 6.12 kt/ktoe (1986–1995), and 6.01 kt/ktoe (1996–2005), where numbers in parentheses are years. We thank an anonymous referee for his/her invaluable comment.

[3] It is arguable that the ML index employing the windows analysis is similar with our SML index in that it constructs a production possibility set by using observations of some consecutive years. The ML index with the windows analysis is widely used in previous studies, including Färe et al. (2001), Färe et al. (2007b), Yörük and Zaim (2005), Kumar (2006), Zhou et al. (2010) and Yu et al. (2008). These studies construct production possibility sets by using observations of three or more consecutive years. For example, when measuring directional distance functions at time period t, observations over the period between $t-2$ and t construct a production possibility set. This approach has an advantage that it can solve an infeasibility problem of mixed-period directional distance function, as argued by Färe et al. (2001). Another advantage is that measured directional distance functions are smoothed over the studied period since observations of some consecutive years construct an approximately smoothed surface (Yu et al., 2008). Usage of the ML index with the windows analysis mainly comes from these advantages. This also means that the purpose of the ML index with windows analysis is quite different from the SML index since the initial starting point of the former is not to reflect the progressive nature of technology. In this sense, we see that the SML index is different from the ML index with windows analysis. We thank an anonymous referee for this invaluable comment.