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Economic restructuring and air pollution in Russia in 1999-2006

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Author’s declaration

No portion of the work referred to in this thesis has been submitted in support of an application for another degree or qualification of this or any other university or other institute of learning.

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ABSTRACT OF THESIS submitted by:
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Concepts addressing the relationship between economic development and environmental performance of a state include the "environmental Kuznets curve", the "pollution haven" hypothesis, and various theories connecting economic liberalization with increases in efficiency

This thesis contributes empirical evidence testing and refining these theories by quantifying and analyzing the effects of the restructuring of the industrial sector in Russia in 1999-2006 on air pollution. The thesis specifically focuses on the effects that industrial restructuring as well as transformation of individual branches have on pollution intensity. General additive decomposition and Fisher Ideal Index decomposition techniques are utilized to distinguish between the effects of these two factors.

The research reveals a rise of industrial emissions during 1999-2006 which accompanied economic growth. However, the overall pollution intensity of the Russian industrial sector has dramatically declined by 220% during this period.

This significant decline in pollution intensity contrasts with the observations made in the 1990s which demonstrated that the Russian economy was shifting towards more pollution intensive branches. Although a further shift towards the "dirty four" industries (fossil fuel extraction, metallurgy, electricity generation and petrochemical sectors) has continued in 1999-2006, it has been much slower. Its negative effects were fully counteracted by changes in pollution intensity of individual industrial branches mainly attributed to significantly increased productivity.

Keywords: pollution intensity, economic restructuring, decomposition analysis, Russia, Fisher Ideal Index, air pollution

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1. INTRODUCTION AND OBJECTIVES

1.1. Introduction

Environmental performance has become one of the key elements of overall performance of any nation. Understanding factors influencing it is vital, especially in rapidly changing, globalizing world. After collapse of the Soviet Union (SU) Russia has been undergoing market liberalization, economic deregulation and restructuring integrating into the globalizing world. Thus, inevitably, environmental concerns closely related to economic processes have become an issue to deal with in light of common aspiration for sustainable development. Understanding an interrelationship between economic restructuring, development and environmental performance of Russia since late 1990s is essential to reveal possibilities and threats to more sustainable development of Russia in the 21st century.

There are four major theories describing how economic restructuring and development can influence environmental performance of states. The oldest one is perhaps the Environmental Kuznets curve, which links economic development and environmental performance (in terms of various types of pollution) proclaiming that at first, states are focused on growth and development and only then gradually start addressing environmental issues. This process might be described as a "first grow, then clean up" approach (Kuznets 1965; Kuznets 1966; Stern 2004).

Another theory suggests that market liberalization and deregulation of economy may result in positive impacts on the environment due to improved efficiency, investments in cleaner technologies and elimination of governmental subsidies into heavy industries (including military industry) (Sachs 1995; Cherp *et al*. 2003).

The third common theory called "pollution haven" states that economic deregulation and market liberalization and consequent economic and political difficulties are likely to divert attention of government and society from environmental matters and, thus, weaken environmental control and promote profit-oriented ways of doing business that are based on intensive utilization of natural resources (WB 1996; Cherp and Vrbensky 2002).

Finally, there is a "theory of competitive advantage" suggesting that in transition to market economy, contrarily to planned economies, different states tend to shift towards those sectors of industry, products of which are the most demanded on the market. Hence, whether this transition would positively or negatively affect environment, depends on historical and geographical "specialization" of the state (OECD 1999).

These theories are of interest in case of the Russian Federation, especially in the period from 1999 onwards when most remarkable economic growth since the collapse of the SU has been occurring (WB 2008). Particular importance in testing those theories lies in the fact that there are several studies done on analysis of interrelations between economic restructuring and environment for the 1990-1999 period (e.g. Cherp *et al*., 2003; Olshanskaya 2004), hence, just before and straight after collapse of the SU, however, so far there is no comprehensive studies on impacts of the recent economic boom on environmental performance of the Russian Federation.

OECD (1999) has studied and reported effects of economic transition on environmental performance. One of the main outcomes was that depending of various conditions there is either "positive decoupling" – an event when pollution declines faster (or grows slower) than GDP of a state – or "negative decoupling" – an event when pollution declines slower (grows faster) than GDP. OECD suggested that while positive decoupling happens in countries undergoing faster and more sophisticated reforms, negative decoupling characterizes countries “legging” in this respect. However, Cherp *et al*. (2003) argues that reality is much more complex and there is little evidence backing up any direct relationship between the state of market reforms and consequent changes of environmental performance. Thus, more comprehensive and clear links between economic restructuring and development and environmental performance would be helpful for further research and economic and environmental decision-making of a nation. This can be done by quantifying impacts of various factors related to economic restructuring and growth on the environmental performance.

In order to investigate influence of the ongoing economic development on the environment in Russia we employ data on air pollution as the most suitable proxy for assessment of the overall environmental performance taking into account availability of statistical data and as it enables comparability of the results to those of earlier studies.

Pollution intensity, i.e. the net amount of air pollution emitted per unit of Gross Industrial Output (GIP), has been chosen as an indicator of the environmental performance of the Russian Federation. This indicator has a number of advantages: firstly it comprises economic and environmental dimensions of sustainability; secondly, it can be calculated for the whole industrial sector and for individual industrial branches of the Russian economy; and thirdly, it allows addressing of the decoupling phenomenon suggested by OECD (1999).

1.2. Thesis aim, objectives and structure

Aim of the thesis is to explore effects of industrial restructuring on air pollution in Russia in a period between 1999 and 2006.

Objectives of the thesis are as follows:

- to analyze trends in air pollution intensity of the industrial sector of the Russian Federation during the period of recovery and development of the Russian economy in 1999-2006;
- to quantify impacts of the industrial sector restructuring as well as impacts of changes within separate industrial branches on the overall pollution intensity;
- to test four selected theories of interrelationship between economic restructuring, growth and environmental performance of a state.

Thesis structure: **Chapter 2** discusses main theories of influence the economic restructuring on environmental performance of a nation, reviews overall situation in the Russia Federation in the period between 1999 and 2006 with a focus on analysis of economic and industrial growth and changes in air pollution emissions; it also discusses the issues of environmental polices and governance in Russia during the transition period. **Chapter 3** provides information on different decomposition methodologies being used for similar studies. It also proposes two methods: general *additive decomposition* and a *multiplicative perfect decomposition technique*, namely ***Fisher Ideal Index***, to be employed for decomposing the pollution intensity, i.e. for quantifying two main factors separately: the sector structural changes and changes within individual industrial branches. Moreover, it discusses issues and concerns related to statistical data selected for the study and talks about particulates of the *Fisher Ideal Index* calculation. **Chapter 4** presents the results of the decomposition analysis of the pollution intensity of Russian industrial sector in between 1999 and 2006 with further discussion of the main factors influencing particular trends in air pollution emission from industrial stationary sources. **Chapter 5** includes discussion of the study results and conclusions. **Annexes I-III** contain statistical information and main results of calculations.

2. ECONOMIC RESTRUCTURING, DEVELOPMENT AND ENVIRONMENT: THEORETICAL FRAMEWORKS AND CURRENT SITUATION IN RUSSIA

This chapter focuses on four major theoretical frameworks addressing relationship between economic restructuring and environmental performance. Further on, it reveals the pre- and post-1998 crisis economic trends in Russia, time when financial and development “bottom” was achieved and, thus, it became a natural benchmark for recovery and development after “stormy times” of transition in 1990s in Russia. It also addresses major issues of Russian environmental policies and governance, which has been under reconsideration after several years of development in early 1990s. Finally, it discusses changes in Russian environmental performance in terms of air pollution emissions from industrial stationary sources for a period between 1995 and 2006.

2.1. Theoretical framework

Interrelationship of economic restructuring, growth and environmental situation has been in focus for some 40 years now. There are four major theories addressing this issue. One of the earliest and most often applied theories linking economic development with environment is perhaps the Environmental Kuznets curve (Kuznets 1965, Kuznets 1966). It states that at the beginning of economic growth the environmental situation deteriorates, however, it happens till the moment when society is already rich enough and became environmentally-concerned, so it starts messaging its concerns to the government in order to make it change the situation. In other words, as Dasgupta *et al.* (2002) expresses it, the growth should come first, as the environmental consequences would be dealt with later. However, it is quite logical that this reasoning is not as universal as it used to be considered before (Cole *et al.* 1997). In particular, Stern (2004) argues that the Kuznets curve should be seen as just an empirical fact calling for decomposition analysis to study the relationship between economic growth and environment. It means that there should be factors taken into consideration which are accountable for changes in this complex relationship. These factors are changes in scale of economy, technological changes, composition of economy and last but not least, policy changes and their influence on environment, e.g. on air pollution (Stern 2004).

The second theory of interrelationship between economic growth and environmental performance claims that due to economic deregulation and market liberalization, the environmental performance of a state is likely to improve. It should happen because of introduction of realistic market prices for primary sources of energy and other raw materials which were previously regulated by the state and had reduced values. Thus, the new realistic prices push resource consumers to increase rate of resource utilization and efficiency of their processes (Sachs, 1995; OECD 2004). Market reforms would also bring foreign investments into efficient and cleaner technologies and know-how, contributing to environmental performance improvements. Additionally, at some point after the transition is launched, the state should gradually reduce its presence in different sectors of economy, thus, allowing equal opportunities for competition and eliminating subsidies that used to keep wasteful and unproductive industrial branches alive (in particular, inflated military sector typical for socialist countries). Lastly, the openness to international markets would motivate domestic industries for striving for better and cleaner performance and products in order to compete with environmentally-concerned producers of the Western world (Cherp at al, 2003).

The third – "pollution haven" – theory is rather a counterargument to the second one, stating that market reforms and restructuring are likely to bring along economic and political instability that, in turn, may divert attention of authorities and public from environmental issues and make them concentrate all efforts on profit-making (Cherp and Vrbensky 2002). In this case a state would motivate production of more resource and pollution intensive enterprises as with lax environmental regulations these enterprises would have competitive advantage over those which are much strictly controlled and regulated. Thus, the state would become a "pollution haven", a center attractive for investments due to both market considerations and lax environmental policy what, in turn, would increase extraction and use of natural resources due to ever-growing demand of the international markets further degrading environment (Brunnermeier and Levinson 2004).

It seems that a common argument for both latter theories is, however, that neither market reforms or environmental regulations and control alone can play the main role in determining economic and environmental performance. A substantial set of factors is needed to be addressed to truly understand the dynamics of economic development, thus, it resembles the case with the Environmental Kuznets curve discussed above.

Lastly, the fourth theory – "theory of competitive advantage" – suggests that different countries have their specific "specializations" in terms of industrial production which are determined by geographical location, availability of land, natural resources, energy, level of industrialization and other factors (OECD 1999). Thus, economic deregulation and market liberalization occur when countries are trying to provide the market with the most demanded products within their "specialization" with different consequences for environmental performance. For example, Central and East European states after the collapse of the SU shut down their heavy industries, famous for energy, resource and pollution intensity (Olshanskaya 2004) and gradually shifted towards much less environmentally-degrading sectors of economy. In this case, they could not afford these wasteful technologies as they did not have sufficient resources domestically, and import became much more expensive. At the same, Russia and some central Asian countries rich in natural resources have chosen another pathway. Post-collapse times were characterized by reductions in environmental pressures, but gradually pollution trends are reversing as economical crises passed and economies of countries are growing (Expert 2006).

2.2 Economic growth in numbers and figures

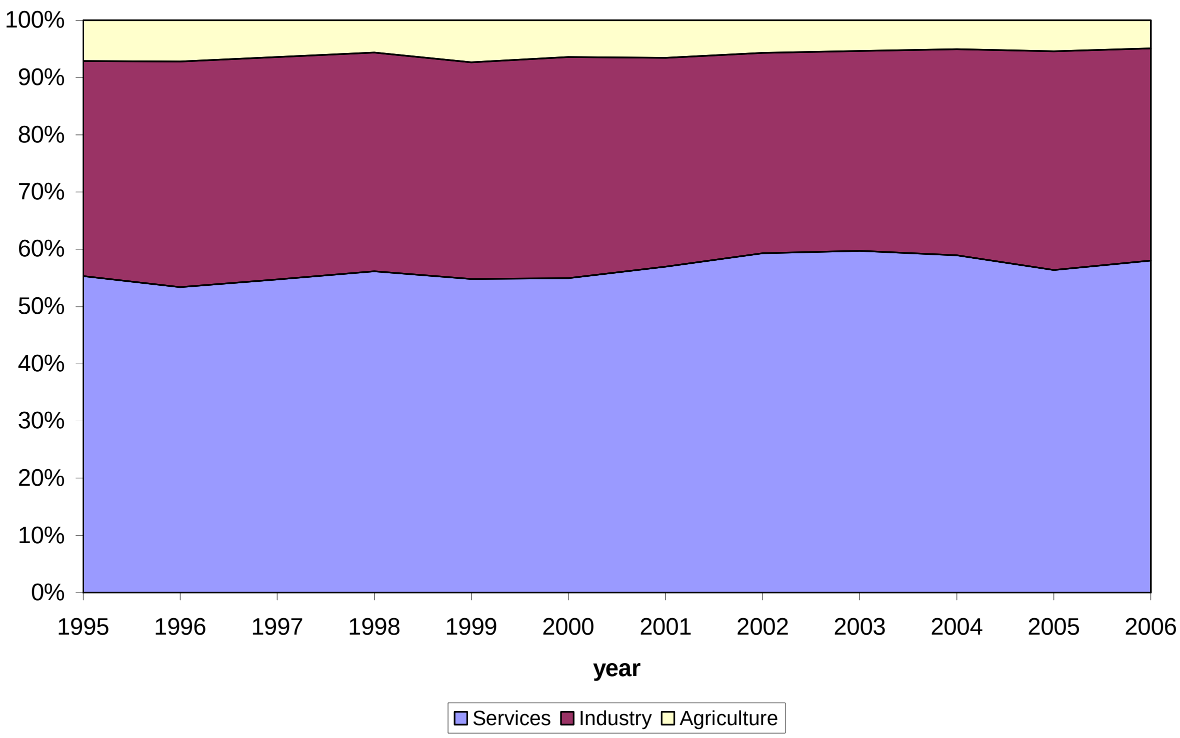
Since 1999 a dramatic recovery of the Russian economy has been observed. After the fall of economy in 1998 when GDP level achieved its "bottom", steady rise of economy started and has been going on. Figure 2.1 shows that GDP has almost doubled in 9 years with somewhat uneven, yet rather stable annual growth. According to WB (2008) this growth has been driven mainly by growing domestic demand and consumption as well as by growing prices of main export commodities: oil, gas and metals.

Figure 2.1. Dynamics of Russian GDP in monetary terms and in percentage to previous year.

Source: Rosstat (2007a) and WB (2007).

At same time, the structure of GDP has significantly changed since 1999 in terms of shares of main economic sectors – agriculture, industry and services – in comparison to drastic changes in early 1990s (Cherp *et al*. 2003). In particular, Figure 2.2 shows that since 1995 there have been gradual growth of both service and industrial sectors with diminishing of agricultural sector's share. It means that economic structure was rather stable over 11-year period with fluctuation within 2-5% corridor for all three sectors. Thus, it might mean that today active phase of economic restructuring related to economic deregulation and market liberalization has finished. At the same time, GDP composition should be considered and monitored as an important performance indicator because even changes within 2-4% margin can result in substantial impacts on environmental performance, for example, in case when share of agricultural sector is diminishing and service sector is not growing as strongly as it was doing in 1999-2003.

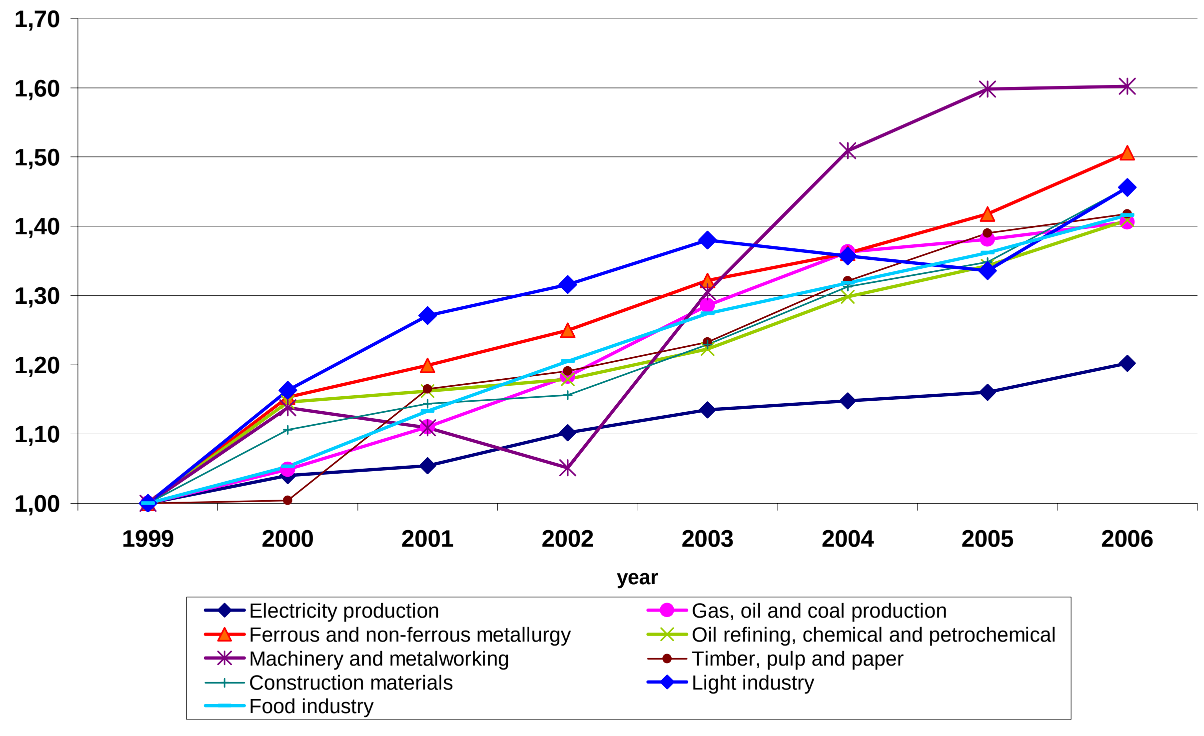
Figure 2.2. GDP composition of Russian economy in 1995-2006.



Source: Rosstat (2007a).

Industrial sector, as the major contributor to air pollution (Cherp *et al*. 2003), is a focus of this paper. Thus, it is essential to study the changes within this sector in order to understand the overall changes in the economy and, hence, its influence on the environmental trends in Russia. Data provided by Rosstat (2007) show the rise of all main individual industrial branches by about 40% since 1999. Before that, since 1991 there was constant decline of industrial production. Figure 2.3 demonstrates that with except of light industry and machinery and metal working industry that have shown rather hectic development patterns, the rest of the industrial branches have been growing steadily with the metallurgy sector leading the way and being followed by food and fossil fuels industries.

Figure 2.3. Production trends of individual industrial branches in Russia in 1999-2006 (1999=1).

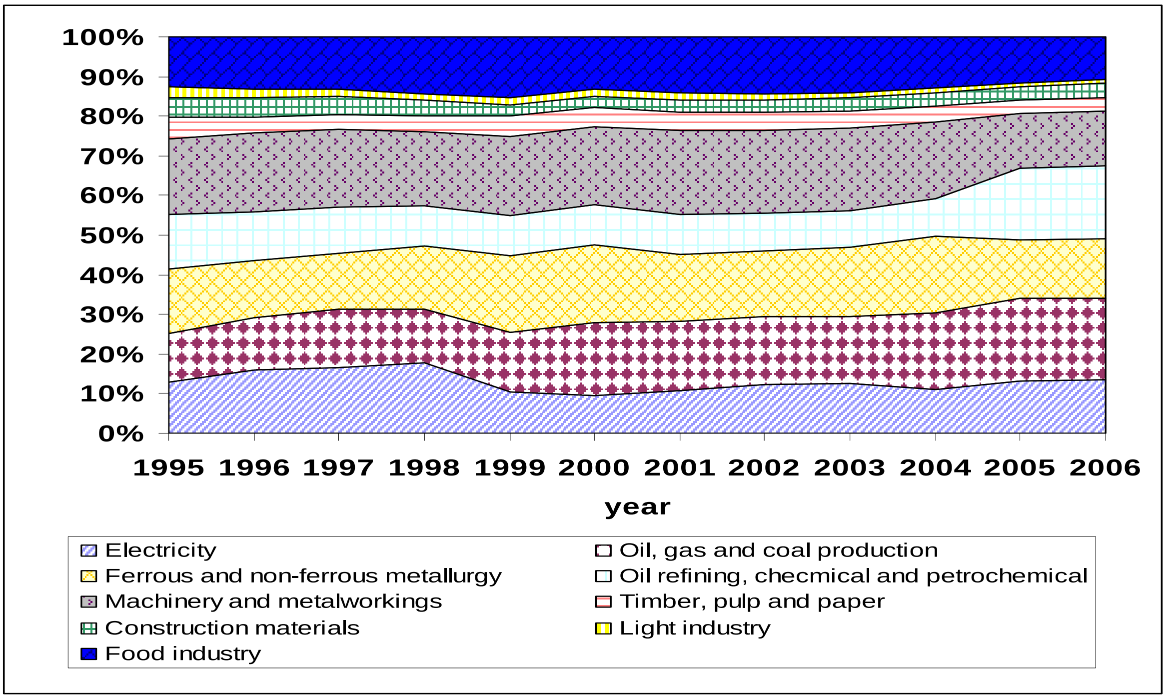


Source: Rosstat (2007).

Finally, completing the picture of situation in the industrial sector, Figure 2.4 presents the shares of individual industrial branches in the total industrial output. Here we can see that there are continuous changes in terms of output of particular branches ever since 1999 – a "bottom" year. For example, oil, gas and coal sector has increased its share as well as the oil refining, chemical and petrochemical sector; electricity production is steadily recovering after 1999. At the same time, "lighter" industries such food, construction materials and timber, pulp and paper have been reducing their shares as the share of light industry has shrunk and become almost non-existent.

Overall, the Russian GDP has doubled since 1999. The main reasons to it are international market trends, favorable for Russia being an energy resources exporting country and overall economic recovery of major industrial branches. At the same time, the composition of GDP has been rather stable ever since 1999. At the same time, composition of the industrial output continued to fluctuate after 1999 with a steady trend towards more resource-intensive branches such as electricity generation, metallurgy, fossil fuel and, recently, oil refining sectors.

Figure 2.4. Shares of individual industrial branches in the Gross Industrial Output of the Russian industrial sector in 1995-2006.



Source: Rosstat (2007a).

2.3. Restructuring of environmental institutions and policies in Russia: brief overview

As noted above, national policy plays one of the major roles in determining development of a state. It is also applied for environmental policies. In order to analyze interrelationship between economic development and environment, Stern (2004) suggests examination of the situation from the environmental policy point of view as one of key elements of the overall analysis. For the purposes of this study we limit this discussion to an overview of changes taken place in governing environmental issues in Russia in recent years.

The history of policies focused on issues of environmental protection in Russia has started not so long time ago. In December 1991 the Supreme Soviet of the USSR adopted a law "On environmental protection" – the very first law governing this kind of issues which had worked for almost ten years after its adoption and collapse of the SU (Larin *et al.* 2003; Expert 2006). It was developed by the Union Committee for Environmental Protection – the first formal body responsible for environmental issues created in 1988 (Wernstedt 2002). Following the adoption of the law, first pollution charges, environmental abatement funds and other economic tools were also (Firsova and Taplin 2007). Shortly afterwards, the Ministry of Environmental Protection and Natural Resources of the Russian Federation was established, thus, one of the first consequences of the dramatic changes in Russia was basically giving a priority to environmental issues. The Ministry had high status in the cabinet and was working rather productively (Larin *et al.* 2003). However, due to different reasons, already in 1996 the Ministry started losing its status as by the Presidential order the ministry was renamed to the State Committee of Environmental Protection (well-known Goskomekologia) with significant reductions in budgets, staff allocation and, of course, power (Larin *et al.* 2003; Expert 2006). Some experts believe that groups involved in heavy industry, primarily oil, gas and metals, being major polluters had lobbied for this change in order to limit the pressure of the environmental authorities on business which had been just privatized and needed significant improvements to meet the environmental standards (Larin *et al.* 2003; Von Ritter and Tsirkunov 2003; Expert 2006).

There were several changes of Goskomekologia's structure and status since 1996 which finally brought it to the point in 2000 when it was abolished and their functions were transferred to a new Ministry of Natural Resources (MNR) that remains up to date (Expert 2006). From this point on one governmental body – MNR – combines two opposite functions: natural resources management and environmental protection which is basically a situation when users of natural resources regulate their own environmental pollution. Indeed, a number of both international and national experts express their concern about this "reconstruction" pointing out that it has further weakened the system of environmental protection (Oldfield 2002; Von Ritter and Tsirkunov 2003; Firsova and Taplin 2007). Moreover, Wernstedt (2002) argues that this change caused increased levels of environmental pollution, loss of environmental funds and sharp decrease in environmental payments for pollution.

The administrative phase of environment-related restructuring was followed by introduction of a new law "On environmental protection" as a substitution of the one remained from the Soviet times and a new environmentally-oriented legislative document called "The Ecological Doctrine of the Russian Federation" which is partly derived from the 1996's President's Order "On the Concept of the Transition of the Russian Federation to SD". Although these legal documents are in general up-to-date and comprise provisions based on international experience, many criticize both of them. In particular, the Law on environmental protection is claimed to be less strict in terms of regulations and control of natural resources consumers (Expert 2006). The Doctrine is a main strategic document setting principles and long-term goals for the national environmental policy. However, Firsova and Taplin (2007) point out that it lacks essential details, thus, making it rather vague and not readily operable.

Overall, there are arguments that both: the reform of environmental authorities and policies in 1990s and yearly 2000s and the administrative reform of 2004 have adversely effected the effectiveness and efficiency of governance in general and in environmental issues in particular (Expert 2006; Illarionov 2007). One of the vocal examples of it is that after 2004's reform the regional environmental authorities lost the majority of their power over issues of the environmental control, thus, the whole system instead of decentralization, became more centralized and, hence, less sensitive to issues of immediate attention. Another issue of the growing concern is corruption spreading over the whole administrative body and setting free major polluters of any responsibility for their deeds (Firsova and Taplin 2007).

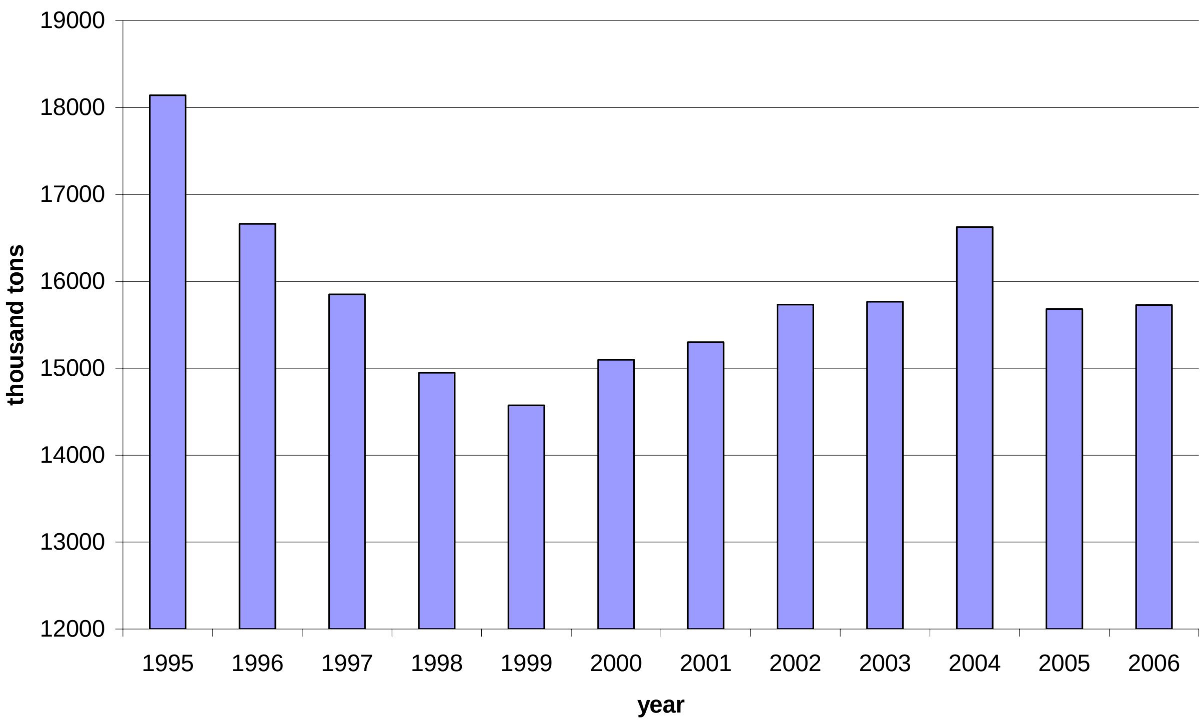
Lastly, Expert (2006) stresses that recently the "environmental card" has been used in politically-motivated decision-making such as in the case of Sakhalin-2 gas field and in several other projects. In contrary to some commentators, stating that it shows the importance of environmental issues (Weitz 2006), there is growing understanding that in many cases it is just a tool to push the owners of this or that enterprise to reconsider certain conditions and renegotiate rules or hand over the ownership to more loyal players.

To sum up, it seems that currently the main strategy of Russia is "first grow, then clean up" (Rastorguev 2003) basically allowing resource and pollution intensive industries to operate as they have been doing postponing environment-related actions. Thus, this situation cannot avoid adversely contributing into the growing environmental degradation especially taking into account ongoing economic development based on natural resources extraction and export.

2.4. Actual changes in air pollution in Russia since 1999.

After a review of economic and policy changes which occurred in Russia in recent years, environmental indicators of these changes will be presented. MNR (2003, 2006, 2007) reports that after the post-collapse decline in air pollution ended in 1999, since 2000 till 2004 there was a steady growth of air pollution from stationary industrial sources by about 13% with a drop by some 6% already in 2005. Figure 2.5 shows the dynamics of these changes.

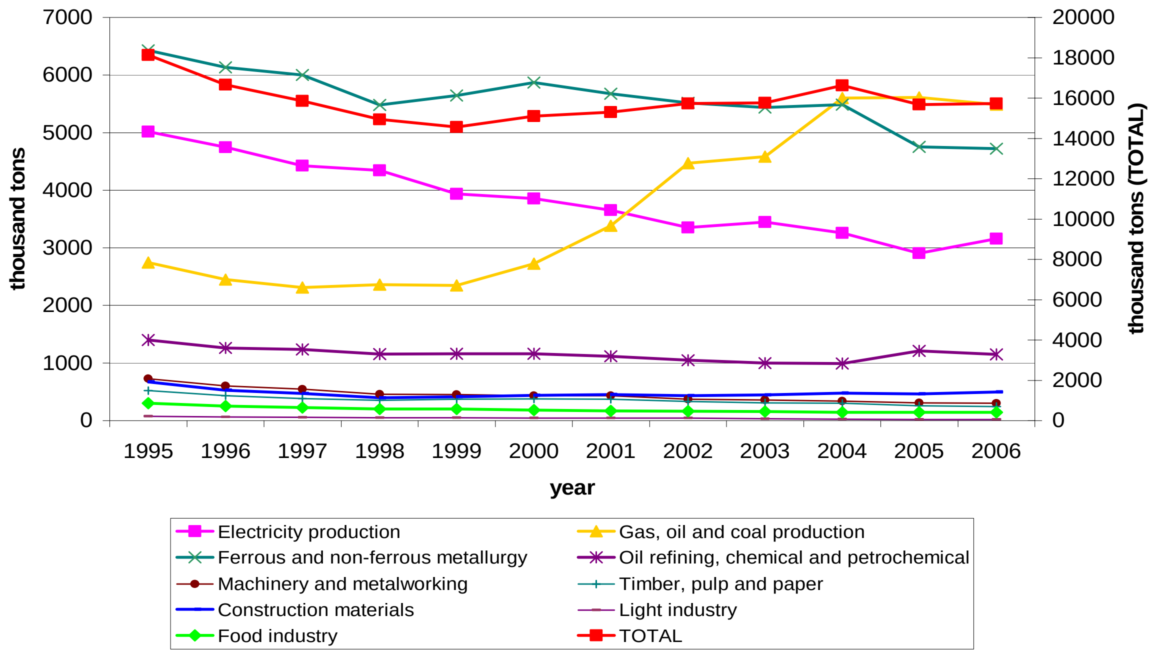
Figure 2.5. Dynamics of air pollution from stationary industrial sources in Russia.



Source: MNR (2003, 2006, 2007).

The rise of air pollution levels correlates with economic recovery and growth during first five years, although already in 2005-2006 air pollution slows down. To have a closer look at main sources of air pollution there is a break down of total air pollution to emissions from individual industrial branches shown on Fig. 2.6. Figure depicts levels of air pollution from main industrial branches among which there are four major contributors: electricity generation, metallurgy, fossil fuel production, oil refining, chemical and petrochemical sectors (these “dirty four” accounts for approximately 90% of all air pollution emissions). Although the overall share of the “dirty four” has remained more or less the same, with all “cleaner” branches such as food, timber, pulp and paper industries, light, construction materials’ and machinery industries, constant changes in emission levels *within* the “four” are obvious. Particularly, the metallurgy sector seems to improve its environment performance showing a decline of air pollution by some 1,7 million tons over 11 years. Even more impressive pollution reduction has occurred in electricity generation. Total decrease since 1995 equaled to 1,9 million tons which can be partially explained by conversion of a number of power generation stations from coal to gas firing (MNR 2006). Finally, oil refining and chemical sector followed similar patterns as former two sectors, with 20% pollution reduction over 11 year. However, despite the efforts of former three out of “four” the fossil fuel sector canceled out all achievements by doubling its air pollution emissions over 11 years. It is obvious that this sector is one accountable for the overall increase of air pollution from industrial stationary sources.

Figure 2.6. Air pollution from individual industrial branches in Russia.



Source: MNR (2003, 2006, 2007).

To sum up, indeed, environmental degradation accelerates when booming economic growth is occurring. However, not all industrial sectors behave identically in this case. As economic growth is mainly based on resource intensive industries, indeed they are the ones to show changes in air pollution levels.

2.5. Economic growth and air pollution in Russia: conclusions.

The review of economic, political and policy situation and their impactions on environmental performance, in particular, on air pollution of the industrial sector in Russia has revealed the following:

- Economic growth is mainly based on resource intensive branches of industry, primarily metallurgy and fossil fuel production and export and it caused doubled growth of GDP since 1999 till 2006 as 1999 was a turning point in economy of Russia;
- Composition of GDP has not significantly changed between 1995 and 2006, although the composition of gross industrial output since 1999 has been changing towards metallurgy and fossil fuel production and electricity generation branches;
- Due to institutional and policy reforms of 1990s and early 2000s the overall situation with environmental policies and environmental protection authorities has changed towards weaker governance in environmental matters, the state seems to have chosen a strategy of “first grow, then clean up” with a current focus on growth;
- Actual levels of air pollution have increased rather proportionately to the economic growth with the fossil fuel production industrial branch as a “leader”, although another three industrial branches our of “dirty four” have shown improvements in their environmental performance.

3. ANALYSIS OF INDUSTRIAL POLLUTION INTENSITY: METHODOLOGY FOR EVALUATING IMPACTS OF STRUCTURAL CHANGES IN THE SECTOR

Pollution intensity (i.e. amount of pollution per amount of economic output) is an indicator reflecting both: environmental and economic dimensions of development. In developing economies, especially based on extensive exploitation of natural resources, it is particularly important to study determinants of shifts towards more (or less) polluting branches of industry, as well as those influencing changes within different branches. To reveal those factors and to quantify their contribution into the overall pollution intensity, the decomposition analysis as a tool proved to be useful for this kind of analysis will be employed. This chapter discusses main decomposition techniques which exist up to date and proposes a specific technique to be used in this study. After that, it presents data used for the study, their sources and other related issues such as accuracy and limitations. Additionally, it describes details of Fisher Ideal Index calculations and national economic and air pollution factors adopted for the calculations as well as it defines the time frames for the analysis.

3.1 Decomposition analysis: an overview

Since late 1970s there has been a growing interest in decomposition methodology, especially in the energy- and, to a lesser extend, environment-related fields (Ang and Zhang 2000). A literature survey by Liu (2004) reports 172 decomposition studies and Ang and Liu (2007) suggest that the interest and, thus, number of decomposition studies are still growing by several studies a year. Methodology itself, being referred to as decomposition analysis, is basically a disaggregation of total energy intensity or pollution intensity (like in our case) into separate factors influencing changes in an industrial sector activity composition and in separate industrial branches pollution intensity, i.e. *structural and intensity effects* respectively (Olshanskaya 2004). .

Decomposition analysis is mainly used in energy efficiency studies in developed countries. For environmental performance related issues it is used significantly less and mainly for energy-related carbon intensity of industrial and transport sectors. Ang and Zhang (2000) found that only two out of 124 studies were on ex-Soviet Union or Central European countries by 2000. Just recently countries in transition (CITs) and developing countries have been brought into focus of academic and research community by studies like EBRD (2002), Cherp *et al.* (2003) and Olshanskaya (2004). Additionally, the International Atomic Energy Agency (IAEA 2005) issued a publication "Energy Indicators for Sustainable Development: Guidelines and Methodology" which suggests a broader use of decomposition analysis techniques for energy-related factors having impacts on sustainable development in ***developing countries***.

The general format of the pollution decomposition equation provided in Ang and Zhang (2000), EBDR (2002), Cherp *et al*. (2003) and Olshanskaya (2004) is the following:

$$PI = \sum_{i=1}^{N} S_{i,t} I_{i,t} , \qquad (1)$$

where:

PI – total pollution intensity of the economic sector;

$\boldsymbol{S_{i,t}}$ – share in gross production of a branch *i*;

$\boldsymbol{I_{i,t}}$ – pollution intensity of a separate industrial branch *I*;

t – a time parameter.

Time plays a particularly important role in decomposition analysis. There are two basic ways of employing time in this analysis. The first-one is to use a "periodwise" approach, i.e. to set a base year (e.g. 1999), a comparison year (e.g. 2006), make calculations and analyze outcomes. The second-one is to use chaining approach on so-called rolling basis, i.e. to employ yearly data from 1999 to 2000, from 2000 to 2001 and so on, thus, enabling a more accurate analysis in cases of rapid changes in factors involved. Olshanskaya (2004) and Ang and Liu (2007) point out that chaining is preferred in any case, although it is admitted to be much more data intensive.

There are two main ways of expressing a change in total pollution intensity when it varies between $\boldsymbol{PI_0}$ and $\boldsymbol{PI_T}$, where $\boldsymbol{PI_0}$ is total pollution intensity of a base year and $\boldsymbol{PI_T}$ is total pollution intensity of a comparison year (Olshanskaya 2003).

The first approach is called Multiplicative decomposition

$$RI = PI^{T} / PI^{0} = D_{str} / D_{in} + D_{res} , \tag{2}$$

where:

$\boldsymbol{RI}$ is ration of intensities, $\boldsymbol{D_{str}}$ is accounted for structural changes, $\boldsymbol{D_{in}}$ is accounted for changes in pollution within separate industrial branches and $\boldsymbol{D_{res}}$ is a residual term, or so-called "unexplained" change which originates from mathematic interactions between factors in the decomposition (Ang and Liu 2007);

The second approach is called Additive decomposition

$$\Delta PI_{total} = PI^{T} - PI^{0} = \Delta PI_{str} + \Delta PI_{in} + D_{res} , \tag{3}$$

where:

$\boldsymbol{\Delta PI_{total}}$ is an overall change of pollution intensity, $\boldsymbol{\Delta PI_{str}}$ and $\boldsymbol{\Delta PI_{in}}$ indicate changes related to industrial composition and pollution intensities of separate industrial branches respectively, $\boldsymbol{D_{res}}$ is also a residual term;

$$\Delta PI_{str} = \sum_{i=1}^{N} \Delta S_i^T I_i^T , \tag{4}$$

where $\mathbf{I_i^T}$ are figures of pollution intensities of individual industrial branches averaged in the given pairs of years;

$$\Delta PI_{in} = \sum_{i=1}^{N} S_i^T \Delta I_i^T \quad , \tag{5}$$

where $\mathbf{S_i^T}$ are the values of shares of individual industrial branches in the total production output averaged in the given pairs of years.

In general, residual term is deemed as one of main drawbacks of many decomposition techniques, thus, motivating academic society to development methods without this problem. However, a number of studies as well as guidelines on implementation of decomposition methodologies both: nationally and internationally, adopt techniques which have a residual term (e.g. see IEA 2004, IAEA 2005), always suggesting that this residual term is comparatively small and, thus, is insignificant and may be omitted. However, Ang *et al.* (2003), Ang and Liu (2007) warn that often there is often no grounds to state that a residual term plays very little or no role as almost never results gained from decomposition techniques with a residual are checked by other, so-called "perfect decomposition" methods, providing full decomposition without residual. Thus, currently there is a growing number of studies developing new and refining already known techniques with a single goal of making them "perfect", i.e. eliminating the residual problem (Ang *et al.* 2003; Boyd and Roop 2004). Major techniques of latter kind are discussed below.

Coming to selection of either a multiplicative or an additive technique for disaggregation of pollution intensity in the Russian Federation in 1999-2006, an extensive review included in Olshanskaya (2004) suggests adoption of the multiplicative technique when an analysis is done on a year-to-year basis over a period of time. Moreover, a multiplicative technique yields its results in a percent change between periods which may be more descriptive in comparison to additive method, providing results in a unit of pollution/monetary unit. However, for purposes of updating and validation of the study carried out by Cherp *et al.*

(2003), besides the contemporary multiplicative decomposition approach we will also adopt a general additive approach proposed by the authors in the following way:

$$\Delta PI_{total} = PI^{T} - PI^{0} \approx \Delta PI_{str} + \Delta PI_{in}, \qquad (6)$$

with conscious omission of the residual term. Thus we can use two approaches in parallel and then compare outcomes.

3.2 An overview of perfect multiplicative decomposition techniques

There are several perfect decomposition techniques developed during last five to ten years. Although despite of rather long time which passed since the introduction of the first method of this kind a number studies adopting them is still less then of those using conventional methods. As we are looking at multiplicative methods only (see Section 3.1 above), a number of the methods which may be adopted for this study is reduce to three methods. They are presented in Table 3.1.

Table 3.1. Perfect multiplicative decomposition methods.

Index	Formula	Comments
1	**2**	**3**
Fischer Ideal Index (Fisher)	$D_{str} = \sqrt{(L_{str} x P_{str})}$ $D_{in} = \sqrt{(L_{in} x P_{in})}$	The Index is a geometric average of the Laspeyres and Paasche indices, formulae for which are provided below
Laspeyres	$D_{str} = \frac{\Sigma S_i^T x I_i^0}{\Sigma S_i^o x I_i^0}$ $D_{in} = \frac{\Sigma S_i^o x I_i^T}{\Sigma S_i^o x I_i^o}$	The change in relevant variable (structural or intensity impact) is measured keeping other variable at its original level (at t=0)
Paasche	$D_{str} = \frac{\Sigma S_i^T x I_i^T}{\Sigma S_i^0 x I_i^T}$ $D_{in} = \frac{\Sigma S_i^T x I_i^T}{\Sigma S_i^T x I_i^{)}}$	The change in relevant variable (structural or intensity impact) is measured keeping other variable at its final level (at t=T)

1	2	3
Log mean Divisia I (LMDI I)	$D_{str} = \exp\left(\sum_i \frac{L(PI_i^T, PI_i^0)}{\sum(PI_i^T, PI_i^0)} \ln(\frac{S_i^T}{S_i^0})\right)$ $D_{in} = \exp\left(\sum_i \frac{L(PI_i^T, PI_i^0)}{\sum(PI_i^T, PI_i^0)} \ln(\frac{I_i^T}{I_i^0})\right)$	Where $L(a,b)=(a*b)/\ln(a/b)$ represents log mean of two variables; $w_i^T=PI_i^T/PI^T$, $w_i^0=V_i^0/V^0$; Logarithmic average of w_i $[L(w_{i,T},w_{i,0})/\sum L(w_{i,T},w_{i,0})]$ is used to weight changes in measured variable.
Log mean Divisia II (LMDI II)	$D_{str} = \exp\left(\sum_i \frac{L(w_i^T, w_i^0)}{\sum(w_i^T, w_i^0)} \ln(\frac{S_i^T}{S_i^0})\right)$ $D_{in} = \exp\left(\sum_i \frac{L(w_i^T, w_i^0)}{\sum(w_i^T, w_i^0)} \ln(\frac{I_i^T}{I_i^0})\right)$	

Adopted from Olshanskaya (2004) and Ang *et al*. (2003).

All three methods presented in the table above are relatively new, in particular LMDI II was presented by Ang and Choi in 1997, LMDI I – by Ang and Liu in 2001 and Fisher – by Boyd and Roop in 2004. All of them are time-reversal and are able to compute even with values equal to zero, which implies that decomposition may be done in both directions – prospectively and retrospectively (Olshanskaya 2004). Moreover, all three methods show consistency in results, in particular, during the last validation study, presented in Ang and Liu (2007) techniques showed required residual free performance which was also very similar in results.

Taking into account several criteria, such as data intensity, complexity of mathematical apparatus, and, thus, computational ease, and certain level of understandability of the results to non-specialists, as proposed by Olshanskaya (2004) and Nanduri (1998) ***we choose the Fisher Ideal Index*** for adoption in the study aggregate pollution intensity of Russian industrial sector because it fits into most of those criteria.

3.3 Data details and related issues

Data employed for this study are acquired from the "Statistical Yearbooks of the Russian Federation" issued by the Federal State Statistics Service of the Russian Federation in 2001 and 2007 (Rosstat 2001, 2007). In particular, data on gross industrial output of major branches of the industrial sector of Russia in current prices (Table I-1 in Annex I) and the Industrial Price Index (Table I-2 in Annex I) are used to calculate gross industrial output of major industrial branches in constant prices of 1999 (results are presented in Table I-3, Annex I). Data on the structure of Russian industrial production, are obtained by dividing gross industrial output of separate industrial branches at constant prices (Table I-3, Annex I) by respective figures of total industrial output (provided in Table I-4, Annex I).

Data on total air pollution from the stationary sources of separate industrial branches in the Russian Federation (Table II-2, Annex II) are adopted from the State of the Environment (SoE) reports compiled and issued by the Ministry of Natural Resources of the Russian Federation in 2002, 2005 and 2006 (MNR 2003, 2006, 2007). Net amount of air pollution comprises SO_2, NO_x, CO, hydrocarbon compounds, volatile organic compounds (VOCs) and particulate matter (PM).

Particular data-related issues arose during the compilation of statistical data sets because of a major reform undertaken by Rosstat in 2003-2004, i.e. transition from the All-Union Classifier of Sectors of the National Economy to the All-Russian Classifier of Economic Activities and changes in presentation of data. Such actions have resulted in the following: instead of economic and environmental performance indicators such as gross industrial output and gross air pollution for 13 major industrial branches, since 2005 in all statistical reports there have been these two indicators only for nine branches. Moreover, data on output of such branches as oil, gas and coal production, ferrous and non-ferrous metallurgy – without a doubt the most important ones both economically and environmentally – have been aggregated. At the same time, information on such branches as textile, garment manufacturing and leather and shoe making has become disaggregated. Overall, due to these changes there is a raising concern in usefulness of data as it is much harder to monitor performance of separate branches and to estimate their impacts. This adds up to a doubt of general quality and accountability of environmental data often expressed by researchers (Cherp *et al.* 2003, Olshanskaya 2004). Unfortunately, Rosstat is the only source of statistical data in the Russian Federation, thus, we have to employ these data in our analysis, still considering possible to reveal the overall trend, regardless of the general accuracy of numbers. This is the most important task and it can be done with the available data.

Due to the reasons discussed above, in this study, respective data on oil, gas and coal production as well as ferrous and non-ferrous metallurgy will be aggregated for all years from 1999 to 2006. We also assumed that it would be reasonable to agglomerate data on separate branches previously included into "Light industry" sector but currently disaggregated, i.e. statistics of textile, garment manufacturing and leather and shoe making were put together.

3.4 Research methodology

Thus, in this research we study the factors which influence changes in pollution intensity of separate industrial branches and, thus, on the whole industrial sector of the Russian Federation by employing two decomposition analysis techniques, namely, formulae for the general additive decomposition (6) (see Section 3.1) and Fisher Ideal Index (see Table 3.1) for disaggregation of overall intensity into structural changes and changes in the actual intensity of separate branches.

Initial estimates of the separate industrial branches' pollution intensity are calculated by dividing air pollution figures of each branch (Table II-2, Annex II) by gross industrial output in constant prices of a respective branch (1999) (Table I-3, Annex I). Branches' pollution intensity figures are presented in Table II-2 (Annex II).

Fisher Idea Index is calculated with a set of formulae, presented in Table 3.1, in particular:

Laspeyres Index is calculated as:

$$D_{str} = \frac{\Sigma S_i^T x I_i^0}{\Sigma S_i^o x I_i^0}$$

$$D_{in} = \frac{\Sigma S_i^o x I_i^T}{\Sigma S_i^o x I_i^o},$$

Paasche Index is calculated as:

$$D_{str} = \frac{\Sigma S_i^T x I_i^T}{\Sigma S_i^0 x I_i^T}$$

$$D_{in} = \frac{\Sigma S_i^T x I_i^T}{\Sigma S_i^T x I_i^{)}}$$

and the Fisher Ideal Index, as a geometric average of Laspeyres and Paasche Indices, is calculated as:

$$D_{str} = \sqrt{(L_{str} x P_{str})}$$

$$D_{in} = \sqrt{(L_{in} x P_{in})}$$

where:

D_{str} – input of the structural changes into the aggregate pollution intensity;

D_{in} – input of the changes in pollution intensity of separate branches into the aggregate pollution intensity;

S_i^T – share of separate industrial branches in total industrial production at a respective year (Table I-4, Annex I);

I_i^T – pollution intensity of separate industrial branches at a respective year (Table II-2, Annex II).

For the purposes of updating an earlier study on the industrial pollution intensity in Russia, conducted by Cherp *et al*. (2003) we decided to use the general additive decomposition formulae in parallel with the Fisher Ideal Index to test the outcomes and a scale of probable difference between them because, as it was mentioned above, the general formulae, adopted in the earlier study was omitting a residual term, that does exist, thus the results were to be distorted to some extent. Fisher Ideal Index, though, is a perfect decomposition technique, thus, it is residual free. Hence, carrying out a double decomposition analysis enables us to find out actual inputs of structural and intensity changes into the aggregate pollution intensity, test the general formulae and verify the results.

$$\Delta PI_{total} = PI^T - PI^0 \approx \Delta PI_{str} + \Delta PI_{in},$$

where:

$$\Delta PI_{str} = \sum_{i=1}^{N} \Delta S_i^T I_i^T$$

$$\Delta PI_{in} = \sum_{i=1}^{N} S_i^T \Delta I_i^T$$

3.5 Choosing methodology: conclusions

Review of existing methodologies made above enables us to make the following conclusions:

1. There is a little number of studies based on decomposition analysis of environmental performance, namely air pollution intensity of the industrial sector, carried out for developing countries and no studies employing contemporary perfect multiplicative decomposition to air pollution intensity for any ex-SU country.
2. Perfect multiplicative decomposition techniques are the most developed and reliable to date for pollution intensity disaggregation analysis. It is especially important in case their application for developing countries which have uneven development patterns.

Otherwise, residual term, which is a distinctive feature of conventional decomposition techniques, may be too large and, thus, misleading. However, a general additive decomposition method, used in Cherp *et al*. (2003) is also chosen for verification of previous findings for air pollution intensity of the Russian industrial sector in 1990s.

3. Time-series, or chaining approach will be used for our study as in this case all fluctuations in industrial performance at the time of rapid growth of Russian economy are accounted for.
4. The Fisher Ideal Index is selected from other perfect multiplicative decomposition techniques due to its residual-free nature, relative simplicity of mathematical apparatus employed and comprehendible of results.

4. ANALYSIS OF POLLUTION INTENSITY OF RUSSIAN INDUSTRY: STUDY RESULTS

This chapter presents the results of decomposition analysis of air pollution intensity of the Russian industrial sector for the 1999-2006 which was carried out using two decomposition techniques: *Fisher Ideal Index* and the *general additive decomposition* method.

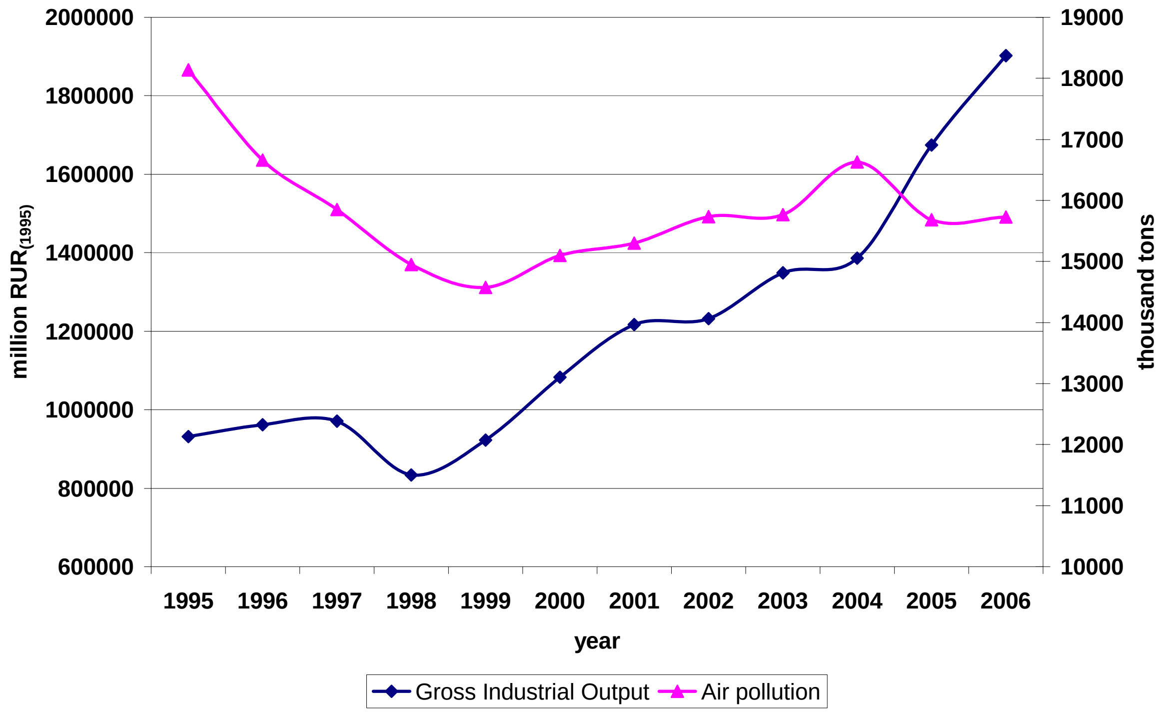
4.1 Economic performance and air pollution

As discussed in Chapter 2, the period of time under investigation is 1999–2006 – years of rapid economic growth. Moreover, according to Rosstat (2003, 2005, 2007) gross industrial output in 2006 more than doubled the 1999's figure. During this economic growth, the environmental dimension of the industrial performance, i.e. air pollution levels, has changed as well. In particular, in 2004 emissions to air exceeded the 1999's level by 14%, sharply declining in 2005 with further growth in 2006 (MNR 2003, 2006).

Figure 4.1 shows the trends in gross industrial output and air pollution from the industrial stationary sources in Russia between 1995 and 2006. In particular, in can be seen that a ***positive decoupling*** of economic and environmental performance of Russia which was occurring right after collapse of the SU (Cherp *et al.* 2003) stopped in 1999. For the next five years there was nearly no decoupling. In 2005-2006 the situation changed again back into the ***positive decoupling***.

To analyze this complex relationship between economic output and air pollution in the Russian industrial sector we adopted two decomposition techniques and carried out the analysis, results of which are presented in the following section.

Figure 4.1. Industrial output and air pollution in Russia.



Source: MNR (2003, 2006, 2007) and Rosstat (2003, 2005, 2007).

4.2 Pollution intensity and shares of individual branches of the Russian industrial sector

Pollution intensity of individual industrial branches and shares of these branches in gross industrial output (GIO) are the two main determinants of changes in the overall pollution intensity of the industrial sector. Table 4.1 provides the structure of the Russian industrial sector and shows data on changes within different branches. In particular, we can see a similar trend to one described by Cherp *et al.* (2003), i.e. shares of all industrial branches considered to be of higher pollution intensity in GIO have increased. The leader of growth is oil refining, chemical and petrochemical industries sector – 8,1% growth in 2006 comparing to 1999. The second top is electricity generation and distribution sector with 3% growth. It is interesting, though, that despite the boom in natural resources market, overall change in growth for oil, gas and coal sector as well as metallurgy sector is not as significant, and is, in fact, moderate.

Although the heavy industrial sectors acquiring bigger share every year, the lighter sectors of lower pollution intensity steadily reducing their shares: e.g. machinery and metal working sector has lost 6,1% over 9 years, food industry lost 4,6% and timber, pulp and paper industries – 1,6%. These data clearly illustrate the shift of the Russian economy towards more pollution intensive sectors of economy, which corresponds with the trend during economic transition in 1990s (Cherp *et al.* 2003).

Table 4.1. Pollution intensity and shares of major industrial branches in Gross Industrial Output in the Russian Federation in 1999-2006.

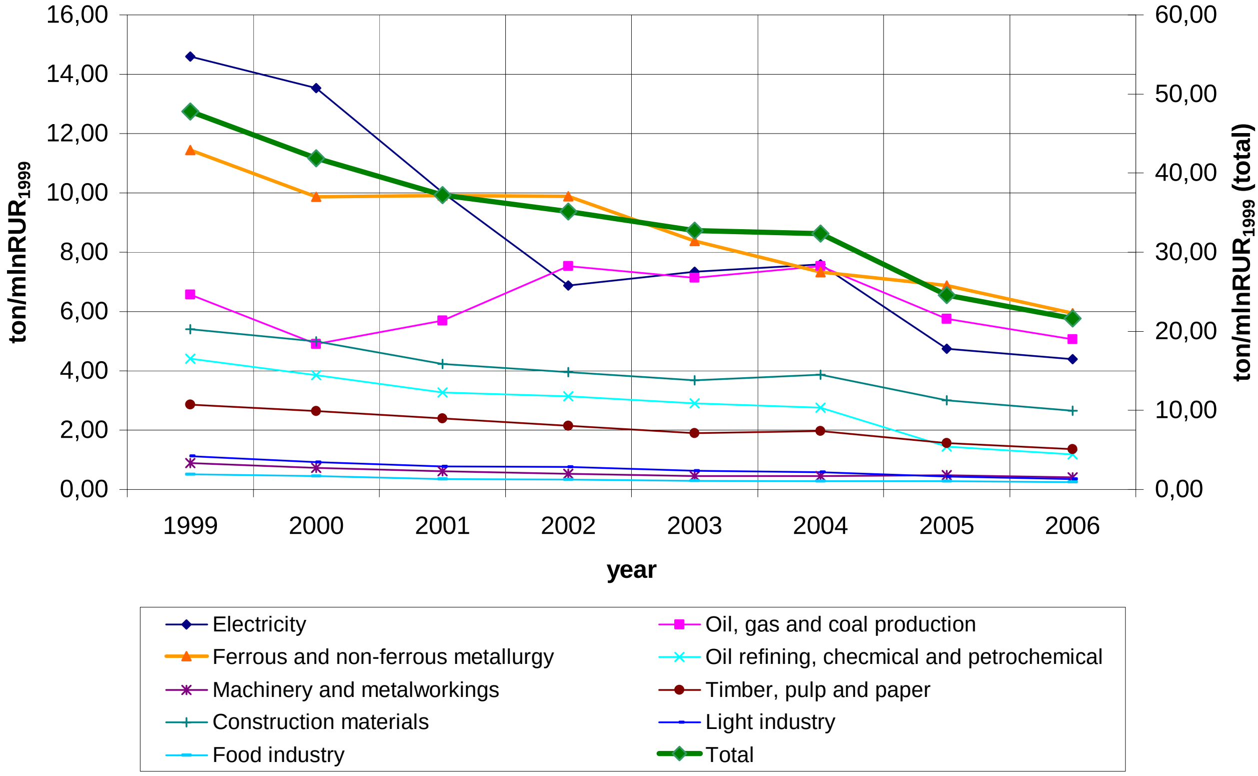
Industrial branch	Pollution intensity, tons/mln Rubles$_{(1999)}$		Share in Gross Industrial Output, %								Change in 1999 -2006, %
	Range	Average	1999	2000	2001	2002	2003	2004	2005	2006	
Branches with higher pollution intensity											
Electricity	4,40-14,60	6,15	10,5	9,5	10,8	11,0	12,5	11,1	13,2	13,5	**+3,0**
Oil, gas and coal production	4,90-7,54	4,74	19,2	18,5	17,5	17,6	17,1	19,3	20,9	20,4	**+1,2**
Ferrous and non-ferrous metallurgy	5,94-11,45	6,32	14,9	19,7	16,9	16,5	17,3	19,4	14,8	15,0	**+0,1**
Oil refining, chemical and petrochemical	1,18-4,40	2,01	10,3	10,0	10,1	9,9	9,1	9,3	18,0	18,4	**+8,1**
Construction materials	2,66-5,41	2,87	3,0	2,9	3,2	3,2	3,2	3,2	3,3	3,5	**+0,5**
Branches with lower pollution intensity											
Machinery and metalworking	0,41-0,88	0,40	20,0	19,7	21,0	21,0	20,9	19,6	13,7	13,9	**-6,1**
Timber, pulp, and paper	1,35-2,85	1,51	5,0	4,8	4,6	4,6	4,3	4,0	3,6	3,4	**-1,6**
Light industry	0,35-1,13	0,48	1,8	1,6	1,7	1,6	1,4	1,2	0,9	1,0	**-0,8**
Food industry	0,25-0,50	0,24	15,3	13,3	14,2	14,6	14,0	13,0	11,6	10,7	**-4,6**

Source: MNR (2003, 2006, 2007) and Rosstat (2003, 2005, 2007).

Despite of the shift towards more pollution intensive industries, indicators of individual industrial branches show a decline in terms of pollution intensity over last nine years (Table II-2, Annex II). However, Fig. 4.2 based on data from Table II-2, illustrates that the process of environmental performance improvement was not equally stable for all branches. Specifically, pollution intensity of the gas, oil and coal production sector was increasing from 2000 till 2004, with a fall afterwards. Decline in pollution intensity was not also steady for electricity generation and metallurgy sectors. Though, by 2006 the overall pollution intensity of the Russian industrial sector has decreased from 47,8 tons/mln RUR_{1999} to 21,6 tons/mln RUR_{1999}, i.e. by approximately 220%.

Rates of contribution to this decline by economic restructuring and changes within individual industrial branches were estimated by using two decomposition techniques discussed above and the results of the analysis are presented in the following section.

Figure 4.2. Pollution intensities of individual branches of the Russian industrial sector in 1999-2006.



Source: MNR (2003, 2006, 2007) and Rosstat (2003, 2005, 2007).

4.3 Decomposing pollution intensity: results

The quantitative results of both decomposition techniques are presented in Annex III. In particular, Table III-1 and Table III-2 contain figures of contributions of industrial restructuring and actual changes in pollution intensities of individual industrial branches into the overall pollution intensity of the Russian industrial sector respectively. Table III-3 shows the results of the Fisher Ideal Index calculations.

4.3.1 General additive decomposition results

Estimates of the cumulative impacts of structural changes and changes in actual pollution intensity of branches, calculated using the general additive decomposition technique are presented in Tables 4.2 and 4.3.

Table 4.2. Contribution of industrial restructuring to the change in air pollution intensity of the industrial sector in the Russian Federation in 1999-2006 (tons/mln RUR_{1999}).

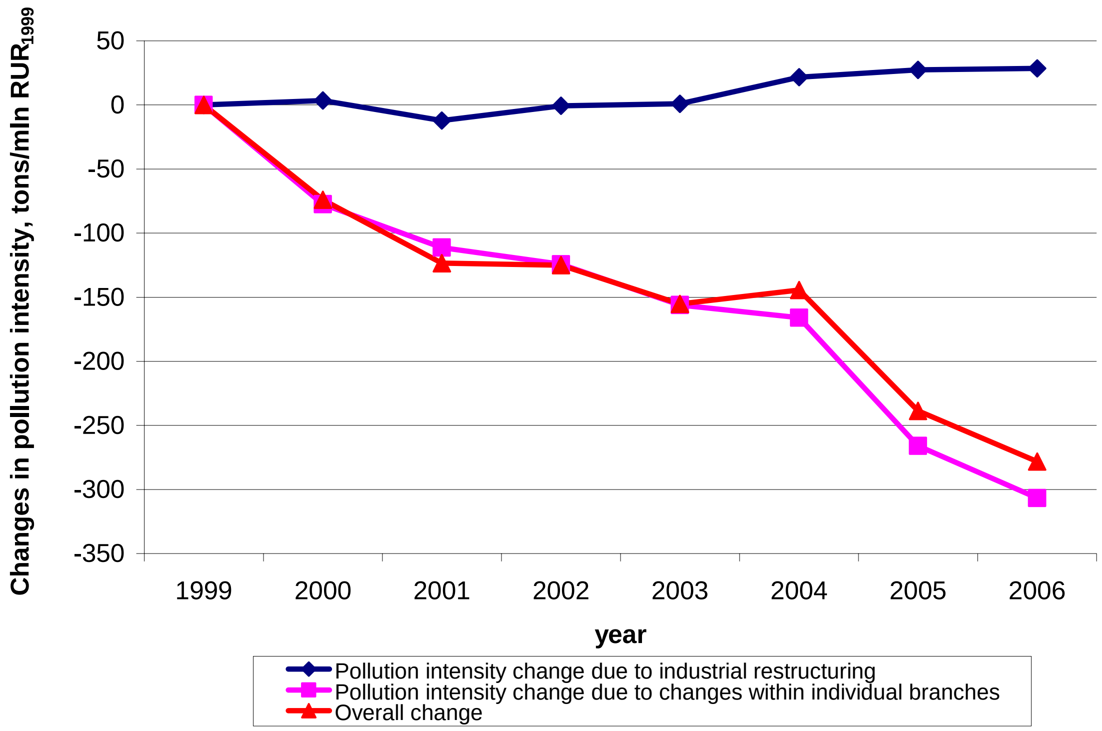
	Years						
	'99-'00	**'00-'01**	**'01-'02**	**'02-'03**	**'03-'04**	**'04-'05**	**'05-'06**
Change in industrial PI due to restructuring	3,38	-15,48	11,40	1,59	20,70	5,71	1,22
Cumulative change calculated since 1999	**3,38**	**-12,10**	**-0,70**	**0,90**	**21,60**	**27,32**	**28,53**

Table 4.3. Contribution of changes in pollution intensity of individual industrial branches to the overall air pollution intensity of the Russian industrial sector in 1999-2006 (tons/mln RUR_{1999}).

	Years						
	'99-'00	**'00-'01**	**'01-'02**	**'02-'03**	**'03-'04**	**'04-'05**	**'05-'06**
Change in industrial PI due to changes in individual PI	-77,46	-33,87	-12,98	-31,85	-9,91	-99,97	-40,66
Cumulative change calculated since 1999	**-77,46**	**-111,33**	**-124,31**	**-156,16**	**-166,07**	**-266,04**	**-306,69**

The results obtained by the general additive decomposition show that changes in pollution intensity due to restructuring during a period after the 1998^{th} economic crises and up to 2001 was either slightly positive or significantly negative, thus contributing to the shift towards less pollution intensive industrial branches. However, already in 2002 the trend reversed along with the ongoing economic growth based on natural resources extraction and export, thus, contributing to the shift towards more pollution intensive branches. To sum up, the overall contribution of the industrial restructuring increased by nine times in comparison with its 1999-2000s level.

Figure 4.3. Influence of industrial restructuring and real pollution intensity changes on the overall pollution intensity of the Russian industrial sector in 1999-2006.



With regard to the impacts of changes of pollution intensities within individual industrial branches, we found out that, that although yearly indicators have been fluctuating, there has been a steady negative trend, i.e. trend towards reduction of pollution intensity of the Russian industrial sector. Figure 4.3 illustrates impacts of industrial restructuring and changes of pollution intensities within individual branches, as well as the overall change in the pollution intensity of the Russian industrial sector. As we can see both from the Tables 4.2 and 4.3 and Fig. 4.3, the main contributor to the overall fall of the industrial pollution intensity is the change in pollution intensity of individual industrial branches. There may be several reasons of these significant improvements: increased productivity, introduction of modern, thus, more efficient technologies of production, additional investments into the emission abatement actions and removal of older and inefficient equipment. Further analysis of possible factors which affected air pollution intensity reductions of Russian industrial sector are discussed in the following chapter.

4.3.2 Fisher Ideal Index decomposition results

Results of calculations of the Fisher Idea Index are presented in Table III-3 (Annex III). Cumulative contributions of industrial restructuring and changes in actual pollution intensity of individual industrial branches are presented in Table 4.4 and Table 4.5 respectively. Figures in these tables show results similar to those of the general decomposition method presented in the previous section. In particular, input of the restructuring is rather positive, however not significantly. The highest figure of its contribution is 5% during the 2003-2004 with an overall change equals to 8% since 1999.

Table 4.4. Contribution of industrial restructuring to the change in pollution intensity of the industrial sector in the Russian Federation in 1999-2006.

	Years						
	'99-'00	**'00-'01**	**'01-'02**	**'02-'03**	**'03-'04**	**'04-'05**	**'05-'06**
Change in industrial PI due to restructuring, %	+2	-3	+3	0	+5	+1	0
Cumulative change calculated since 1999, %	+2	-1	+2	+2	+7	+8	+8

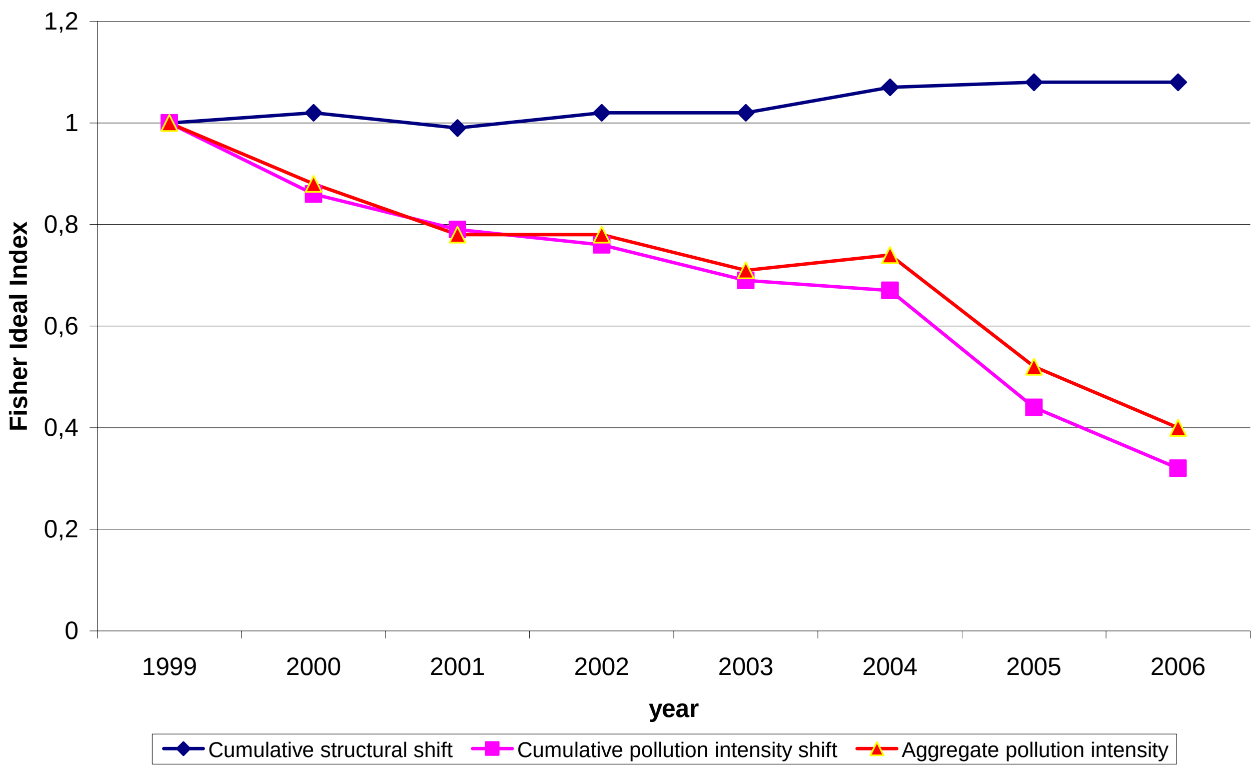
Table 4.5. Contribution of changes in pollution intensity of individual industrial branches to the overall pollution intensity of the Russian industrial sector in 1999-2006.

	Years						
	'99-'00	**'00-'01**	**'01-'02**	**'02-'03**	**'03-'04**	**'04-'05**	**'05-'06**
Change in industrial PI due to changes in individual PI, %	-14	-7	-3	-7	-2	-23	-12
Cumulative change calculated since 1999, %	-14	-21	-24	-31	-33	-56	-68

At the same time, significant changes within individual industrial branches can be observed. Pollution intensity decreases with an annual rate of 9% on average, resulting in 68% decline by 2006 in comparison to 1999 level.

Figure 4.4 illustrates Fisher Ideal Indexes for industrial restructuring and changes of actual pollution intensities within individual industrial branches, as well as the cumulative change of the Russian industrial sector pollution intensity.

Figure 4.4. Fisher Ideal Indices for structural changes and changes in actual pollution intensity of the Russian industrial sector in 1999-2006 (1999=1).



4.4 Decomposing pollution intensity of the Russian industrial sector: conclusions

Both sets of decomposition results show strong and relatively steady negative trend in the overall pollution intensity of the Russian industrial sector being led by a significant decline (by about 68%) in pollution intensity within individual industrial branches. At the same time, there is a clear shift towards more pollution intensive branches of industry which can be explained by more and more natural resources-oriented structure of Russian economy. However, the current results show a drastically different picture in comparison to the one provided by Cherp *et al.* (2003), where structural and intensity shifts were canceling each other and the overall pollution intensity was positive over 1990s. Moreover, shapes of both graphs (results of the general additive decomposition and of the Fisher Ideal Index decomposition) are very similar, having only minor deviations from each other, what means that the results obtained by using the general decomposition technique, adopted in Cherp *et al.* (2003), are reliable enough to analyze trends of the environmental performance of the Russian Federation.

5. DISCUSSION OF FINDINGS, OVERALL CONCLUSIONS AND RECOMMENDATIONS

This chapter presents a discussion of the decomposition analysis outcomes and attempts to explain them through closer look at main industrial branches affecting the overall air pollution levels as well as pollution intensity of the Russian industrial sector. This Chapter also includes analysis of four theories exploring relationships between economic restructuring, growth and environmental performance and their relevance to the case of Russia. Lastly, it provides a summary of main conclusions of this research, agenda for future research and recommendations.

5.1. Understanding pollution intensity decomposition results and its determinants

The aim of this thesis was to explore relationship between economic development and air pollution in Russia in 1999 – 2006. Particular focus was on air pollution from the Russian industrial sector as a main source of air pollution emissions and also as a key economic sector accountable for economic growth in Russia since 1999. The results show that since the economic recovery started in 1999, overall air pollution from the industrial sector has increased by about 10% by 2006. Moreover, as air pollution levels were growing since 1999 till 2004 proportionately to GDP growth, a period of a *positive decoupling* of economic and environmental performance observed from 1991 till 1999 ended and turned into ***zero decoupling***. However, already in 2005-2006 with a drop in air pollution and yet undisturbed growth of industrial output the ***positive decoupling*** occurred again.

With regard to the main contributors of air emissions – "dirty four" of electricity generation, fossil fuel production, metallurgy and oil refining and chemical industrial sectors – they are already facing difficulties to further growth of their industrial output (Expert 2006a) and desperately need extensive investments to improve main production processes and upgrade capacities, thus, leaving environmental considerations completely aside. On the other hand, the existing production capacities are worn out, thus, will not last much longer and gradually will be shut down naturally reducing emissions. Overall, the main reason for the growth of industrial air pollution is growing production and utilization of fossil fuels, namely oil, coal and less significantly, gas.

At the same time, *pollution intensity* of the industrial sector chosen as an indicator comprising both economic and environmental factors of sustainability was found to be declining rather intensively over these years with a drop of about 220% in 2006 comparing to 1999 level. The factors determining this change in pollution intensity of the whole sector and individual branches are the following:

1. Changes of pollution intensity within individual industrial branches;
2. Significantly reduced influence of industrial restructuring on the overall pollution intensity since 1999 in comparison to 1990s period.

With regard to dynamics of pollution emissions and pollution intensities of individual industrial branches the following sectors are of particular importance. As noted in Chapter 2 there is so-called "dirty four" of industrial branches which are accountable for about 90% of all air pollution emissions from the Russian industrial sector, thus, there sectors are of the main interest and will be discussed below.

1. **Fossil fuel extraction sector**. Sector comprising oil, gas and coal extraction, has become the main contributor among "the four" since 2003. By 2005 it has doubled its 1999 emission level. At the same time, in terms of pollution intensity it has shown most uneven dynamics among all industrial branches, fluctuating from 2001 till 2005 and returning to almost the 1999 level in 2006. Due to increased market demand, oil

and gas production has increased significantly (about 43% and 16% respectively) (Rosstat 2007). It was growing since 2002 till the end of 2007, thus the main reason of an increase of air emissions from the sector is increased production and burning of oil gas, amount of which is growing proportionately to the oil extraction (MNR 2002). Moreover, this shift towards fossil fuels sector contributes to positive industrial restructuring factor, thus, increasing pollution intensity. Yet another contribution to air pollution levels was made by coal sub-sector as there is an increasing interest in coal (production increased by about 26% since 1999) (Rosstat 2007), because domestic prices for oil and gas are growing. Lastly, despite significant profits, oil companies cannot afford upgrading their technologies and install new capacities, because major share of all earnings are retrieved by the state government in form of export taxes (Economist 2008).

2. **Metallurgy sector.** The flagship of Russian heavy industry, it used to be the main source of air pollution emission during Soviet times (MNR 2002) and retained its "leadership" till 2002. Overall pollution has been slowly decreasing since 1990s followed by short-term rise in 2000. Pollution intensity has also decreased by 50% since 1999. This improved environmental performance was followed by increasing production of ferrous and non-ferrous metals due to increasing market demands since early 2000s. OECD (2004) suggests that increased productivity of existing capacities has been the main factor of sustainable production growth along with improvement of environmental situation. Additionally, metallurgy sector as a main consumer of electric energy has been pushed for more thoughtful and rational management by raised prices for electricity.

3. **Electricity generation sector**. This sector has been showing improvements both in terms of pollution emissions reduction and declining pollution intensity. Main reasons

to that are improved efficiency of fuel firing, transition of several major power plants from coal/oil to gas and overall increased productivity of electricity generation (Expert 2006; MNR 2002).

4. **Oil refining, chemical and petrochemical sector.** This sector traditionally has had comparatively low air emissions and pollution intensity, at the same time after decline of emission in 1990s and early 2000s since 2004 there is a rise which correlates with changes in sector's share in gross industrial output. However, pollution intensity of the sector is decreasing steadily since 1999.

Overall, the results show that industrial sector is restructuring towards more pollution intensive branches of industry which confirms observations made by Cherp *et al.* (2003) for Russian economy during transition period of 1990s.

One of objectives of the thesis was to test major theories of interrelationship between economic restructuring, growth and environmental performance addressed in Section 2.1. of Chapter 2. The above discussion of economic restructuring and growth influence on environmental performance partially supports three out of four theories outlining influence of economic restructuring and growth on environmental performance. The theory which cannot be fully justified by the above analysis is the Environmental Kuznets curve, because even though economic growth in Russia is evident and is being pushed further, however, environmental concerns in Russia are not actively addressed neither by the government or society up to date. Even though from the legislative point of view, recent Ecological Doctrine and a new Law on Environmental Protection do address environmental concerns of the country, it can be argued that they declare these concerns only formally, on paper (Larin *et al.* 2003; Expert 2006). As it has been observed, the motto of Russia since late 1990s is "first grow, then clean up".

Further analysis of correlations of the results of the research with the theories demonstrates that changes on the market and openness to international trade as well as deregulation of economy do have their positive influence on economic and environmental performance of the industrial sector. Good examples here are improved productivity in fossil fuel production, electricity generation and metallurgy sectors, although it general, it is more or less applicable to all industrial branches. However, we believe that main gains are brought from the productivity improvements as investments in cleaner technologies and increased competitiveness with foreign producers still contribute much less into overall production and environmental efficiency.

Further on, this research revealed certain pieces of evidence justifying that due to weak environmental regulations and lack of sufficient environmental control in Russia in 1990s and 2000s more resource- and pollution intensive sectors of industry developed faster and easier than they could have developed otherwise. Moreover, there have been suggestions that there was certain political will towards lax environmental controls (Larin *et at* 2003; Expert 2006; Firsova and Taplin 2007) as since late 1990s resource and pollution intensive industrial branches have been profitable due to increasing demand from international markets.

Finally, the situation in Russia is seemed to correlate with the “theory of competitive advantage” in various respects. First of all, contemporary Russia is still dependent on production of those sectors which remain as the SU legacy: various types of heavy industry. Secondly, due to abundance of natural resources, primarily fossil fuels and metals, and growing market demands of there resources, Russia has naturally took an opportunity to benefit from both own resource wealth and market trends. Thus, it has been extensive exploitation of the resources as domestic prices for energy resources have been low since 1990s till mid-2000s which allowed production with low costs. Thus, overall the pathway taken by Russia has led to more resource- and pollution intensive industrial structure. However, again, other (primarily market) determinants, such as increased competitiveness and constantly growing demand have made production less pollution intensive, i.e. unit of production per unit of pollution ratio has declined. Here it can be assumed that, in fact, economic development has influenced industrial restructuring and increased efficiency, thus contributing to *better environmental performance*.

5.2. Economic restructuring, growth and air pollution in Russia: conclusions

The main objective of the thesis was to explore and analyze pollution intensity of the Russian industrial sector and its determinants between 1999 and 2006 which was the time of economic recovery and intensive industrial growth. Through an extensive literature and data review it was found out that industrial restructuring and changes within individual industrial branches are the key determinants of the overall pollution intensity. Also, four theories addressing interrelations between economic restructuring and growth and environmental performance were chosen for testing. In order to select an appropriate methodological tool for this research a review of existing and most advanced techniques for decomposition analysis was carried out. It is presented in Chapter 3 with additional discussion on specific practical issues related to Russian statistical data.

Experts in decomposition analysis recommend *Fisher Ideal Index* as an efficient yet easy-to-utilize tool, thus it was chosen for the analysis (Ang et al. 2003; Boyd and Roop 2004; Olshanskaya 2004). At the same time, as there was aspiration to make the results of this study useful and comparable to previous research, a *general additive decomposition*, used by Cherp *et al.* (2003) for a similar study for 1990s was also adopted in order to compare results of both studies and, at the same time, to validate the results of the previous study. Overall, both methodologies have proved to be applicable and useful, allowing quantification of inputs of structural changes and changes within individual industrial branches into the overall change of pollution intensity of the Russian industrial sector. The results of the general additive decomposition technique were proved to be reasonably accurate and correlated with results of the Fisher Ideal Index decomposition technique.

Analysis of industrial pollution intensity reviled that although the overall air pollution from industrial sources in Russia increased by about 10% since 1999 till 2006, pollution intensity of the whole industrial sector has drastically decreased by approximately 220% during the same period. Further on, it was found out that pollution intensity of all major individual industrial branches has declined, yet fossil fuel production sector seemed to follow its own trend, i.e. between 2001 and 2004 growth of pollution intensity had occurred with letter return back to 1999 level. Overall, changes of the total pollution intensity attributed to industrial restructuring were revealed to be contributing to higher levels of intensity, though the changes within individual industrial branches have by far offset influence of the former. In particular, cumulative contribution of structural changes into the overall pollution intensity reached +8% since 1999 by 2006 as cumulative contribution of changes within individual industrial branches amounted –68% for the same period. The latter change was found to be likely attributed to the increased productivity of major branches within the same capacities, thus, increasing efficiency, and consequently contributing to better environmental performance by reducing unit of production per unit of pollution ration.

Finally, analyzing research results through application of theoretical framework, the following conclusions were drawn: market liberalization and economic development do motivate higher productivity, deregulation of economy and consequent rise of energy tariffs promotes better resource- and energy efficient operational techniques and equipment. However, in case of Russia several pieces of evidence show that the strategy of “first grow, then clean up” has been chosen and is followed by up to date with a focus on growth as so far there is little evidence, if any, of raising environmental awareness neither of government of society. A shift towards more resource intensive branches of industry is evident. Lack of strong political will to improve environmental regulations and control provokes further environmental degradation despite technological improvements.

Summing up, this research has demonstrated a strong relationship between economic restructuring and growth and environmental performance in Russia in 1999-2006. Currently, the efficiency of the industrial sector in terms of pollution intensity is increasing due to internal changes within individual industrial branches. However, with further restructuring towards resource intensive branches when the existing capacities work at top loads, thus, almost no more productivity growth is possible situation in not so distant future is likely to change towards higher air pollution. Strategic planning on the governmental level, tax reform for resource extraction and processing industries, besides, substantial investments into major industrial restructuring and installation of new capacities are needed in order to sustain economic growth and preserve the environment from drastic degradation.

5.3. Future research agenda and recommendations

The research on environmental implications of economic restructuring and growth presented in this paper can be carried on and advanced in a number of directions. Firstly, as the study revealed changes of pollution intensity within individual industrial branches which are the main contributor to the overall industrial pollution intensity indicator, thus, future research should be focused on determinants of these changes. Performance of the “dirty four” of industrial branches should be deeper scrutinized in terms of limits to further efficiency and environmental performance improvements. Our research was focused on industrial air emissions. We believe that secondly, in order to draw a fuller picture of the Russia’s industrial sector environmental performance during economic and consumption boom, investigation of trends in waste and waste water generation should be carried out. Thirdly, upon accumulation of statistical data on CO_2 emissions from industrial activities greenhouse potential of the Russian industry can be and should be estimated, especially taking into account Kyoto Protocol ratified by Russia in 2004 (UNFCCC 2006). Fourthly, assuming that environmental policy and control in Russia were intentionally weakened by the government to motivate industrial development as suggested by several experts (Larin *et al.* 2003; Von Ritter and Tsirkunov 2003; Expert 2006) it would be logical to investigate to what extent these changes actually affected decision-making in industries and of investors.

With regard to recommendations, the following actions should be considered as essential in order to sustain and improve environmental performance of the Russian industrial sector:

- Methodology of collection and reporting statistics on industry and environment should be amended in order to make data more disaggregated and transparent.
- Excessive taxes on exported natural resources should be reduced simultaneously creating a legislative environment that companies would invest in cleaner, more productive and efficient technologies;

Environmental issues and considerations should regain its priority in strategies of the national development.

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ANNEX I. DATA ON INDUSTRIAL PRODUCTION IN THE RUSSIAN FEDERATION FOR 1999-2006.

Table I-1. Industrial production by branches, current prices, mln Russian rubles.

Industrial sector	1999	2000	2001	2002	2003	2004	2005	2006
Electricity	269551	375088	519993	706639	886190	1042502	1691000	2182000
Gas, coal and oil production	383660	731960	845934	994452	1211059	1807611	2686000	3293000
Ferrous and non-ferrous metallurgy	492883	783235	815320	937393	1224470	1820877	1903000	2416000
Oil refining, chemical and petrochemical	264079	397551	487430	559736	647999	869801	2309000	2964000
Machinery and metalworking	513399	780260	1014920	1190786	1482577	1835897	1762000	2245000
Timber, pulp and paper	128670	188888	220729	260295	307619	374340	460000	554000
Construction materials	77096	116049	153251	183862	229447	297822	426000	569000
Light industry (Textile and leather)	45041	65019	80750	91852	101881	111751	120700	155700
Food industry (incl. beverages and tobacco	392599	526793	687371	824803	993865	1219024	1486000	1729000
TOTAL	*2566978*	*3964843*	*4825698*	*5749818*	*7085107*	*9379625*	*12843700*	*16107700*

Source: Rosstat (2002, 2005, 2007)

Table I-2. Industrial Price Index (IPI), 1999=100%.

	1999	2000	2001	2002	2003	2004	2005	2006
IPI, % to previous year	100	131,6	108,3	117,7	112,5	128,8	113,4	110,4
IPI, % to 2000	100	131,6	142,5	167,7	188,7	243,0	275,6	304,2

Source: Rosstat (2001, 2007)

Table I-3. Industrial production by branches in constant prices (1999), mln Russian rubles.

Industrial sector	1999	2000	2001	2002	2003	2004	2005	2006
Electricity	269551	285021	364907	487337	469629	429013	613570	717291
Gas, coal and oil production	383660	556201	593638	592995	641791	743873	974601	1082512
Ferrous and non-ferrous metallurgy	492883	595163	572154	558970	648898	749332	690493	794214
Oil refining, chemical and petrochemical	264079	302090	342056	333772	343402	357943	837808	974359
Machinery and metalworking	513399	592903	712225	710069	785679	755513	639332	738001
Timber, pulp and paper	128670	143532	154898	155215	163020	154049	166909	182117
Construction materials	77096	88183	107545	109637	121594	122560	154572	187048
Light industry (Textile and leather)	45041	49407	56667	54772	53991	45988	43795	51183
Food industry (incl. beverages and tobacco	392599	400299	482366	491832	526691	501656	539187	568376
TOTAL	*2566978*	*3012799*	*3386455*	*3494600*	*3754694*	*3859928*	*4660269*	*5295102*

Source: Rosstat (2001, 2007), own calculations.

Table I-4. Structure of industrial production in the Russian Federation in 1999-2006.

Total industry =1.

Industrial branch	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**
Electricity production	0,11	0,09	0,11	0,11	0,13	0,11	0,13	0,14
Gas, oil and coal production	0,15	0,18	0,18	0,18	0,17	0,19	0,21	0,20
Ferrous and non-ferrous metallurgy	0,19	0,20	0,17	0,17	0,17	0,19	0,15	0,15
Oil refining, chemical and petrochemical	0,10	0,10	0,10	0,10	0,09	0,09	0,18	0,18
Machinery and metalworking	0,20	0,20	0,21	0,21	0,21	0,20	0,14	0,14
Timber, pulp and paper	0,05	0,05	0,05	0,05	0,04	0,04	0,04	0,03
Construction materials	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,04
Light industry	0,02	0,02	0,02	0,02	0,01	0,01	0,01	0,01
Food industry	0,15	0,13	0,14	0,15	0,14	0,13	0,12	0,11
TOTAL	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00

ANNEX II. AIR POLLUTION LEVELS AND POLLUTION INTENSITY OF THE RUSSIAN FEDERATION INDUSTRIAL SECTOR.

Table II-1. Air pollution levels from separate branches of the Russian industrial sector in 1999-2006, thousands of tons.

Industrial branch	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**
Electricity production	3935,5	3857,3	3655,8	3352,7	3446,6	3257,7	2906,8	3155,2
Gas, oil and coal production	2345,3	2724,3	3381,9	4469,8	4582,3	5603	5612,2	5489,9
Ferrous and non-ferrous metallurgy	5641,4	5872,9	5673,3	5520,9	5439,9	5489,7	4749,4	4721,2
Oil refining, chemical and petrochemical	1162,8	1163,3	1116,6	1048,8	997,1	988,8	1209,6	1151,5
Machinery and metalworking	454,1	433,2	432,7	370,1	356	340,1	310,7	304,3
Timber, pulp and paper	367,3	378,9	371,7	332,2	308,7	303,5	259,9	246,4
Construction materials	416,9	440,7	455	434	448	474	465,9	497,6
Light industry	50,6	45,4	43,6	41,2	33,9	26,6	19,5	17,8
Food industry	198,2	181,8	168,4	162,9	155,1	142,6	147	144,6
TOTAL	*14572,1*	*15097,8*	*15299,0*	*15732,6*	*15767,6*	*16626*	*15681*	*15728,5*

Source: MNR (2003, 2006, 2007)

Table II-2. Pollution intensity of individual industrial branches in the Russian Federation in 1999-2006 (tons/mln RUR_{1999}).

Industrial branch	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**
Electricity production	14,60	13,53	10,02	6,88	7,34	7,59	4,74	4,40
Gas, oil and coal production	6,57	4,90	5,70	7,54	7,14	7,53	5,76	5,07
Ferrous and non-ferrous metallurgy	11,45	9,87	9,92	9,88	8,38	7,33	6,88	5,94
Oil refining, chemical and petrochemical	4,40	3,85	3,26	3,14	2,90	2,76	1,44	1,18
Machinery and metalworking	0,88	0,73	0,61	0,52	0,45	0,45	0,49	0,41
Timber, pulp and paper	2,85	2,64	2,40	2,14	1,89	1,97	1,56	1,35
Construction materials	5,41	5,00	4,23	3,96	3,68	3,87	3,01	2,66
Light industry	1,12	0,92	0,77	0,75	0,63	0,58	0,45	0,35
Food industry	0,50	0,45	0,35	0,33	0,29	0,28	0,27	0,25
TOTAL	*47,79*	*41,89*	*37,25*	*35,14*	*32,72*	*32,36*	*24,59*	*21,62*

Source: MNR (2003, 2006, 2007) and Rosstat (2003, 2005, 2007).

ANNEX III. DECOMPOSITION CALCULATION RESULTS: GENERAL ADDITIVE DECOMPOSITION AND FISHER IDEAL INDEX.

Table III-1. Contribution of industrial restructuring to the change in pollution intensity of the industrial sector in the Russian Federation in 1999-2006 (tons/mln RUR_{1999}).

Industrial branch	'99-'00	'00-'01	'01-'02	'02-'03	'03-'04	'04-'05	'05-'06
Electricity production	-14,63	15,49	26,78	-10,22	-10,40	12,65	1,74
Gas, oil and coal production	20,15	-4,93	-3,71	0,91	15,98	10,91	-2,54
Ferrous and non-ferrous metallurgy	5,90	-28,28	-8,91	11,75	16,74	-32,65	1,17
Oil refining, chemical and petrochemical	-1,08	0,26	-1,76	-1,22	0,36	18,31	0,56
Machinery and metalworking	-0,26	0,90	-0,40	0,30	-0,61	-2,74	0,10
Timber, pulp and paper	-0,68	-0,48	-0,30	-0,20	-0,68	-0,72	-0,21
Construction materials	-0,40	1,15	-0,16	0,39	-0,24	0,49	0,61
Light industry	-0,12	0,03	-0,08	-0,09	-0,15	-0,13	0,01
Food industry	-0,96	0,38	-0,06	-0,01	-0,30	-0,40	-0,22
TOTAL	**7,92**	**-15,48**	**11,40**	**1,59**	**20,70**	**5,71**	**1,22**

Table III-2. Contribution of changes in pollution intensity of individual industrial branches to the overall pollution intensity of the Russian industrial sector in 1999-2006 (tons/mln RUR_{1999}).

Industrial branch	'99-'00	'00-'01	'01-'02	'02-'03	'03-'04	'04-'05	'05-'06
Electricity production	-10,65	-35,56	-38,80	6,08	3,01	-34,67	-4,52
Gas, oil and coal production	-27,86	14,38	31,75	-6,78	7,13	-35,64	-14,21
Ferrous and non-ferrous metallurgy	-30,74	0,88	-0,64	-24,85	-19,40	-7,66	-13,92
Oil refining, chemical and petrochemical	-5,61	-5,90	-1,20	-2,23	-1,30	-17,97	-4,76
Machinery and metalworking	-3,05	-2,51	-1,78	-1,40	-0,06	0,60	-1,02
Timber, pulp and paper	-1,05	-1,12	-1,17	-1,08	0,32	-1,56	-0,72
Construction materials	-1,22	-2,34	-0,86	-0,87	0,59	-2,77	-1,21
Light industry	-0,35	-0,25	-0,03	-0,19	-0,07	-0,14	-0,09
Food industry	-0,72	-1,45	-0,25	-0,52	-0,14	-0,14	-0,20
TOTAL	**-81,24**	**-33,87**	**-12,98**	**-31,85**	**-9,91**	**-99,97**	**-40,66**

Table III-3. Calculations of the Fisher Ideal Index for the Russian industrial sector in 1999-2006.

	1999	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**
Laspeyres Str	1	1,02	0,975	1,037	1,006	1,0514	1,0345	1,0038
Laspeyres In	1	0,865	0,9384	0,9832	0,9321	0,9785	0,7891	0,8793
Paasche Str	1	1,011	0,9607	1,0136	1,0007	1,0482	0,9898	1,0038
Paasche In	1	0,857	0,9246	0,9608	0,9269	0,9755	0,7551	0,8794
Fisher$_{(Str)}$	**1**	**1,02**	**0,97**	**1,03**	**1,00**	**1,05**	**1,01**	**1,00**
Fisher$_{(In)}$	**1**	**0,86**	**0,93**	**0,97**	**0,93**	**0,98**	**0,77**	**0,88**
Structural shift	***1***	***1,02***	***0,99***	***1,02***	***1,02***	***1,07***	***1,08***	***1,08***
Intensity	***1***	***0,86***	***0,79***	***0,76***	***0,69***	***0,67***	***0,44***	***0,32***
Aggregate PI	***1***	***0,88***	***0,78***	***0,78***	***0,71***	***0,74***	***0,52***	***0,40***