Ecological Economics 69 (2010) 1666–1674

Contents lists available at ScienceDirect

Ecological Economics

journal homepage: www.elsevier.com/locate/ecolecon

Analysis

An economic analysis of Midwestern US criteria pollutant emissions trends from 1970 to 2000

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ARTICLE INFO

Article history:
Received 14 April 2009
Received in revised form 21 March 2010
Accepted 21 March 2010
Available online 3 May 2010

Keywords:
Emission intensity
Regional environmental–econometric input–output model
Economic structure

ABSTRACT

From 1970 to 2000, U.S. economic output doubled but emissions of four criteria pollutants from economic activity—CO, NO*x*, VOC, and SO_2—decreased by 20%. Understanding what factors have contributed to this pollution reduction in the U.S. as a whole, as well as in various regions within the country, has important policy implications. A recently developed regional environmental–econometric input–output model for the Midwestern states of the U.S. has been used to examine the causes of pollution reduction in this regional economy over a thirty-year period. Simulations conducted with this model suggest that, for the rate of growth experienced over the period, technological improvement has dominated economic structural change in the reduction of pollutant emissions. On average, technological improvement has accounted for approximately 80% of emissions reduction, while economic structural change explains the remaining 20% of the decrease. Our analysis suggests that, while much remains to be done in reducing emissions in both developed and developing countries, policies that are informed by an understanding of the role of structural change and which promote the adoption of more recently developed technologies may contribute substantially to sustainable development.

1. Introduction

The 1970 Clean Air Act and the establishment of the United State Environmental Protection Agency (USEPA) initiated a new era of protecting human health and the ecosystem from harmful air pollution in the U.S. Since then, emissions of airborne so-called ‘criteria pollutants’ in the country (http://www.epa.gov/air/urbanair/) have decreased markedly. For example, from 1970 to 2002, emissions of carbon monoxide (CO), nitrogen oxides (NO*x*), volatile organic compounds (VOC), and sulfur dioxide (SO_2) decreased by 48%, 17%, 51%, and 52%, respectively (USEPA, 2003), while U.S. economic output doubled. These reductions are believed to have been achieved largely through technological advances induced by strict regulations and market forces. On the other hand, economic structural change, or the change in the composition of an economy's industrial output, may also have contributed to reduced emissions (Casler and Blair, 1997; Selden et al., 1999; Kimmel et al., 2002; Tao et al., 2007). Selden et al. (1999) analyzed the U.S. emissions trends from 1970 to 1990 and found out that the economic structural change reduced emissions at a smaller scale than technology (including energy efficiency and other technique) did. Kimmel et al. (2002) concluded that the decreases in CO, SO_2 and NO*x* emissions in the capital of Estonia were due largely to the restructuring of the Estonia economy and shift away from the usage of sulfur-rich fuel. The causes of U.S. economic structural change are manifold. First, demand for services has grown faster than that for manufactured goods; second, productivity in manufacturing has increased more than that in services, leading to higher wages in manufacturing and a substitution away from labor to service inputs in manufacturing production, hence to higher output from the service sector; and third, in the era of globalization, relocation of some manufacturing production out of the country has resulted in services accounting for a larger share of gross product in the entire economy. These structural changes may have effectively reduced pollution in regions that outsourced production by heavily polluting industries while the goods produced in these sectors were obtained through international trade generating increased pollutant emissions in other parts of the world.

Answering the question of what accounts for reductions in some pollutant emissions of US industry—technology vs. economic structural change—has important policy implications (Levinson, 2008). If economic structural changes, not technological improvements, account for the majority of pollution reductions in the U.S., then the U.S. pattern of industrial production is not sustainable and cannot be replicated elsewhere in the world, since the least developed countries

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0921-8009/$ – see front matter
doi:10.1016/j.ecolecon.2010.03.016

may never be able to import pollution-intensive goods from even poorer countries. Levinson (2008) has analyzed the causes of pollutant emissions reductions in the U.S. manufacturing sectors and pointed out that approximately 75% of the reduction has been due to improved technologies and that changes in the composition of output have accounted for the remaining 25%. Since the 1980s, there have been other studies focusing on the impacts of structural and technological changes on energy consumption and its related gas emissions, particularly carbon dioxide (CO_2), using various decomposition methods (see, e.g., Dietzenbacher and Los, 1998; Ang and Zhang, 2000; and Hoekstra and van den Bergh, 2002, 2003). Ang and Zhang (2000) reviewed the decomposition methods developed and applied from the late 1970s to 2000 in analysis of energy and environmental emissions. Among all methods, they found that the revised Laspeyres method and the log mean divisia method showed superiority to others in that they were complete decompositions and no residual was produced.

Despite the progress made in analyzing the relationship between changes in industrial structure and technology and CO_2 emissions, little has been done in the way of systematic analysis of the relationship between pollutant emissions reduction and regional economic structure as a whole. In this paper, we report on research in which a newly developed regional environmental–econometric input–output model has been used to explore the sources of and changes in pollutant emissions generated by economic activity in the Midwestern U.S. The emissions selected for study come from a wide range of sources, including those resulting from energy consumption, material usage, and beyond. We also explore how technological and structural changes have contributed to reductions in emissions in this region between 1970 and 2000. In the next section, the Midwest model will be presented; Section 3 provides the results and their interpretation, and the paper concludes with some summary comments in the final section.

2. Methods

2.1. Midwest Regional Econometric Input–output Model (MW-REIM)

The core of the modeling system we employ is the Midwest regional econometric input–output model (MW-REIM) developed in the Regional Economics Applications Laboratory (REAL) of the University of Illinois at Urbana-Champaign (http://www.real.uiuc.edu). The MW-REIM is a dynamic general-equilibrium model that covers 5 Midwestern states (Illinois, Indiana, Michigan, Ohio, and Wisconsin) and the rest of the U.S. (RUS), and includes 13 economic sectors and government activity for each region. It highlights economic linkages among the system variables via two components—an input–output (I-O) module and a time-series module—and identifies comprehensively the sectoral and regional linkages (Hewings and Parr, 2007). The I-O module is based on 1992 and 1997 multiregional input–output tables, and annual regional economic data from 1969 to 2000. In addition, the I-O module allows forward and backward linkages to be extracted by generating annual input–output tables (Israilevich et al., 1997). The I-O module enables a detailed analysis of purchases and sales between industries and makes it possible to integrate the overall environmental effects, e.g., pollutant emissions and demand–supply interactions among economic sectors. The time-series module allows for the analysis of inter-temporal change in the transaction flows of goods and services. Together these two modules yield a detailed analysis of structural change over time at the sectoral level.

The original discrete-time MW-REIM has been adapted to a continuous-time formulation, such that the inter-temporal changes in the time-series module are characterized by a system of non-linear differential equations. The equations of the model are solved by a numerical variable-step, variable-order Adams method and the model's parameters have been estimated by a non-linear quasi-full-information maximum-likelihood method (Wymer, 1993, 1997). Further details can be found in Williams et al. (2008) or Donaghy et al. (2007).

The model's solution fits the available annual economic data very well (in-sample) and is also structurally stable in dynamic simulations out of sample—none of the endogenous variables has a proportionate forecast error larger than 4% (Williams et al., 2008). Therefore, we have chosen the in-sample period model solution to represent actual economic output in this study.

For this study, we have extended the continuous-time MW-REIM to examine industrial emissions of three criteria pollutants (CO, NO_x, SO_2) and VOC, an important contributor to ozone pollution. These pollutants were chosen for consideration because they were either criteria pollutants or precursors to criteria pollutants that had been regulated by the US EPA, and time-series observations on them were available in the U.S. EPA emissions inventories. For simplicity, we have treated all four pollutants as criteria pollutants in this study. We have excluded CO_2 from current analysis because it is not designated as or links to the criteria pollutants.

By analyzing emissions and economic activity of each sector of the model, we were able to formulate sectoral emission intensity (I) in each sample year. I characterizes emissions per unit of sectoral economic output (in constant monetary terms) and reflects the impact on emissions of technological advances. Sectoral output is a function of economic structure. Pollutant emissions (EMS) are then determined by emissions intensity factors I and levels of sectoral output as shown in Eq. (1):

$$EMS = I \times output. \quad (1)$$

Combinations of I and sectoral output from different years yield projections of pollutant emissions under various scenarios of combinations of technology and economic structural changes, and thus, in an internally consistent way, allow for quantitative analysis of contributions from either factor to reduced pollution in the U.S. since 1970s.

2.2. Emission Intensity (I)

Development of emission intensity factors, I, is necessary to analyze the impact of technology and economic structural changes on pollutant emissions. Rearranging Eq. (1) yields I, given known emissions and sectoral outputs. In this study, the present emissions are represented by the 1999 U.S. National Emissions Inventory (NEI99) that includes point, area, and on-road mobile sources (http://www.epa.gov/ttn/chief/net/1999inventory.html). The sectoral economic output is obtained from the MW-REIM as described in Section 2.1. Since the economic output from MW-REIM incorporates a measure of how much an endogenous variable changes in response to changes in exogenous variables, the sectoral I calculated based on Eq. (1) also includes the multiplier effect.

NEI99 is organized and reported according to the Source Characterization Code (SCC, http://www.nj.gov/dep/aqm/es/scc.pdf), which reflects the actual pollutant emitting process. On the other hand, MW-REIM uses either Standard Industrial Classification code (SIC, http://www.osha.gov/pls/imis/sic_manual.html) or North American Industry Classification System (NAICS, http://www.census.gov/epcd/www/naics.html) to group and analyze economic activities (Table 1). Thus, mapping NEI99's SCC emissions to MW-REIM's SIC/NAICS emissions is essential to generating sectoral output based I. There are nearly 10,000 Source Characterization Codes (SCCs) in NEI99 vs. 13 economic sectors used in MW-REIM. In NEI99, all point source SCCs and approximately 16% of nearly 1200 area SCCs have an associated SIC. Another 4% of the area SCCs are related to household activities that are excluded from this analysis. The USEPA has developed the Economic Growth Analysis System (EGAS, http://www.epa.gov/ttn/chief/emch/projection/index.html) to generate activity growth factors used in the development of emissions inventories. We assigned 30% of area SCCs to a particular SIC following the EGAS mapping. The mapping of the remaining 50% of the