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Abstract

A number of previous studies on China's carbon emissions have mainly focused on two facts: 1) the continuous growth in emissions up till the middle of the 1990s; 2) the recent stability of emissions from 1996 to 2001. Decomposition analysis has been widely used to explore the driving forces behind these phenomena. However, since 2002, China's carbon emissions have resumed their growth at an even greater rate. This paper investigates China's carbon emissions during 1971-2003, with particular focus on the role of biomass, and, the fall and resurgence in emissions since the mid-1990s. We use an extended Kaya identity and the well-established logarithmic mean Divisia index (LMDI I) method. Carbon emissions are decomposed into effects of various driving forces. We find that: (1) A shift from biomass to commercial energy increases carbon emissions by a magnitude comparable to that of the increase in emissions due to population growth; (2) The technological effect and scale effect due to per capita GDP growth are different in the pre-reform period versus the post-reform period; (3) The positive effect of population growth has been decreasing over the entire period; (4) The fall in emissions in the late 1990s and resurgence in the early 2000s may be overstated due to inaccurate statistics. The rapid growth since the early 2000s, therefore, may not indicate a "new trend"; (5) Carbon emissions exhibit a correlation of 0.99 with coal consumption, which points to explicit policy suggestions.

Keywords: China; Biomass; Carbon Emission; Decomposition analysis

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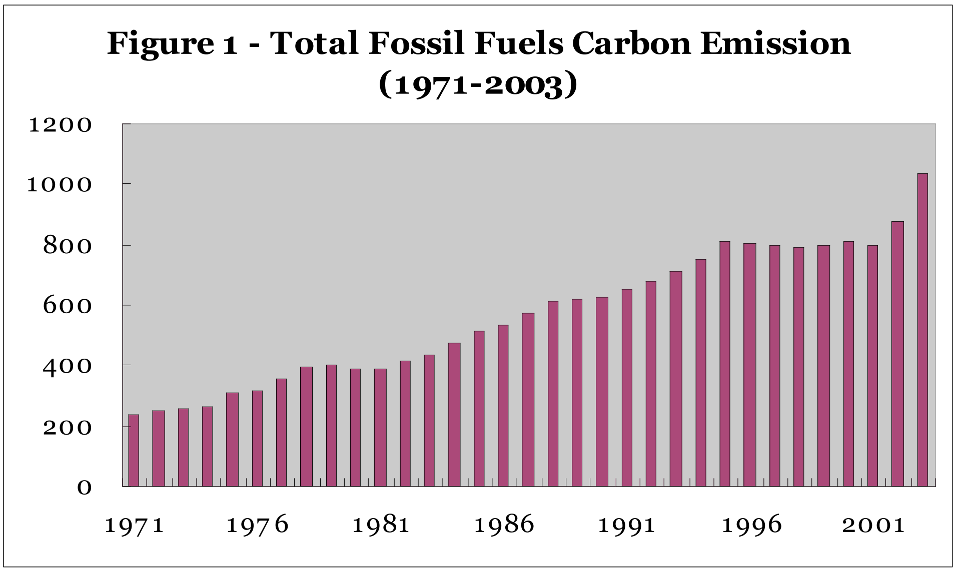
China's Carbon Emissions 1971-2003

Introduction

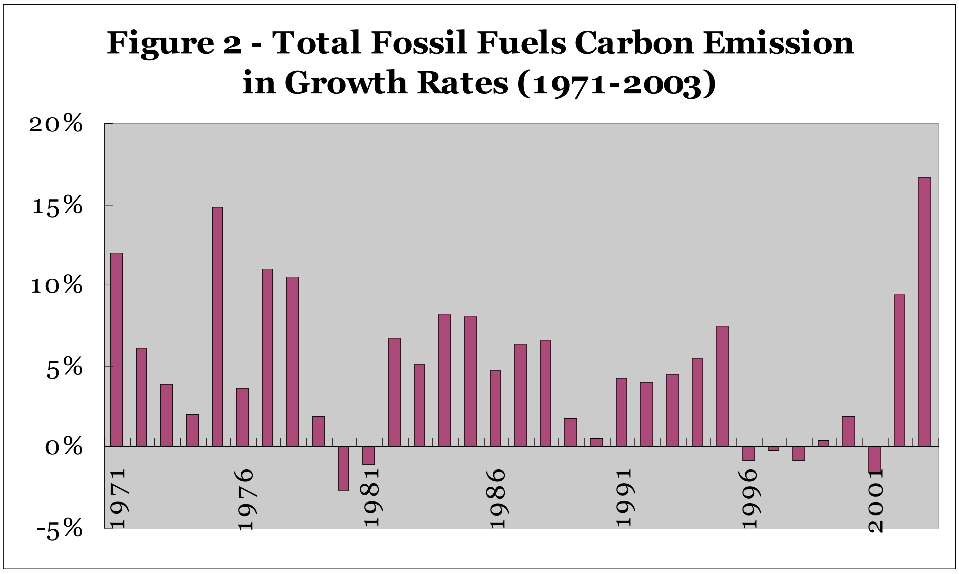
With 13.7% of the world's total energy-related carbon dioxide emissions, China is the second largest emitter after the United States (CDIAC, 2006). EIA (2006) forecasts predict that China will experience the largest growth in carbon dioxide emissions between now and the year 2030. Harvard's China Project predicts that China will surpass the United States in annual emissions of carbon dioxide within a decade and, in a few decades, in total cumulative emissions of carbon dioxide since the beginning of the Industrial Revolution (Shaw, 2002). Due to these trends, China's carbon emissions are a focal subject for many empirical studies which explore the driving forces behind their long-run growth and short-run variations. A large number of previous studies focused on two facts about China's carbon emissions: 1) the continuous growth up till the middle of the 1990s except for a short period in the early 1980s; 2) the recent stagnancy or stability of emissions from 1996 to 2001. However, China's carbon emissions have resumed their growth since 2002 at an even faster rate (Figure 1 & 2). Does this recent faster growth indicate a change in the long-run trend or something else?

By far the largest source of CO_2 emissions is fossil fuel combustion, which accounts for three quarters of anthropogenic CO_2 emissions in China (Streets et al., 2001). Although fossil fuels assume the majority share of China's fuel combustion, as a developing country, China still consumes a significant amount of biomass. The absolute level of biomass consumption has increased little over the years, and its share of total primary energy consumption decreased (Figure 3 & 4). Biomass consumption is usually excluded from total energy consumption in studies on China's carbon emissions. Biomass related emissions are not included in emissions from fuel combustion in estimation of the greenhouse gas inventory in order to avoid double-counting as they are accounted for when computing emissions due to land-use. However, the IPCC (1997) recommended including biomass consumption in energy consumption, especially in non-OECD countries. We include biomass in the current study, which to the best of our knowledge, has not been included in previous studies of China's carbon emissions.

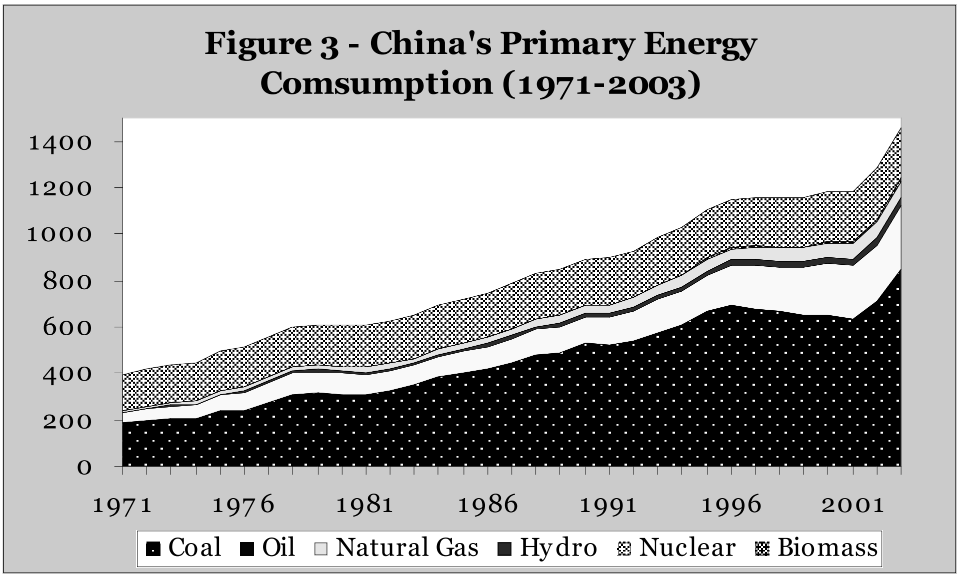


1) Data Source: 1971-95: Carbon Dioxide Information Analysis Center (CDIAC), 2006, excluding emissions from cement production; 1996-2003: Authors' estimate; 2) data are in million tons of carbon equivalents (mtc).

Various economic, technological, legislative and social factors have been identified by previous studies as the driving forces behind China's energy-related CO_2 emissions (Ang & Pandiyan, 1997; Zhang, 2000[a] & 2000[b]; Dhakal et al., 2003; Wu et al., 2005; Wang et al., 2005; Lee & Oh, 2006; Wu et al., in press). However, a fundamental fact about carbon emissions is that they mainly come from energy consumption. Examining energy consumption should, therefore, provide a first-order explanation. China is one of the world's most coal-dependent major economies. During the period of 1971-2003, coal consumption accounted for 66-79% of annual total commercial energy consumption and 45-60% of annual total primary energy consumption (commercial plus biomass) (IEA, 2005). Coal is notorious as the most polluting fossil fuel, emitting more carbon dioxide than other primary energy carriers. During the same period, about 66-84% of total energy related carbon emissions in China came from coal burning (CDIAC, 2006). China's heavy dependence on coal burning should, therefore, serve as the starting point for all analyses of China's carbon emissions and policy recommendations for their control.

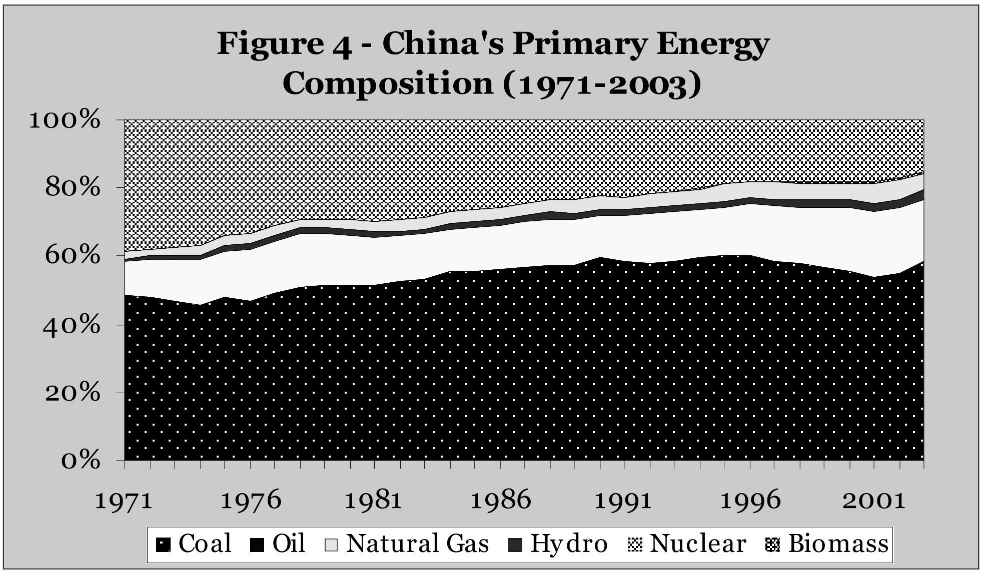


1) Data Source: CDIAC & authors' estimate.



1) Data Source: Energy Balances of Non-OECD Countries, various issues, International Energy Agency (IEA); 2) data are in million tonnes of oil equivalents (mtoe).

The paper is organized as follows. Section 2 briefly reviews previous studies on China's carbon emissions. Section 3 describes the method and data used to decompose the energy related carbon emissions through an extended Kaya identity. Section 4 conducts the decomposition and presents the results, followed by analyses and discussions. Section 5 concludes.



1) Data Source: IEA.

Literature Review

The so-called *IPAT* identity (Equation (1)) is often used as a basis for investigating the role of the various factors that drive carbon emisions (Chertow, 2001):

$$IMPACT(I) = POPULATION(P) \times AFFLUENCE(A) \times TECHNOLOGY(T) \qquad (1)$$

The *Kaya* identity (Equation (2)) is a variant of the *IPAT* identity (Kaya, 1990), which has been specifically applied in studies of energy related carbon emissions. In Equation (2), *C* is carbon emissions; *E* is energy use; *O* is economic output; and *P* is population. The first term on the right hand side (*C/E*) represents the carbon intensity of energy use and the second term (*E/O*) denotes the energy intensity of economic activity. These two terms correspond to the *TECHNOLOGY* factor in

Equation (1). The last two terms (*O/P* and *P*) correspond to the *AFFLUENCE* and *POPULATION* factors respectively, which jointly give the effect of economic scale.

$$C = \frac{C}{E} \cdot \frac{E}{O} \cdot \frac{O}{P} \cdot P \qquad (2)$$

The *Kaya* identity has been further developed to include other effects. For example, a variant of the *Kaya* identity can be specified as:

$$C = \frac{C}{FE} \cdot \frac{FE}{TE} \cdot \frac{TE}{O} \cdot \frac{O}{P} \cdot P \qquad (3)$$

Where *FE* is fossil fuel consumption, *TE* is total energy consumption, and, *C*, *O* and *P* have the same definitions as in Equation (2). The first term on the right hand side (*C/FE*) represents the effect of substitution among fossil fuels with different carbon emission coefficients, and the second term (*FE/TE*) denotes the penetration effect of carbon-free energy. There are two varieties of such models in the literature on the decomposition of environmental impacts: decomposition of absolute emissions and decomposition of emission intensity (as a ratio of emissions to GDP).

Ang and Pandiyan (1997) used a similar specification to decompose China's aggregate carbon dioxide intensity in manufacturing in the 1980s. They show that the aggregate CO_2 intensity has been decreasing at a rapid rate over this period and the main cause is the reduction in sectoral energy intensities. Carbon coefficients, inter-fuel substitution, and structural change play small roles. Zhang (2000[a] and 2000[b]) decomposed the annual carbon emissions between 1980 and 1997 into inter-fuel substitution, energy conservation (a decline in energy intensity), economic growth, and population expansion effects via the above mentioned variant of the *Kaya* identity (Equation (3)). Decline in energy intensity is found to be dominant in reducing carbon emissions. This effect alone reduces the increase in carbon dioxide emissions to half what they otherwise would be. Inter-fuel substitution does reduce carbon emissions, but the effect is minimal. Economic growth and population expansion have major effects on increasing emissions. Wu et al. (2005) compiled a unique dataset by aggregating provincial statistics instead of using national statistics due to the widespread suspicion regarding the quality of China's national energy statistics in the late 1990s (See Sinton, 2001; Streets et al., 2001; and Sinton & Fridley, 2003).[1] The data revealed a "sudden stagnancy" of energy consumption, supply, and energy-related CO_2 emissions in China from 1996 to 1999. Wu et al.found that the slowing rate of decline in energy intensity and a slowdown in the growth of average labor productivity of industrial enterprises are the dominant contributors to this "stagnancy". They characterized the decline in China's energy-related CO_2 emissions as a short-term fluctuation and argued that emissions will resume their increase in the near future. This has in fact occurred.[2]

Wang et al. (2005) conducted a decomposition study of China's aggregate CO_2 emissions from 1957 to 2000 which is by far the longest period examined. Their conclusions are similar to the above-mentioned studies. China's improved energy intensity has made a considerable contribution to decreasing its CO_2 emissions. In addition, inter-fuel switching and carbon-free energy penetration have also helped reduce emissions but to a much lesser degree. While all the above mentioned studies were conducted on a nation-wide scale, Dhakal et al. (2003) applied a factor decomposition analysis to emissions from China's two biggest cities, Beijing and Shanghai, over the period from 1985 to 1998.[3] The decomposition was conducted on sectoral emissions from the transportation sector, the residential sector, and the commercial sector as well as total city emissions. Despite some differences between the analyses at the sectoral level, the city-level analyses both show that the income

[1] Although it makes sense to compare the two provincial and national datasets, it is unclear which one is superior because: 1) Statistics at both levels are subject to similar bureaucratic bias if any such biases exist; 2) There are reasons to believe that the provincial data are more likely to be bureaucratically inflated; 3) Furthermore, the national statistical bureau could also make adjustments to any inflated provincial data under suspicion and it is unclear whether these adjustments are improvements or further biases.

[2] See Wu et al. (in press) for further discussion of the sources of the fluctuations.

[3] The study examined four cities in East Asia: Beijing, Shanghai, Tokyo, and Seoul.

effect was primarily responsible for increasing emissions while the energy intensity effect tended to decrease emissions. Similar results were also found by Lee and Oh (2006) in their analysis of CO_2 emissions in 15 APEC countries over the period of 1980-1998. China experienced the largest increase in carbon emissions among the fifteen countries accounting for 41% of the total increase in APEC during this period. China made the most significant improvement in energy efficiency, resulting in substantial emissions reduction; however, the effect of increasing per capita GDP and population more than offset the effects of improvements of energy efficiency, carbon emissions efficiency, and fuel substitution.

All of these studies focus on two facts about China's carbon emissions: 1) the continuous growth until the mid-1990s; 2) the stagnancy in the late 1990s. However, the latest data show that China's carbon emissions have resumed their growth at an even higher speed since 2002. This "new trend" has not yet been investigated. Furthermore, none of these previous studies has investigated the role of biomass fuel in China's carbon emissions.

Methodology

An aggregated energy or environmental indicator such as energy consumption, carbon emissions, or their corresponding intensities (ratios to GDP) can be decomposed into the contributions of various predetermined factors through index decomposition analysis (IDA), which has been well developed and widely applied in the past two decades. Surveys of the methods can be found in Hoekstra and van der Bergh (2003) and Ang (2004). Ang and Zhang (2000) provide a survey of empirical IDA applications. This method has also been applied in recent studies of China's carbon emissions (Ang and Pandiyan, 1997; Zhang, 2000[a] and 2000[b]; Dhakal et al., 2003; Wu et al., 2005; Wang, 2005; Wu et al., in press). Ang (2004) argued that the logarithmic mean Divisia index (LMDI I) method should be preferred to other decomposition methods as it has the advantages of path independency, ability to handle zero values, and consistency in aggregation. We, therefore, adopt this method in the current study. For details of the LMDI I method, refer to Ang et al. (1998) and Ang and Liu (2001).

We use an extended *Kaya* identity with the biomass factor included:

$$C = \frac{C}{FF} \cdot \frac{FF}{CF} \cdot \frac{CF}{TF} \cdot \frac{TF}{O} \cdot \frac{O}{P} \cdot P = ES_1 S_2 IGP \quad (4)$$

With the variables defined as follows:

Terms	**Interpretation**
C	carbon emission from fossil fuels combustion
FF	fossil fuels combustion (coal + oil + natural gas)
CF	carbon-based fuel combustion (FF + biomass)
TF	total fuels combustion (CF + carbon-free fuels)
O	gross domestic products (GDP)
P	population
E	carbon emissions coefficient of fossil fuels
S_1	share of fossil fuels in total carbon-based fuels
S_2	share of carbon-based fuels in total fuels
I	energy intensity of economic output
G	per capita GDP

As shown in Figure 4, the share of biomass in China’s total energy consumption has decreased over time. Equation (4) is intended to examine the effect of a reduced share of biomass consumption in total carbon emissions due to fuels combustion, besides the fossil fuel substitution effect, carbon-free energy penetration effect, technological effect, and economic scale effect.

The IDA is conducted on Equation (4). An index-decomposition can be conducted in two forms: additive or multiplicative (Ang, 2005). Which form one should use depends on the purpose of study - absolute changes (additive) or relative changes (multiplicative), as well as ease of application. Ang (2004) shows that the two forms are linked through a simple relationship. For cases where there is no disaggregation within each predetermined factor as in the current study (Equation (4)), the multiplicative form is much easier to implement. Therefore, in this study we use the multiplicative decomposition. Wang et al. (2005) and Lee and Oh (2006) provide examples of the additive specification, while Wu et al. (2005) used the multiplicative form. Taking logarithms and complete derivatives (with respect to time) on both sides of Equation (4) yields:

$$d\ln C = d\ln E + d\ln S_1 + d\ln S_2 + d\ln I + d\ln G + d\ln P \tag{5}$$

This specification is similar to that used in Zhang (2000[a]). It indicates that, for small to moderate changes in the extended Kaya components between any two years, the sum of the percent changes in each of the variables closely approximates the percent change in carbon emissions between those two years.

Integrating with respect to time and then taking anti-logarithms on both sides of Equation (5) yields a multiplicative form of decomposition:

$$\frac{C_t}{C_{t-1}} = \frac{E_t}{E_{t-1}} \cdot \frac{S_{1t}}{S_{1t-1}} \cdot \frac{S_{2t}}{S_{2t-1}} \cdot \frac{I_t}{I_{t-1}} \cdot \frac{G_t}{G_{t-1}} \cdot \frac{P_t}{P_{t-1}} \tag{6}$$

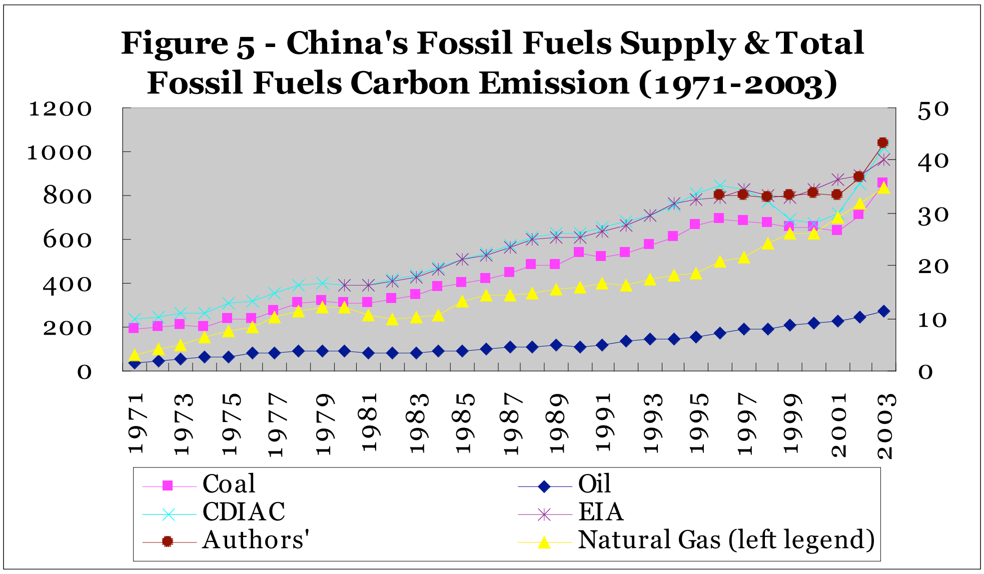
Although this specification is obvious from Equation (4), the standard transformations show that it is a special case of the multiplicative form of LMDI I where the weight function always equals unity, which makes the total effect simply a product of the ratios of each predetermined factors. Equation (6) can be rewritten as:

$$D_{tot} = D_{fs} \cdot D_{bs} \cdot D_{cp} \cdot D_{te} \cdot D_{pg} \cdot D_{pp} \quad (7)$$

D_{tot}, D_{fs}, D_{bs}, D_{cp}, D_{te}, D_{pg}, and D_{pp} denote the total effect, the fossil fuels substitution effect, the biomass substitution effect, the carbon-free energy penetration effect, the technological effect, the scale effect due to per capita GDP growth, and the scale effect due to population growth, respectively.

Data

The period of study is restricted by the availability of data. Figures for biomass consumption do not make their way into China's national energy statistics until recent years. The longest data series available for China's biomass supply starts in 1971, published by the International Energy Agency (IEA). This study, therefore, covers the period from 1971 to 2003. Energy supply data (Coal, Oil, Natural Gas, Biomass, Nuclear and Hydro) are taken from various issues of China's Statistical Yearbook (CESY) published by the National Bureau of Statistics of China (NBSC[a]), and *Energy Balances for Non-OECD countries* published by the IEA. Energy data are in million tonnes of oil equivalents (mtoe). Carbon emissions data are collected from Carbon Dioxide Information Analysis Center (CDIAC), 2006; International Energy Annual 2003, published by Energy Information Administration (EIA); and authors' estimate. As shown in Figure 5, the CDIAC carbon series and the EIA carbon series tracked each other closely until the middle of the 1990s; however, the variations in the CDIAC series during 1996 – 2003 are much more drastic than those of the EIA series. Compared with the IEA energy data which shows a steady increase in natural gas and oil use and less drastic variations in coal over this period, the dramatic dip and resurgence in the CDIAC carbon series look rather suspicious. To investigate this issue, we make our own estimates of carbon emissions for the 1996-2003 period by applying the IPCC (1997) methodology to IEA's energy data (see Appendix A for details). The results are also shown in Figure 5. The new estimate is closer to the EIA series, both of which are more compatible with the energy series than the CDIAC series. One advantage of the CDIAC carbon series is that it is available for earlier years than the EIA series. The carbon data used in the current study is therefore a combination of the CDIAC data (1971-1995) and the new estimate (1996-2003). Data on non-energy use of fuels (feedstock), which is used in our own estimate of carbon emissions, are collected from various issues of CESY, and, China Energy Databook Version 6.0 published by Lawrence Berkeley National Laboratory (LBNL). Since we are studying the impacts of energy consumption on carbon emissions, we excluded the carbon emissions from cement which is also reported in the CDIAC data. The data are in million tonnes of carbon equivalents (mtc). GDP data are collected from various issues of China's Statistical Yearbook (CSY) published by NBSC. The GDP data are converted to constant 2000 prices. The population data are taken from the World Development Indicators database.



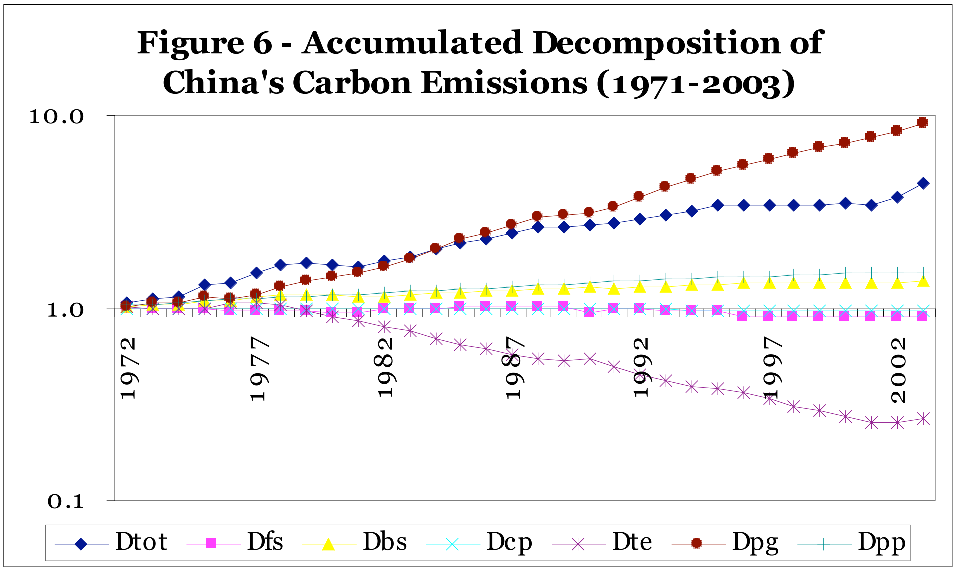
1) Data sources: CDIAC, IEA, International Energy Annual 2003 (Energy Information Administration (EIA)), and authors' estimate; 2) energy data are in mtoe and carbon emissions data are in mtc.

Results and Discussion

Results

The complete time-series decomposition results are listed in the Appendix. Figure 6 presents the accumulated effects. The accumulated effects over the entire period show that the dominant positive effect is the scale effect due to per-capita GDP growth (D_{pg}), followed by the scale effect due to population growth (D_{pp}) and the effect of a shift away from biomass (D_{bs}). Technological change (D_{te}), which is measured by the decline in energy intensity is the most important negative effect, followed by the substitution effect among fossil fuels (D_{fs}) and the carbon-free energy penetration effect (D_{cp}). The total negative effects are much more than offset by the total positive effects, which more than quadrupled China's carbon emissions (D_{tot}) in the 1971-2003 period with an annual growth rate of 4.76%. These general results are mostly consistent with those of previous empirical studies, which could be summarized as follows:

1) The scale effect (D_{pg} + D_{pp}) is the dominant factor in increasing carbon emissions;
2) The technological effect (reduced energy intensity) (D_{te}) contributes most to decreasing carbon emissions;
3) Both the fossil fuels substitution effect (D_{fs}) and the carbon-free energy penetration effect (D_{cp}) contribute to decreasing carbon emissions, but the magnitude of the accumulated effects is rather small over the entire period.
4) Accumulated negative effects are more than offset by accumulated positive effects, which gives rise to a substantial increase in overall carbon emissions (D_{tot}).



1) Data Source: CDIAC, 2006; authors' calculation; figure in logarithm.

We also present the accumulated results by periods (Tables 1 & 2): 1) The pre-reform period (1971-1977); 2) The part of the post-reform period during which China's carbon emission experienced a steady increase (1977-1996); 3) The period of "sudden stagnancy" when carbon emissions decreased (1996-2001); 4) The latest period of rapid increase (2001-2003); 5) The entire period (1971-2003).

Table 1 - Decomposition of Carbon Emissions (1971-2003)

	D_{tot}	D_{fs}	D_{bs}	D_{cp}	D_{te}	D_{pg}	D_{pp}
1971-1977	1.512	0.965	1.127	0.996	1.059	1.176	1.122
1977-1996	2.258	0.936	1.192	0.978	0.341	4.709	1.291
1996-2001	0.998	0.991	0.993	0.984	0.706	1.397	1.045
2001-2003	1.278	1.000	1.040	0.995	0.970	1.249	1.020
1971-2003	4.422	0.899	1.393	0.963	0.265	9.053	1.532

1) In a multiplicative decomposition, a number greater or less than one denotes an increasing or decreasing effect, corresponding to a number positive or negative in Table 2.

Table 2 - Decomposition of Carbon Emissions in Annual Growth Rates (1971-2003)

	D_{tot}	D_{fs}	D_{bs}	D_{cp}	D_{te}	D_{pg}	D_{pp}
1971-1977	7.14%	-0.58%	2.01%	-0.07%	0.96%	2.73%	1.93%
1977-1996	4.38%	-0.35%	0.93%	-0.12%	-5.51%	8.50%	1.35%
1996-2001	-0.05%	-0.19%	-0.13%	-0.32%	-6.73%	6.91%	0.88%
2001-2003	8.53%	-0.02%	1.32%	-0.18%	-1.02%	7.70%	0.68%
1971-2003	4.76%	-0.33%	1.04%	-0.12%	-4.07%	7.13%	1.34%

An examination of Tables 1 & 2 by period also reveals:

5) The shift from biomass to commercial energy (D_{bs}) results in a major increase in carbon emissions, which has a comparable magnitude to the population effect. This change in energy composition has a much more significant effect on carbon emissions than fossil fuels substitution or carbon-free penetration. As a developing country, China still consumes a significant amount of biomass. The average rural household still depends on biomass for about 80% of final energy needs (Sinton and Fridley, 2003). Biomass consumption increased from 154.24 million tons of oil equivalent (mtoe) in 1971 to 218.96 mtoe in 2003. However, the share of biomass in total primary energy consumption dropped from 38.81% to 15.02%. The difference was taken up by commercial energy carriers.
6) The technological effect (D_{te}) resulted in an increase in carbon emissions during the pre-reform period while it plays a dominant role in reducing carbon emission in post-reform periods. This difference (also see Wang, 2005) reveals the government's development policies and investment priorities towards fast industrialization, which gave rise to increasing energy intensity in the pre-reform period. Since China's economic reform took off in 1978, energy intensity has declined during most of the post-reform period due to sectoral energy efficiency improvements and economic structural change. However, in our recent study on China's energy intensity (Ma and Stern, in press), we found that the effect of

economic structural change is rather different at different sector levels. Structural change at industry level actually increased energy intensity in the 1980s and 1990s while the structural changes at sector and sub-sector level decreased energy intensity.

7) Over the period from 1971-1996, carbon emissions (D_{tot}) increased at an average annual rate of 5.25%; however, China's carbon emissions experienced a "sudden stagnancy" during 1996-2001 and even decreased at 0.05% annually. Since 2001, carbon emissions have resumed their growth at a much higher annual rate of 8.53%. It is obvious from Table that the recent high growth rate is mainly due to the slowdown of decreasing effect of technology change (D_{te}).
8) There is a clear difference in the growth rates of the per-capita income effect in the pre-reform and post-reform periods. This can be explained by the success of China's economic reform, which significantly increased per-capita income in the post-reform period. Also obvious is the declining contribution from the population effect over the entire period, which can be attributed to the family planning and birth control policy launched in the late 1970s.

Coal Consumption & Carbon Emissions, and Energy Statistics

These decomposition results have to be interpreted critically. A fundamental fact about carbon emissions is that they mainly come from energy consumption. A look at energy consumption should, therefore, provide a first-order explanation for variations in carbon emissions. As Sinton and Fridley (2003) nicely put it "the story of China's energy statistics is really a story of coal", so is that of carbon emissions. Figure 6 clearly shows that the trend of China's carbon emissions is very similar to that of China's coal use. China's carbon emissions increased in most years from 1971 to 2003 and decreased in 1980, 1981 and the late 1990s. The same is true of coal use; but not of oil and natural gas consumption. The correlation between carbon emissions and coal use is as high as 0.99 while the correlation with oil or natural gas consumption is much lower. Given the high correlation and the fact that majority of

China's energy consumption comes from coal, the accuracy of the coal statistics will have a large impact on that of the carbon emissions figures. Many observers have raised doubts about the accuracy and reliability of China's energy statistics, which show an unprecedented decline in energy use in the late 1990s, while reported economic growth remained strong (Sinton, 2001; Streets et al., 2001; Sinton and Fridley, 2003). China launched a campaign to close small mines in the late 1990s; however, many of these are believed to have since reopened. Output from these nominally closed mines was, therefore, left out of the official statistics. It has been shown (Sinton, 2001) that even if only half of the closed mines reopened, their output would account for the "missing supply" in China's statistics on coal consumption. Given what is known about the campaign to close coal mines and the inability of NBSC to report production from mines that are ostensibly closed, they conclude that the production figures for the late 1990s appears to have resulted from a combination of real factors and faulty statistics even after NBSC revised its coal statistics in 1999. Sinton and Fridley (2003) compare the energy statistics and economic growth, output of industrial goods, investment, prices, and trade and found that the rapid growth in energy use, particularly coal use, in the early 2000s is very likely driven by an episode of overheated investment and economic expansion. They also pointed out that problems in reporting of coal statistics in the late 1990s may have led to exaggeration of actual trends, such that the fall and resurgence in energy output and use have been overstated. If these critiques on China's coal statistics are valid, China's carbon emissions are therefore subject to similar critiques, which will bias our decomposition results. Although we do not use China's official energy statistics directly, they are probably the basis of other published statistics and estimates including the IEA data and CDIAC data that are used in the current study. Accordingly, the fossil fuels substitution effect, biomass substitution effect, carbon-free energy penetration effect, technological effect, and the total effect will all be biased downwards for the period from 1996-2000 while the opposite is true in the early 2000s period. In other words, the abnormal variations in carbon emissions over the turn of the twenty first century may have been similarly overstated. The more rapid annual growth in carbon emissions (8.53%) since 2001 may not indicate a "new trend".

GHG Emissions Projection and Control

The current study does not simply aim to understand the past development of China's carbon emissions, but to also be of relevance to future greenhouse gas (GHG) emissions projection and control. If the international community is to assess the potential of global warming and other climate changes, it must be able to project GHG emissions trajectories with reasonable accuracy. Thus, a good understanding of the drivers behind the GHG emissions trajectories of the world's second largest carbon emitter is of political relevance and of significance to global efforts to control the buildup of GHGs in the atmosphere. A special issue of the *Journal of Environment and Development* (March, 2005) contributed to a better understanding of the socioeconomic drivers of GHG emissions, particularly based on the Environmental Kuznets Curve (EKC) framework. The inverted U shape curve was first used to describe the income inequity by Kuznets (1955). The concept has been applied to study the income-emissions relationship since the seminal work in the early 1990s (Grossman & Krueger, 1993, 1995; Panayotou, 1993; Selden & Song, 1994; Shafik & Bandyopadhyay, 1992) and has, therefore, been coined the "Environmental Kuznets Curve" (EKC). However, the EKC framework is by no means the only one that can be used to study the relationship between emissions and other socioeconomic factors. The substantial EKC research during the recent decade is to some extent due to the simplicity of the income-emissions specification in the EKC theory. Empirical work has not yet achieved any consensus on the EKC hypothesis, let alone stylized facts. Actually, several analytical challenges suggest that it is not a satisfactory framework to identify the socioeconomic drivers and project GHG emissions. First, Aldy (2005) and López & Galinato (2005) provided evidence that income alone is insufficient to explain the emissions and there are other significant drivers. Second, Perman & Stern (2003) and Stern (2004) found that the simple relationship between income and emissions demonstrated in previous empirical EKC studies is actually an artifact of limitations of the econometric techniques that due to non-stationarity of the data which may result in spurious results. Third, as far as the income-emission relationship is concerned, there is heterogeneity among different kinds of emissions, stages of development, countries, socioeconomic drivers and even the ways that these drivers exert effects, which are hard to be captured within the conventional EKC framework. The heterogeneity also exists in environmental technology diffusion. Stern (2005) conducted a study of the environmental technology frontier and found that there is only a weak association between income per capita and the rate of diffusion of emissions reducing technology. Other factors, such as a country's population density and the potential level of pollution in the absence of abatement may have more important effects. Given all these challenges, Leifman and Heil (2005) pointed out that there is a need for alternative approaches to identify heterogeneous socioeconomic factors. One alternative is to decompose the emissions changes over time into the effects of scale, compositional factors, and technological factors. Furthermore, the technological factors can be decomposed into energy mix (substitution), energy intensity, and other technical effects. Meanwhile, the magnitude of each factor can be gauged. The decomposition analyses can help fill some of the analytical gaps and answer some of the questions introduced by EKC models. The development patterns of China's carbon emissions provide a good illustration of the heterogeneity of the socioeconomic drivers behind the emissions. Our analysis also illustrates the power of the decomposition approach to identify these heterogeneous drivers. Although the long run trend has been dominated by the income effect, the stagnancy in the late 1990s and resurgence in the early 2000s is clearly not an income effect. Rather, it is mostly policy driven with possible energy statistical bias. It is the change of coal policy – closing coal mines – that has caused the fluctuation in coal consumption which consequentially influenced the carbon emissions over this period. In the current study, we have also seen significant effects (other than the income effect) from either a single policy (birth control and family planning) or a comprehensive policy (economic reform). The economic reform launched in the late 1970s not only has income effects, but also improved the energy efficiency of industry and adjusted the industrial structure of the economy. The high correlation between coal consumption and carbon emissions suggest that endowment effects might play a role here (see Aldy, 2005, for more empirical evidence). All these different factors have had an impact on China's carbon emissions, which cannot be fully captured by a simple income-emissions relationship. Projections of GHG emissions should therefore take into account these identified drivers. Decomposition analysis provides an alternative to identify various socioeconomic drivers and produce better emissions projections.

Policy Implications

This study also provides insights on the answer to the following question: How should China most effectively limit its carbon emissions? As a developing country, China is not an Annex I country and, therefore, is not subject to the mandatory emission-reduction targets specified in the 1997 Kyoto Protocol. However, China is currently the world's second largest carbon emitter after the United States and has been facing mounting international pressure on this issue. Limiting carbon emissions is, therefore, of political relevance and national as well as global significance. Various economic, technological, legislative, and other social factors have been identified by previous empirical studies as the driving forces behind China's energy-related CO_2 emissions. Although specified differently, these predetermined factors can be classified into three kinds: 1) scale effects; 2) technological effects; 3) structural effects. It is usually unacceptable to limit carbon emissions through scale effects which basically mean to control population growth and constrain the ever-increasing per capita demand for goods and services, particularly material needs and energy. Thus, most policy prescriptions come down to altering technological effects and structural effects. We assume that China is not likely to follow a fully market-based solution in the near future. On the one hand, energy related carbon emissions can be limited through reducing the energy intensity of the economy in general, which is usually interpreted as the technological effect. This can be achieved through energy efficiency improvements in production of goods and services, consumption of goods and services, and, transformation and distribution of energy carriers. Although all technologies that help to increase energy efficiency should be advocated, priorities should be given to those that most effectively limit carbon emissions such as the "Clean Coal" technologies which not only increase thermal efficiency but also effectively capture carbon emissions so that they could be transformed into forms that are more benign to the environment. On the other hand, the facts of heavy dependence on coal consumption and high correlation between coal consumption and carbon emissions point to another explicit option: carbon emissions can be most effectively limited by lowering the share of coal in total energy consumption. This can be achieved by a switch from coal to cleaner fossil fuels such as oil and natural gas, or more effectively from fossil fuels to carbon-free energy carriers such as nuclear, hydro, wind, solar etc. For example, Skeer and Wang (2006) explored how carbon charges and carbon sequestration technology could tip the balance in favor of natural gas over coal in China's power sector in an effort to significantly reduce carbon emissions. Additionally, we found that a decreased share of biomass in total energy consumption contributes to increasing carbon emissions. However, this is only true given the current energy consumption structure. It can not be generalized to advocate the consumption of biomass in an effort to limit carbon emissions. Moreover, biomass consumption has other negative environmental effects as well.

Of course, both options may be restricted in the short or medium terms under which the society may be locked in by resources endowments, technological conditions, and policy barriers that favor certain types of energy carriers and technologies. In the long run, however, the situation can be changed through consistent commitment in legislation, enforcement, and policies in an effort to limit the carbon emissions, which suggests that it is wise to take early actions. Fortunately, China has recently adopted both options and taken measures. On the one hand, the newly approved Five-Year Plan (2006-2010) for the first time makes reduction in energy intensity a national development objective. It states that energy intensity will be reduced by 20% by 2010 compared with the 2005 level, which is equivalent to an annual 4.4% reduction. This seems reasonable compared with the annual 5.2% rate of decline in energy intensity over the period of 1980-2000. However, it is a rather difficult task given the recent tendency for the decline in energy intensity to halt and maybe even reverse since 2000 (Ma & Stern, in press). Energy intensity has actually increased from 2003 to the first half of 2006. According to the statistics of NBSC, the energy intensity increased 0.8% in the first half of 2006 and decreased 1.23% for the whole year (NBSC[b], 2006) This reduction was the first since 2003 and the magnitude is far below the 4.4% objective. On the other hand, China's first Renewable Energy Law [4] (REL) was approved in 2005 and came into force in 2006, covering all non-fossil fuels. The law lays the legislative foundation for the development of renewable energy and explicitly points out the objective of establishing the Renewable Energy Target Policy (RETP). However, the law removed such concrete objectives as that consumption of renewable energy should be no less than 5% of total energy consumption in 2010 and 10% in 2020, which exists in the draft of 2004. Despite the progressive implications for meeting the ever-increasing energy demands and controlling carbon emissions, lack of such concrete objectives and means to achieve the RETP become major drawbacks. The potential effectiveness of the law is unclear at this time.

[4] http://news.qq.com/a/20050228/000706.htm (in Chinese)

Conclusions

In this study, we decompose China's carbon emissions over the period from 1971-2003 through an extended *Kaya* identity using the LMDI I method. Some of our findings are consistent with those of previous empirical studies. Additionally, we found: 1) A reduced share of biomass consumption makes a significant contribution to decreasing carbon emissions whose magnitude is comparable to that of the increase in emissions due to population increase; 2) The technological effect is a positive effect in the pre-reform period due to the policy priority given to rapid industrialization, and is a negative effect in the post-reform period due to efficiency gains and adjustments in economic structure; 3) The fall in emissions in the late 1990s and the resurgence in the early 2000s may be overstated if the critiques on China's energy statistics are valid, and, the rapid growth in emissions since 2000, therefore, does not indicate a "new trend" - growth in carbon emissions will probably return to more moderate levels soon; 4) Per capita GDP effect is obviously growing more rapidly in the post-reform period than in the pre-reform period thanks to the successful economic reform. The declining importance of the population effect can be explained by the family planning and birth control policy launched in the late 1970s; 5) China's carbon emissions are highly correlated with coal consumption, which points to explicit policy suggestions. Compared with the conventional EKC framework, such decomposition analyses are much more helpful in identifying the socioeconomic drivers behind changes in emissions which could contribute to better projection of GHG emissions. Despite some suspicions about the effectiveness of its recent policies, China is taking actions to limit its carbon emissions.

Appendix A –Estimate of China's Carbon Emissions[5]

Using disaggregated data on coal, oil, and natural gas consumption, carbon emissions can be estimated following the procedure specified in IPCC (1997). IPCC (1997) recommends a simple method (Tier 1) for carbon estimation from fuel combustion: Emissions from all sources of combustion are estimated on the basis of the quantities of fuel consumed and average emission factors. Emission factors are usually expressed as mass of pollutant per energy unit of activity (e.g. kg CO_2/TJ). There are two main approaches: the Reference Approach and the Sectoral Approach. We use the simpler Reference Approach.

The first part of the Reference Approach is to calculate the apparent consumption, which is the total amount of fossil fuels available for consumption in the country or region in that year. Based on apparent consumption, carbon emissions are estimated using the following equation:

$$C = \sum_i E_i (1 - \alpha_i s_i) e_{fi} o_i \tag{A1}$$

where:

E_i – Apparent consumption of the various fossil fuels, i.e. coal, oil, and natural gas;

α_i - Proportion of fossil fuels used for non-energy purposes, such as raw materials/feedstock;

s_i - Ratio of carbon entering long-run storage in products and non-gaseous wastes to total carbon content in fossil fuels used for non-energy purposes. Not all

5 Unless otherwise specified, emissions (carbon and sulfur) in this study only refer to those from fuel combustion. A comprehensive picture of China's role in the global carbon emissions would include other sources of emissions, notably the reabsorption of CO_2 by terrestrial and marine plant life.

non-energy uses of fossil fuels, however, result in storage of carbon for long period of time. For instance, the carbon from natural gas used in ammonia production is oxidized quickly. Therefore, this oxidization should also be included in estimation of the total emission. For coal, carbon is assumed to be completely stored, i.e. s_i =1. The recommended value for natural gas is 0.33. Values for petroleum products vary from 0.5 to 1;

e_{fi} - Carbon emission factors. IPCC (1997) recommends 25.8 tc/Tj, 20.0 tc/Tj and 15.3 tc/Tj for coal, oil and gas respectively. However, IPCC encourages use of other alternative values if supported by research. There is little disagreement on values for oil and gas, but Wang et al. (2005) uses a lower value at 24.7 tc/Tj for coal, and Zhang (2000[b]) uses an even lower value of 0.651 tc/tce, which is equivalent to 22.24 tc/Tj. In this study, the median value of 24.7 will be used to avoid low and high extremes;

o_i - Oxidization factor. Even if fossil fuels are used as energy, the carbon in them is not completely oxidized. Unless other data are available, countries should use the following as default values (IPCC, 1997): 2 percent of carbon in fuel consumed is unoxidized for coal, 1 percent for oil-derived fuels, and 0.5 percent for natural gas. Again, there is little argument about the default values for oil products and natural gas. Wang et al. (2005) use 10 percent for coal. Since coal constitutes the majority of China's apparent consumption the choice of oxidization factor for coal is very important. However, IPCC also recommends the following assumptions (Summers, 1993) that can help to make a selection under various circumstances:

> "*1) For stoker-fired industrial boilers an average value for carbon unoxidised is 5 percent. If countries believe that their operation and maintenance procedures achieve maximum efficiency, a 2 percent carbon loss is suggested. If these procedures are believed to lead to very poor efficiency, then a 10 percent carbon*

loss is recommended. 2) In those cases when coal is used in the commercial or residential sectors, the assumption for unoxidized carbon should be 5 percent."

In case of China, maximum efficiency is hardly achieved; however, a 10 percent factor would be inappropriate because a significant share of coal supply is used in the commercial and residential sectors. Thus, a 95 percent oxidization factor would be more appropriate.

To express the results as carbon dioxide, total carbon oxidized should be multiplied by the molecular weight ratio of CO_2 to C, i.e. 44/12.

Appendix B – Complete Decomposition Results

Table* - Time Series Decomposition of China's Carbon Emissions**

	D_{tot}	D_{fs}	D_{bs}	D_{cp}	D_{te}	D_{pg}	D_{pp}
1972-1971	1.063	0.995	1.016	0.998	1.015	1.013	1.025
1973-1972	1.039	0.994	1.008	0.997	0.963	1.055	1.023
1974-1973	1.020	0.993	1.002	0.997	1.005	1.002	1.021
1975-1974	1.159	1.001	1.048	0.999	1.018	1.068	1.018
1976-1975	1.037	0.993	1.010	1.002	1.049	0.969	1.016
1977-1976	1.116	0.989	1.036	1.003	1.009	1.061	1.014
1978-1977	1.111	0.994	1.031	1.003	0.969	1.102	1.013
1979-1978	1.019	1.002	1.001	0.998	0.946	1.062	1.013
1980-1979	0.974	0.985	0.993	0.997	0.926	1.065	1.013
1981-1980	0.989	1.006	0.991	0.997	0.945	1.039	1.013
1982-1981	1.070	1.030	1.008	0.998	0.946	1.075	1.015
1983-1982	1.052	1.001	1.012	0.998	0.938	1.093	1.015
1984-1983	1.086	1.001	1.022	0.999	0.922	1.137	1.013
1985-1984	1.083	1.027	1.013	0.998	0.919	1.120	1.014
1986-1985	1.049	1.004	1.009	1.001	0.951	1.072	1.015
1987-1986	1.066	1.000	1.014	0.999	0.943	1.098	1.016
1988-1987	1.068	0.999	1.014	0.999	0.948	1.095	1.016
1989-1988	1.019	0.998	1.002	0.998	0.981	1.025	1.015
1990-1989	1.005	0.941	1.013	1.000	1.017	1.023	1.015
1991-1990	1.043	1.042	0.998	1.001	0.918	1.077	1.014
1992-1991	1.040	0.996	1.009	0.999	0.908	1.128	1.012
1993-1992	1.046	0.978	1.014	0.998	0.931	1.122	1.012
1994-1993	1.056	1.003	1.010	0.994	0.931	1.113	1.011
1995-1994	1.077	0.992	1.016	0.996	0.971	1.093	1.011
1996-1995	0.992	0.941	1.009	1.004	0.949	1.085	1.011
1997-1996	0.998	0.995	1.000	0.995	0.927	1.077	1.010
1998-1997	0.991	1.000	0.997	0.998	0.924	1.068	1.010
1999-1998	1.004	1.002	0.997	1.002	0.937	1.061	1.010
2000-1999	1.019	0.998	1.003	1.000	0.943	1.072	1.007
2001-2000	0.985	0.995	0.997	0.990	0.933	1.067	1.007
2002-2001	1.099	0.999	1.017	0.998	1.001	1.076	1.007
2003-2002	1.181	1.005	1.027	1.006	1.039	1.088	1.006
2003-1971	4.422	0.899	1.393	0.963	0.265	9.053	1.532

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