

# Analysis of the trade-off between economic growth and the reduction of nitrogen and phosphorus emissions in the Poyang Lake Watershed, China

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## ABSTRACT

Lake eutrophication leading to water pollution is a major global concern. In recent years, rapid economic growth and the increase in the intensity of resource exploitation in China have caused the influx of nitrogen and phosphorus into lakes. This in turn has led to more severe lake eutrophication, more frequent outbreaks of algal blooms, and the degradation of lake ecosystems. An effective plan balancing economic growth with the reduction of nitrogen and phosphorus emissions is greatly needed. The design and implementation of such a plan requires the collection and analysis of pertinent data. In this paper, we use the environmental computable general equilibrium (ECGE) model to identify the most effective way to balance economic growth with the reduction of nitrogen and phosphorus emissions. For the multi-regional analysis, we use social accounting matrices (SAMs) and a provincial trade matrix based on the assumptions of the gravity model. We consider the Poyang Lake Watershed as a case study to illustrate the utility of the model. Based on present conditions in the Poyang Lake Watershed, restricting nitrogen and phosphorus emissions from sectors with the highest emissions is more effective for balancing economic growth and the reduction of nitrogen and phosphorus emissions than restricting nitrogen and phosphorus emissions from all sectors.

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## 1. Introduction

Lake eutrophication is the primary water quality problem affecting freshwater and coastal marine ecosystems throughout the world (Smith, 2009). Lake eutrophication is caused primarily by human activities and is recognized worldwide as a serious problem for water quality management (Matsuoka et al., 1986; Huang et al., 2008). In 1973, the Organization for Economic Cooperation and Development (OECD) concluded that the influx of nitrogen and phosphorus is the primary cause of lake eutrophication, as indicated by the total nitrogen (TN) and total phosphorus (TP) contents. For example, Sas (1989) found that algae grow uncontrollably once the soluble phosphorus content exceeds 0.01 g/L. Human activity is the primary source of the influx of nitrogen and phosphorus into lakes. Omernik (1976, 1977) examined the relationship between nitrogen and phosphorus concentrations and regional land use, and found that the concentration of nitrogen and phosphorus in water

is extremely high in regions with well-developed industry and agricultural sectors. Although extensive research has been conducted during the past five decades, many key questions remain unanswered (Smith and Schindler, 2009). In waters susceptible to lake eutrophication, human activities have been linked to the extent and magnitude of algal blooms (Paerl et al., 2001). Humans are now strongly influencing almost every major aquatic ecosystem, and their activities have dramatically altered the flux of growth-limiting nutrients between land and water. Unfortunately, these nutrient inputs have had a profound negative effect on the quality of surface water (Smith, 2003).

Lake eutrophication is a dynamic process related to the influx of nutrients, particularly nitrogen and phosphorus, that have a detrimental effect on aquatic ecosystems, water quality, and the internal nutrient cycle (Ikeda and Adachi, 1978; Rabalais, 2002; Camargo and Alonso, 2006). Nutrient exports derived directly or indirectly from human activities can cause rapid and extreme eutrophication in previously uncontaminated waters (Wang and Wang, 2009; Smith, 2009). Thus, controlling nitrogen and phosphorus input from human activity is essential to reducing eutrophication (Havens et al., 2003; Arhonditsis and Brett, 2005). Although several studies have focused on how to control lake eutrophication, few have succeeded in formulating optimum control policies for a

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specific watershed (Hein, 2006). Thus, the systematic investigation of eutrophication in a specific watershed can give us a detailed view of how to control lake eutrophication.

In 1972, the Organization for Economic Cooperation and Development (OECD) decreed that polluters should be responsible for the cost for pollution abatement. Since then, several countries have developed policies based on this principle. This system encourages polluters to reduce pollutants by improving production technologies, employing new equipment, or reducing production (Horridge et al., 2005). Thus, controlling lake eutrophication while sustaining economic growth has become an area of intense research in the field of water quality management.

Many of China's lakes are threatened by eutrophication, in particular those located along the middle and lower reaches of the Yangtze River (Huang et al., 1998; Jin et al., 1999; Zhao and Feng, 2002; Yan et al., 2003). Although eutrophication in Poyang Lake, which plays an important role in the water resource regulation of the Yangtze River, is not yet very serious, the threat of hypereutrophication exists. The water quality of Poyang Lake is steadily deteriorating (Wang et al., 2008). Local governments have been tasked with trying to control the eutrophication of Poyang Lake. In this paper, we explore the trade-off between economic growth and the reduction of nitrogen and phosphorus emissions in the Poyang Lake Watershed using the ECGE model, which permits consideration of the interaction between various sectors and to consider interaction with other regions.

The environmental computable general equilibrium (ECGE) model is a computable general equilibrium (CGE) approach used specifically for environmental policy modeling. The ECGE model has been widely used to evaluate policies for reducing greenhouse gas emissions and pollution control. Jorgenson and Wilcoxon (1990) analyzed the impact of environmental legislation on the US economy using the ECGE model and found that environmental legislation led a 0.2% decrease in the economic growth rate between 1974 and 1985. Their research indicates that the negative effects of environmental legislation on economic growth gradually become marginal over the long term. Bruvoll and Ibenholt (1998) explored the impact of implementing a materials tax in Norway using the ECGE model. They concluded that taxing materials significantly improves the environment, but reduces output and lowers the employment rate.

## 2. Study area

The Poyang Lake Watershed lies in central and southeastern China, along the southern bank of the middle and lower reaches of the Yangtze River. The Poyang Lake Watershed occupies an area of 166,900 km<sup>2</sup> and had a total population of 44 million in 2008 (Bureau of Statistics of Jiangxi, 2009). Poyang Lake (24°29'–30°04' N, 113°34'–118°28' E) is the largest freshwater lake in China (Fig. 1). It is surrounded by the Zhejiang and Fujian Provinces to the east, the Guangdong Province to the south, the Hunan Province to the west, and the Anhui and Hubei Provinces to the north.

The gross domestic product (GDP) of Jiangxi Province has grown rapidly since the late 1970s. Between 1978 and 2000, the GDP per capita in Jiangxi Province increased from 276 to 4851 yuan. By 2008, the GDP of Jiangxi Province had reached 448.03 billion yuan (Bureau of Statistics of Jiangxi, 2009). At the same time, eutrophication of Poyang Lake also increased. Research shows that the average TP and TN contents in the water during the summer of 1988 were 0.076 mg/L and 0.684 mg/L, respectively. Within eight years, the TP content had reached 0.148 mg/L and the TN content had increased to 2.38 mg/L (Li, 1996; Zhu and Zhang, 1997), indicating a direct relationship between economic growth and nitrogen and phosphorus emissions in Jiangxi Province (Deng, 2007; Wang et al., 2008).

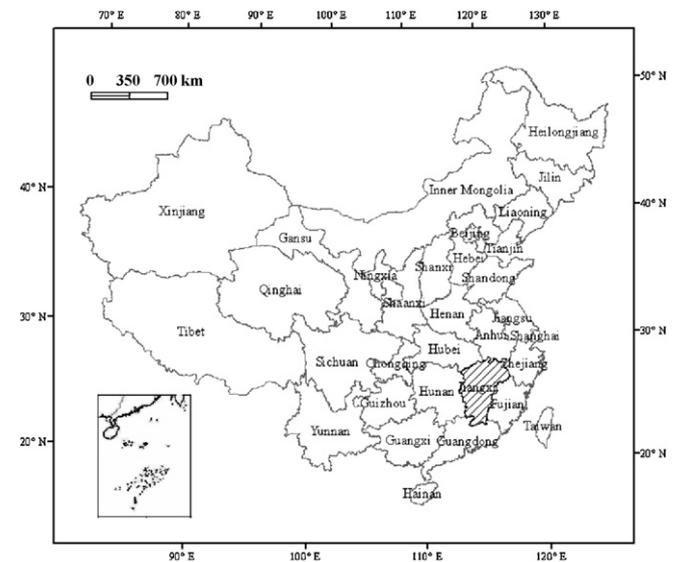


Fig. 1. Location of the study area in China.

Poyang Lake has been subjected to eutrophic conditions for more than half of every year since 1990, indicating that eutrophication of Poyang Lake is very serious (Lu, 1996).

Given that the area of Jiangxi Province accounts for 97% of the total catchment of the watershed, the reduction of nitrogen and phosphorus emissions for the Poyang Lake Watershed is equivalent to that for the entire province. This strategy also facilitates data acquisition because the annual statistic yearbook and sufficient survey data are only available for Jiangxi Province. Focusing on Jiangxi Province is useful for making decisions regarding coordinating economic growth with the reduction of nitrogen and phosphorus emissions because the Poyang Lake Watershed is only a catchment without any governing body. We also considered the other 30 provinces in order to explore the effect of the implementing emission reduction policies in Jiangxi Province on the economy of other parts of China. This is one of the criteria for evaluating the performance of emission reduction policies.<sup>1</sup>

## 3. Data and variables

The data used in this study include individual social accounting matrices (SAMs) for the 31 provinces and a provincial trade matrix describing exchange between them based on input–output data from 2002 (NSBC, 2006). The Food and Agriculture Organization further organized these data by dividing the three agricultural sectors (crops, livestock, and other agriculture) into eighteen sectors and adding 15 sectors to the original 122 (Horridge and Wittwer, 2008). For example, the crops sector was divided into soybeans, corn, wheat, rice, millet, vegetables, apples/citrus, grapes, cotton, and other crops. We used Horridge et al.'s (2005) method to generate the SAMs and the provincial trade matrix.

We also gathered additional data from the NSBC yearbooks and data published by the World Health Organization to supplement the matrices. These data include: (1) output of each province in each of the 137 sectors; (2) rural and urban household consumption in each province; (3) international exports and imports by sector and province; and (4) government expenditures on products from

<sup>1</sup> China has 23 provinces, five autonomous regions, four municipalities, and two special administrative regions. We excluded Taiwan, Hong Kong, and Macau from the analysis because of the lack of available data. For brevity, we refer to the remaining 31 administrative regions as provinces.

**Table 1**  
Output values from different Jiangxi Province sectors.

Sectors	Output value <sup>a</sup>
Plantation	126,452.9
Livestock	159,171.5
Mining	105,705
Manufacturing	1,302,981
Electricity, gas, and water supply	78,993.06
Construction	287,938.8
Transportation, storage, and mail	137,778.4
Information technology, computer service, and software Service	52,862.16
Real estate and rent	276,228.7
Scientific research and geological exploration	107,899.3
Water conservation, environment, and public facilities administration	32,126.85
Social security and public management	52,690.63
	224,580.6

<sup>a</sup> Measured in millions of yuan at 2010 value.

each sector in each province. All data come from the NSBC year-books except information regarding government expenditures. We obtained data on government expenditures on health from the World Health Organization (2005) and assumed that expenditure is proportional to population size in order to fill in the gaps for the sectors with no government expenditure data.

In order to shorten the convergence time of our model, we incorporated the 137 sectors in SAMs and the provincial trade matrix into 13 more aggregated sectors. The 31 SAMs and the provincial trade matrix with 13 sectors were the data used in this study. The output value for each of the 13 sectors in Jiangxi Province in 2002 is shown in Table 1.

**4. Methodology**

The ECGE model used in this study consists of four groups of equations for calculating nominal flow, real object flow, price, and closure. Nominal flow equations describe the relationship between various economic variables, including income, expenditure, and taxes. Real object flow equations describe supply and demand and exchange between provinces and other parts of the world. Price equations incorporate the real object flow and nominal flow equations to calculate the costs associated with production, delivery, and purchase. Closure equations describe the equilibrium between supply and demand, import and export, and income and expenses. Altogether, the ECGE model contains 146 equations, 142 formulae, 115 coefficients, and 149 variables (Table 2).

All coefficients and variables are expressed as part of several matrices which constitute the main framework for the ECGE model. For example, the three-dimensional matrix, **MAKE**(*c,i,d*), represents the output of commodity *c* from sector *i* in province *d*. The formulae for the matrices in the ECGE model that reveal the relationships among production, income, and demand are described in

**Table 2**  
Summary of the indices used in this study.

Index	Data set	Description	Dimensions of elements in the data set
<i>c</i>	COM	Commodities	13
<i>s</i>	SRC	Domestic or imported	2
<i>m</i>	MAR	Marginal commodities	2
<i>r</i>	ORG	Region of origin	31
<i>d</i>	DST	Region of use (destination)	31
<i>p</i>	PRD	Region of marginal production	31
<i>f</i>	FINDEM	Final demanders	4
<i>i</i>	SEC	Sector	13
<i>u</i>	USER	User	17
<i>o</i>	OCC	Technical level	2

Eqs. (1)–(10) using GEMPACK language (Jan et al., 2008):

$$\text{Sum}\{c, \text{COM}, \text{sum}\{s, \text{SRC}, \mathbf{USE}(c, s, i, d)\}\} + \text{Sum}\{c, \text{COM}, \text{sum}\{s, \text{SRC}, \mathbf{TAX}(c, s, i, d)\}\} + \mathbf{FACTORS}(i, d) = \text{VTOT}(i, d) \quad (1)$$

$$\text{DELIVRD}(c, s, r, d) = \mathbf{TRADE}(c, s, r, d) + \text{sum}\{m, \text{MAR}, \mathbf{TRADMAR}(c, s, m, r, d)\} \quad (2)$$

$$\text{Sum}\{i, \text{SEC } \mathbf{MAKE}(c, i, r)\} = \text{TRADE.D}(c, \text{“dom”}, r) \quad (3)$$

$$\mathbf{MAKE.I}(m, p) = \text{SUPPMAR.RD}(m, p) + \text{TRADE.D}(m, \text{“dom”}, p) \quad (4)$$

$$\text{Sum}\{p, \text{PRD}, \mathbf{SUPPMAR}(m, r, d, p)\} = \text{SUPPMAR.P}(m, r, d) \quad (5)$$

$$\mathbf{TRADMAR.CS}(m, r, d) = \text{SUPPMAR.P}(m, r, d) \quad (6)$$

$$\text{Sum}\{c, \text{COM}, \mathbf{MAKE}(c, i, d)\} + \mathbf{STOCKS}(i, d) = \text{VTOT}(i, d) \quad (7)$$

$$\text{USE.U}(c, s, d) = \text{DELIVRD.R}(c, s, d) \quad (8)$$

$$\mathbf{INVEST}(c, d) = \text{PUR.S}(c, \text{“Inv”}, d) \quad (9)$$

$$\text{PUR}(c, i, d) = \mathbf{USE}(c, i, d) + \mathbf{TAX}(c, i, d) \quad (10)$$

The matrices in bold (known matrices) are based on the SAMs. Other matrices can be calculated based on these known matrices. The matrix **USE** describes demand for each commodity, whether domestic or imported, to each destination region for each user. The **TAX** matrix contains elements corresponding to each element of **USE**. The **MAKE** matrix describes the output of each commodity by each sector in each region. The **TRADE** matrix accounts for exchange between provinces based on the source and destination of each commodity, whether domestic or imported. For each element of the **TRADE** matrix, the **TRADMAR** matrix includes the value of the marginal commodity required to facilitate flow. Marginal commodities are the commodities/services, involved in the circulation of merchandise (non-marginal commodity), including infrastructure and means of transportation. The **INVEST** matrix includes the commodity composition of investments for each sector. The **FACTOR** matrix includes the factors of production employed by each sector in each province. The **STOCKS** matrix represents the value of stocks for each sector in each province. The operator “Sum” represents the summation of the elements in brackets.

Since there is no data on interregional trade, we use the gravity formula to estimate these variables. **TRADE** and **TRADMAR** are 31 × 31 matrices with rows and columns representing the provinces of commodity origin and destinations.

**TRADE** describes the flow of non-marginal commodities. **TRADMAR** describes the accompanying trade in marginal commodities. When constructing the **TRADE** matrix, we assume that:

$$\frac{\mathbf{TRADE}(r, d)}{\sum_r \mathbf{TRADE}(r, d)} \propto \frac{\sqrt{\sum_d \mathbf{TRADE}(r, d)}}{D(r, d)^k} \quad (11)$$

where *r* and *d* represent the two provinces (*r, d* = 1, . . . , *S*); *k* is the convenience of trade between the provinces with a value ranging from 0.5 to 2. The larger the *k* is the more unequal the trade is between the provinces. **TRADE**(*r,d*) denotes the value flow of non-marginal commodities between the provinces. *D*(*r,d*) is the distance between the provinces. The diagonal entry of **TRADE** is determined by the following equation:

$$\frac{\mathbf{TRADE}(r, r)}{\sum_d \mathbf{TRADE}(r, d)} = \text{MIN} \left\{ \frac{\sum_d \mathbf{TRADE}(r, d)}{\sum_d \mathbf{TRADE}(d, r)}, 1 \right\} \cdot F \quad (12)$$

where *F* represents the convenience of trade within province *r* with a value ranging from 0.5 to 1. The larger the *F* is the more

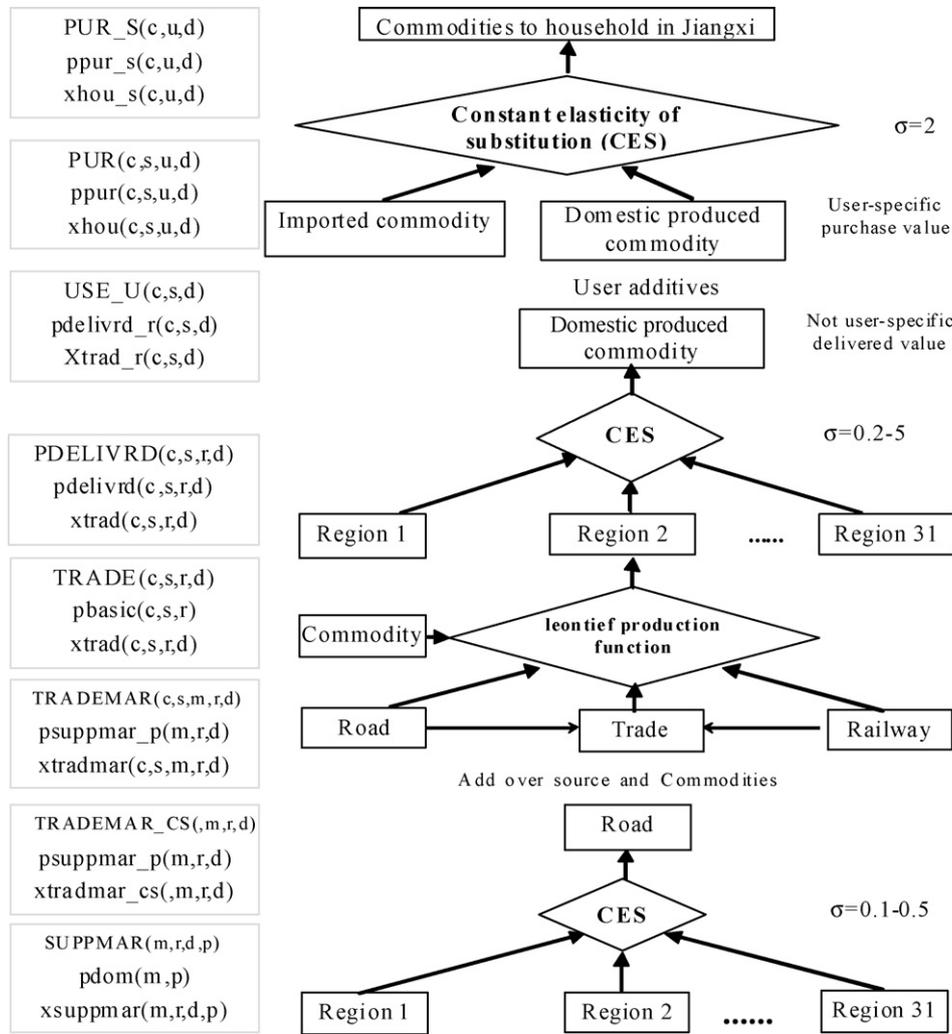


Fig. 2. Flow chart for generating the interregional trade matrix used in this study.

unequal the trade is within the province. For the **TRADMAR** matrix, the marginal commodity consumed in trade between provinces is calculated using the following equation:

$$\mathbf{TRADMAR}(r, d) \propto \sum_r \mathbf{TRADE}(r, d) \sqrt{\sum_d D(r, d)} \quad (13)$$

**TRADE** describes the flow of non-marginal and **TRADMAR** describes the accompanying marginal commodity consumed trade. Nitrogen and phosphorus emissions are calculated by multiplying the total output by the nitrogen and phosphorus emissions coefficient:

$$E(c, i, r) = \mathbf{MAKE}(c, i, r) \times ER(c, i, r) \quad (14)$$

where  $ER(c,i,r)$  is the nitrogen and phosphorus emissions coefficient for activity  $i$  producing commodity  $c$  in province  $r$ . The coefficient is constant and can be calculated using Eq. (15):

$$ER(c, i, r) = \frac{P(c, i, r) \times TE(r)}{\mathbf{MAKE}(c, i, r)} \quad (15)$$

where  $P(c,i,r)$  is the proportion of nitrogen and phosphorus emissions from activity  $i$  producing commodity  $c$  in province  $r$ ;  $TE(r)$  represents total emissions in province  $r$ , calculated using the following equation:

$$TE(r) = \text{Sum}\{c, \text{COM Sum}\{i, \text{SEC } E(c, i, r)\}\} \quad (16)$$

The change in the proportion of total nitrogen and phosphorus emissions in province  $r$ ,  $PCTE(r)$ , can be calculated using Eq. (17):

$$\begin{aligned} PCTE(r) &= \frac{\Delta TE(r)}{TE(r)} = \frac{\text{Sum}\{c, \text{COM Sum}\{i, \text{SEC } \Delta \mathbf{MAKE}(c, i, r) \times ER(c, i, r)\}\}}{TE(r)} \\ &= \text{Sum}\left\{c, \text{COM Sum}\left\{\frac{i, \text{SEC } \Delta \mathbf{MAKE}(c, i, r) \times P(c, i, r)}{\mathbf{MAKE}(c, i, r)}\right\}\right\} \end{aligned} \quad (17)$$

where  $\Delta \mathbf{MAKE}$  is the change in **MAKE**.

Fig. 2 illustrates the steps we took to generate the trade matrix used in the ECGE model. The figure shows commodity demand by households in Jiangxi Province as an example but can be used for all consumers (household, government, investment, and export) in any province in China. The diagram depicts a series of “nests” indicating the various substitution possibilities allowed by the model. Down the left side of Fig. 2, boxes with gray borders show the value flows in each level of the nesting levels in upper case letters and the price ( $p$ ) and quantity ( $x$ ) variables associated with each flow in lower case letters (Eqs. (1)–(10)). The dimensions of these variables and are indicated by subscripts  $c, s, m, r, d$ , and  $p$  (Table 2).

At the top level, a household’s choice between imported and domestic commodities whose elasticity of substitution is 2 is described by the constant elasticity of substitution (CES) function. Demands for imported and domestic commodities are determined by user-specific purchasers’ prices. The **USE.U** matrix (the “**.U**” suffix indicates summation over the user index  $u$ ) summarizes the

**Table 3**

Nitrogen and phosphorus contents (mg/L) in irrigation water, city wastewater, and groundwater in Jiangxi Province.

	NO <sub>3</sub> <sup>-</sup> -N	NH <sub>4</sub> <sup>+</sup> -N	TN	TP
Irrigation water	1.15 ± 1.01	0.90 ± 0.67	13.47 ± 18.07	28.63 ± 75.36
City wastewater	0.97 ± 0.72	5.48 ± 7.42	6.55 ± 5.21	1.15 ± 1.44
Groundwater	7.35 ± 3.45	0.28 ± 0.15	7.80 ± 3.70	0.08 ± 0.11

Data source: experimental data and calculations by the authors.

total demand for domestic commodities, measured in “delivered” values by including basic values and margins (trade and transport) as well as the commodity taxes.

The second level includes the DELIVRD matrix, which describes the distribution of USE.U among the provinces. In this case, the CES range from 0.2 (services) to 5 (merchandise). Provinces producing commodities with lower production and transport costs have larger market shares. In this level, import demand is determined on an all-user basis. Thus, the proportion of each kind of imported commodity among the commodities consumed by households, the government, and investments are the same.

The third level shows the Leontief composite (“delivered” commodity) of non-marginal and marginal commodities (i.e., transportation). The cost share for each marginal commodity (marginal price) in one unit of cost of a “delivered” commodity (delivered price) is specific to the combination of commodity type, origin, destination, and transport conditions. For example, we expect greater transport costs for trade between provinces that are further apart or for heavier or bulkier goods. This variable does not allow for substitution between transport types (i.e., roads and railways).

The bottom level of the nesting structure shows that marginal commodities consumed in transportation between provinces. We expect this to be drawn equally from the commodity origin, commodity destination, and provinces providing marginal commodities. Once again, we assume that for any commodity the share of provinces providing marginal commodities on transport from one province to another is the same. Although not shown in Fig. 2, a parallel system tracks vegetables back to their port of entry.

## 5. Scenario design

Previous research (Wang et al., 2008) suggests that the nitrogen and phosphorus fed into Poyang Lake derive mainly from irrigation water, city wastewater, and groundwater (Table 3). For irrigation water, nitrogen and phosphorus contents reach 13.47 ± 18.07 mg/L and 28.63 ± 75.76 mg/L, respectively. We collected data on wastew-

**Table 4**

Nitrogen and phosphorus emissions by sector for Jiangxi Province.

Sectors	Percent of total emissions (%)
Plantation	11.04
Livestock	13.93
Mining	2.77
Manufacturing	48.9
Electricity, gas, and water supply	12.66
Construction	6.42
Transportation, storage, and mail	0.01
Information technology, computer service, and software	0.01
Service	0.46
Real estate and rent	0.34
Scientific research and geological exploration	3.43
Water conservation, environment, and public facilities administration	0.02
Social security and public management	0.01

ater fed into Poyang Lake from the 13 sectors in the SAMs and estimated their share of nitrogen and phosphorus emissions into Poyang Lake (Table 4). *Plantation, livestock, manufacturing, and electricity, gas, and water supply* sectors account for most of the nitrogen and phosphorus emission in Jiangxi Province.

Production tax is a generic term that encompasses all of the taxes imposed on the production and distribution of commodities and services. We consider two scenarios of changing production tax rates in this study. Scenario #1: increase the production tax for the *plantation* sector, for which sewage treatment facilities are difficult to implement, by 6%; and scenario #2: raise the production tax of several sectors by varying percentages: *plantation* 2%, *livestock* 2%, *mining* 1%, *manufacturing* 1%, *scientific research and geological exploration* 2%, and *water conservation, environment, and public facilities administration* 1% (Table 5).

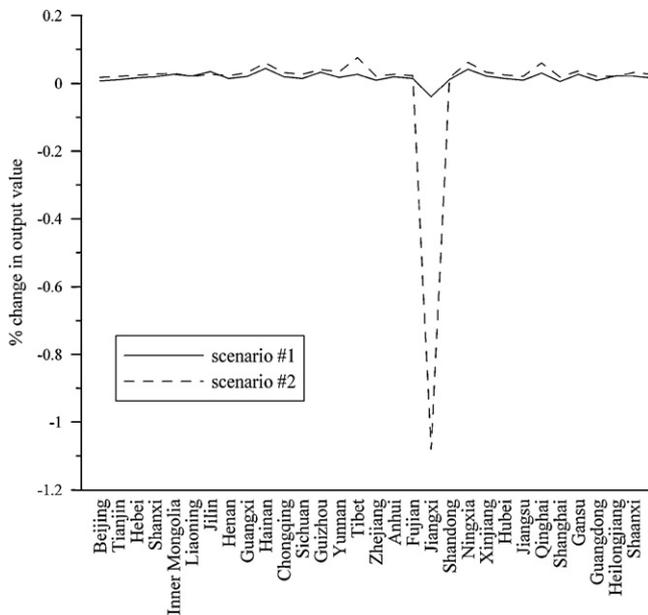
## 6. Simulation results

The productivity of each sector is an endogenous variable, while taxes are regarded as an exogenous variable in the simulation. A 6% increase in the production taxes applied to plantations will result in a 10% decrease in the output of this sector (Table 5). Output from other sectors will increase because the transfer of labor and capital from the plantation sector has a dramatic impact on relevant sectors in other provinces. The final result would be a 0.04% reduction in the output values of Jiangxi Province accompanied by increases of the total output values between 0.01% and 0.05% in the rest of provinces due to the transfer of labor and capital (Fig. 3). This scenario has a greater impact on eastern China (Shandong, Fujian, and

**Table 5**

Scenarios and their corresponding impact on nitrogen and phosphorus emissions in Jiangxi Province, China.

Sectors	Scenario #1			Scenario #2		
	% change in tax rate	% change in output value	% change in emissions	% change in tax rate	% change in output value	% change in emissions
Plantation	6.00	-10.00	-1.10	2.00	-2.00	-0.22
Livestock	0.00	0.40	0.06	2.00	-3.00	-0.42
Mining	0.00	0.51	0.01	1.00	-1.00	-0.03
Manufacturing	0.00	0.40	0.20	1.00	-2.00	-0.98
Electricity, gas, and water supply	0.00	0.36	0.05	0.00	0.41	0.05
Construction	0.00	0.42	0.03	0.00	0.05	0.00
Transportation, storage, and mail	0.00	0.31	0.00	0.00	0.24	0.00
Information technology, computer service, and software	0.00	0.13	0.00	0.00	0.14	0.00
Service	0.00	0.21	0.00	0.00	-0.03	0.00
Real estate and rent	0.00	0.15	0.00	0.00	0.17	0.00
Scientific research and geological exploration	0.00	0.46	0.02	2.00	-1.00	-0.03
Water conservation, environment, and public facilities administration	0.00	0.46	0.00	1.00	-1.00	0.00
Social security and public management	0.00	0.84	0.00	0.00	1.08	0.00
Total	-	-0.04	-0.75	-	-1.08	-1.62



**Fig. 3.** Impact of reducing nitrogen and phosphorus emissions in the Poyang Lake Watershed on the economic growth of different provinces under the two scenarios proposed.

Zhejiang Provinces) where there are advanced secondary and tertiary industries. This is partly due to the fact that labor originally used in the Jiangxi Province plantation sector will begin to move to the developed eastern coastal regions and the food supply there will decrease. Meanwhile, national demand for food will remain constant, leading to an increase in food prices that favors the central and western regions.

Scenario #2 involves a moderate tax increase for several sectors: plantation, livestock, mining, manufacturing, scientific research and geological exploration, and water conservation, environment, and public facilities administration (Table 5). Although the total output values of Jiangxi Province will drop considerably, the output values of other provinces will increase (Table 5; Fig. 3). Although less surplus labor will move to the developed eastern provinces, outputs from the livestock, mining and manufacturing sectors in Jiangxi Province will decrease, increasing the market share of the commodities from the developed eastern provinces. Meanwhile, output from the construction, real estate and rent, social security and public management sectors will increase.

Decreased output results in increased nitrogen and phosphorus emissions in Jiangxi Province. In scenario #1, an increase of 6% in the production tax for the *plantation* sector leads to a 0.75% net reduction in nitrogen and phosphorus emissions (Table 5). For some sectors (i.e., *livestock, mining, manufacturing, electricity, gas, and water supply, construction, scientific research and geological exploration, transportation, storage, and mail, information technology, computer service, and software, and services*), nitrogen and phosphorus emissions increase because output increases.

In scenario #2, the proposed changes in production taxes lead to a 1.62% decrease in nitrogen and phosphorus emissions in Jiangxi Province (Table 5). Emissions from the following sectors decrease: *plantation, livestock, mining, manufacturing, and scientific research and geological exploration*. Emissions from the *water conservation, environment, and public facilities administration* sector are also reduced somewhat as a result of the decrease in output. This is also true for the *service* sector. For other sectors (i.e., *electricity, gas, and water supply, construction, transportation, storage, and mail, information technology, computer service and*

*software, real estate and rent, and social security and public management*) whose output increases, nitrogen and phosphorus emissions increase.

Scenario #1 is more economical than in scenario #2. In scenario #1, for each 1% reduction in the total output value there will be a 17.65% ( $=(-0.75) \times 100\% / (-0.04)$ ) reduction in nitrogen and phosphorus emissions. The corresponding reduction in scenario #2 is just 1.50% ( $=(-1.62) \times 100\% / (-1.08)$ ) (Table 5). Scenario #1 will also be easier to implement since sewage treatment plants facilitate the control of nitrogen and phosphorus emissions from *livestock, manufacturing and electricity, gas, and water supply*, the sectors that experience an increase in output under this scenario. Restricting nitrogen and phosphorus emissions from sectors with the highest-emissions is the most effective tactic for reducing nitrogen and phosphorus emissions. Scenario #1 is also preferable economically as the decrease in Jiangxi Province's total output values will be minimal while that of other provinces will increase.

## 7. Discussion and conclusions

Using the ECGE model, we conducted a scenario-based analysis of the trade-off between economic growth and the reduction of nitrogen and phosphorus emissions in the Poyang Lake Watershed. We explored optimal strategies for controlling nitrogen and phosphorus emissions by comparing two scenarios for reducing emissions with minimal impact on the economy. Our results provide an effective means of nitrogen and phosphorus emissions in Jiangxi Province with minimal negative impact on the economy.

As for the exploration of effective strategies for controlling lake eutrophication, one of the top priorities is to explore the sources of nitrogen and phosphorus and to design strategies for reducing these emissions. In order to internalize the costs of nitrogen and phosphorus emissions, a new taxation system should be introduced to encourage enterprises to adopt new removal technologies and employ new equipment in order to improve the efficiency of nitrogen retention and phosphorus transformation.

Some limitations to this study derive from constraints on the availability of data. For example, some of the coefficients used come from previous studies. Therefore, the simulation results based on these secondary data should be calibrated and validated in future studies. The input data are from the year of 2002. Thus, the updated 2007 input-output table can be used to update the results. Nonetheless, we were able to apply the ECGE model to Jiangxi Province in order to suggest a method for reducing nitrogen and phosphorus emissions with minimal negative effects on the economy.

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## Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at doi:10.1016/j.ecolmodel.2010.08.032.

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