Analysis of Influence Factors of PM$_{2.5}$ in Chengdu Based on VAR Model

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Abstract. Air pollution and smog are the serious harms to public health and has attracted public attention. Based on the vector auto-regressive (VAR) model, we analysed the influence factors of PM$_{2.5}$ in Chengdu, investigated the effect of other kinds of air pollutants and meteorological factors on the PM$_{2.5}$ by using the methods of generalized impulse response function, variance decomposition analysis, Granger causality test and therelated daily data from December 1, 2013 to November 14, 2016 in Chengdu city to the empirical study. The results show that the influence factors of PM$_{2.5}$ were stable: the increase of nitrogen dioxide, ozone, precipitation and temperature difference led to the increase of PM$_{2.5}$ concentration while the increase of the wind speed, PM$_{10}$, sulphur dioxide and carbon monoxide resulted in the decrease of PM$_{2.5}$ concentration. Climate conditions, nitrogen dioxide and ozone are Granger causes for PM$_{2.5}$. It is suggested that the key for the control of PM$_{2.5}$ must be based on the cause and formation rules of PM$_{2.5}$. A further study on nitrogen dioxide and ozone may play an important role in finding out the real source and formation reasons of PM$_{2.5}$.

1. Introduction
With the rapid development of economy, air pollution problems are more and more prominent. Together with smog, atmospheric pollutant PM$_{2.5}$ also attracts public attention. PM$_{2.5}$ in the atmosphere is a kind of particulate that can be breathed into the lung. It is very harmful to human body, which can lead to diseases such as bronchitis, asthma, as well as an important factor that causes smog and dropped visibility.

Since PM$_{2.5}$ has become the focus of attention of the society, the domestic and foreign scholars made deep investigation and extensive researches on it. Chow J C et al. [1] and Houthuijs D et al.[2] did researches in PM$_{2.5}$ and PM$_{10}$, in which they found that PM$_{2.5}$ accounts for large proportion in PM$_{10}$. Vega E et al. [3] used the data of Mexico from year 2000 to 2002 years to analyse the time and spatial variation characteristics of PM$_{2.5}$ concentration, which pointed out that in industrial area and daytime, PM$_{2.5}$ is of higher concentrations. Tran H N Qand Molders N[4] did a research on the relationship between PM$_{2.5}$ and meteorological conditions with 10-years data of PM$_{2.5}$ in Alaska Fairbanks, and found out that different weather conditions have different effects on PM$_{2.5}$ concentration. Huang Fangfanget al. [5] did research into the and the relationship between PM$_{2.5}$ and meteorological factors during 2013-2014 in Beijing, which pointed out PM$_{2.5}$ concentration was significantly higher in winter and significantly higher in the night than day. Yang Leiet al.[6] analysesthe concentration characterization of PM$_{2.5}$ and its impact factors in national road of Zhengzhou, and found out that traffic flow contributed most to the PM$_{2.5}$ mass concentration; relative...
humidity and windspeed contributed to the reduction of the PM$_{2.5}$ mass concentration. Liu Jinpei et al. [7] used VAR model to analyse the dynamic relationship between PM$_{2.5}$ and its influence factors in Xi’an city, which pointed out the increase of carbon monoxide, sulphur dioxide, ozone and the weather led to the increase of PM$_{2.5}$ concentration.

By literature analysis, we can see the existing researches mainly analyse the harm, composition of PM$_{2.5}$ and its relationship with PM$_{10}$, time and spatial characteristics and its relevance between meteorological factors from the static perspective. But there are very few researches on the mutual effects on PM$_{2.5}$ and other atmospheric pollutants and meteorological factors. Therefore, based on the dynamic system constructed by PM$_{2.5}$, other air pollutants and meteorological factors, this paper studies the influence factors of PM$_{2.5}$ of Chengdu city with Vector Auto-regression model (VAR model). It focuses on the study of the influence of other air pollutants and meteorological factors on PM$_{2.5}$ in order to provide corresponding suggestions on comprehensive control of air pollution.

2. Empirical Methods

2.1. VAR model

VAR model is a system with some equations where all variables are treated as dependent variables, which is usually used for predicting interconnected time sequence and analysing the impact of stochastic disturbance on variation system. There is one equation for each variable as dependent variable. Each equation has values for all variables included as dependent variables, including the dependent variable itself. Since there is no explanatory variable included in the model simultaneously, the model is in a reduced form. So equations have the same form as long as they have the same variables on the right side of the equation.

VAR models are also used for the analysis of causality. In general, the empirical analysis of meteorological data, the relationship of cause and effect is very difficult to determine. If we consider two variables x and y and see that these variables show a high correlation then we can say that they have an apparent tendency to move together, but in the absence of more information, cannot add more significantly in the direction of causality. The correct way to interpret these tests is to consider as graphical analysis that is required to see if the performance of a variable precedes another.

2.2. Data

In order to comprehensively reflect the changes of PM$_{2.5}$, in our paper we have considered eight variables, which are as follows: PM$_{10}$; Sulphur dioxide (SO$_2$); Nitrogen dioxide (NO$_2$); Carbon monoxide (CO); Ozone (O$_3$); Temperature difference (T); Wind speed (FF) and Precipitation (RR). All data were collected on a daily basis from December 1, 2013 to November 14, 2016 in Chengdu, involving a total of 1080 observations. Through auto regression vectors model (VAR) we will try to discover the link between these variables to conclude which of the model equations is more important. Through various tests such as causality test of Granger we will try to determine which of the dependent variables is independent and which dependent, therefore to determine which of them is the cause or the consequence of other variables.

2.3. Stationarity Test

For the considered variables the stationarity testing was done with the Augmented Dickey - Fuller Test, the results are reported in table 1 and indicate that all the variables are stationary.
Table 1. Augmented Dickey - Fuller Test (ADF).

| Test for unit root in | t-Statistic | Prob. |
|----------------------|------------|-------|
| PM<sub>2.5</sub>     | -10.1099   | 0.0000*** |
| PM<sub>10</sub>      | -11.2068   | 0.0000*** |
| SO<sub>2</sub>       | -7.1531    | 0.0000*** |
| CO                   | -270.6010  | 0.0001*** |
| NO<sub>2</sub>       | -11.5696   | 0.0000*** |
| O<sub>3</sub>        | -4.7857    | 0.0000*** |
| T                    | -17.7520   | 0.0000*** |
| FF                   | -28.7673   | 0.0000*** |
| RR                   | -29.1090   | 0.0000*** |

Notes: *, **, *** signifies the rejection of the null hypothesis (the presence of unit root or absence of stationarity) at a significance level of 10%, 5%, 1%.

2.4. Lag Order Selection
The choice on the number of lags was done based on the evaluation criteria of informational content (Likelihood ratio test, Final prediction error, Akaike information criterion, Schwarz information criterion and Hannan-Quinn information criterion). The results are reported in table 2 and provide more support to lag 3 times for VAR model.

Table 2. The judgments of lag time for VAR model.

| Lag | LogL  | LR    | FPE    | AIC    | SC     | HQ     |
|-----|-------|-------|--------|--------|--------|--------|
| 0   | -29257.88 | NA    | 4.18e+12 | 54.60240 | 54.64418 | 54.61822 |
| 1   | -27047.04 | 4380.449 | 7.86e+10 | 50.62880 | 51.04667* | 50.78708 |
| 2   | -26882.05 | 324.1150 | 6.72e+10 | 50.47212 | 51.26607* | 50.77285* |
| 3   | -26776.52 | 205.5546 | 6.42e+10* | 50.42634* | 51.59638* | 50.86954 |
| 4   | -26701.88 | 144.1272 | 6.50e+10 | 50.43821 | 51.98433 | 51.02386 |
| 5   | -26650.76 | 97.8516 | 6.87e+10 | 50.49396 | 52.41615 | 51.22206 |
| 6   | -26603.61 | 89.47360 | 7.32e+10 | 50.55710 | 52.85538 | 51.42765 |
| 7   | -26519.84 | 157.5296 | 7.29e+10 | 50.55194 | 53.22630 | 51.56495 |
| 8   | -26448.99 | 132.0578* | 7.43e+10 | 50.57087 | 53.62131 | 51.72633 |

Note: * indicates the lag order selected according to the standards.

2.5. VAR model construction
The VAR model can be written as:

\[ BY_t = A_0 + \sum_{i=1}^{n} A_i Y_{t-i} + \varepsilon_t (1) \]

Where \( Y_t \) is the \( n*1 \) vector \((Y_t, Y_{t2}, ..., Y_m)'\), \( Y = (PM_{2.5}, PM_{10}, SO_2, CO, NO_2, O_3, T, FF, RR)' \), \( \varepsilon_t \) is the \( n*1 \) vector of white-noise contemporaneously uncorrelated shocks \((\varepsilon_{t1}, \varepsilon_{t2}, ..., \varepsilon_{tm})'\).
2.6. **AR Root Test**  
We use AR characteristic polynomial root test to inspect the stability of VAR model system. The result shows that, all roots are less than 1, that is, locates within the unit circle, as shown in figure 1, which indicates that VAR model system is stable.

![Inverse Roots of AR Characteristic Polynomial](image)

**Figure 1.** The verification of the VAR model stability.

3. **Empirical Results**

3.1. **Impulse Response**  
Figure 2 shows the impulse responses produced by a one standard deviation shock to each of the series. The PM\textsubscript{10}, SO\textsubscript{2} and CO shock cause PM\textsubscript{2.5} to decrease and continue to be negative through day ten. On the other hand, the NO\textsubscript{2}, Precipitation and Temperature difference shock increase the PM\textsubscript{2.5} and continue to be positive through day ten. PM\textsubscript{2.5} initially increases after an O\textsubscript{3} shock, but the point estimates turn negative around day 4 and remain negative through day ten. Finally, the Wind speed shock causes PM\textsubscript{2.5} to decrease by day two and the point estimate continues to be negative only through day four.

![Impulse Response Functions](image)

**Figure 2.** Impulse Response Functions.
3.2. Variance decomposition

According to table 3 at a time horizon of five days, the PM$_{2.5}$ variation is explained in proportion of 80.568% of personal innovations, 12.787% of shocks in the Temperature difference, 2.009% shock of $O_3$, 1.424% shock of NO$_2$, 1.166% shocks of CO. Also, the change in PM$_{2.5}$ is not significantly influenced by Wind speed. On a longer time horizon (ten days), the variation in PM$_{2.5}$ is explained in the proportion of 75.587% of personal innovations, 14.269% of shocks in the Temperature difference, 5.101% shock of $O_3$, 1.457% shock of NO$_2$, 1.166% shocks of CO.

**Table 3.** The variance decomposition of PM$_{2.5}$.

| Period | S.E.  | PM$_{2.5}$ | PM$_{10}$ | NO$_2$ | SO$_2$ | $O_3$ | CO  | FF  | RR  | T    |
|--------|-------|------------|-----------|--------|--------|------|-----|-----|-----|------|
| 1      | 22.926| 100        | 0         | 0      | 0      | 0    | 0   | 0   | 0   | 0    |
| 2      | 30.252| 93.255     | 0.152     | 1.608  | 0.3    | 1.394| 0.739| 0.179| 0.008| 2.365|
| 3      | 33.927| 86.926     | 0.319     | 1.617  | 0.365  | 1.297| 0.883| 0.199| 0.119| 8.275|
| 4      | 36.361| 82.631     | 0.499     | 1.458  | 0.402  | 1.507| 1.021| 0.177| 0.627| 11.678|
| 5      | 37.937| 80.568     | 0.641     | 1.424  | 0.421  | 2.009| 1.116| 0.179| 0.856| 12.787|
| 6      | 39.09 | 79.133     | 0.752     | 1.46   | 0.417  | 2.532| 1.152| 0.196| 0.9   | 13.458|
| 7      | 39.998| 77.923     | 0.827     | 1.471  | 0.405  | 3.165| 1.167| 0.193| 0.933| 13.915|
| 8      | 40.697| 76.981     | 0.871     | 1.465  | 0.392  | 3.829| 1.175| 0.186| 0.957| 14.145|
| 9      | 41.247| 76.224     | 0.893     | 1.46   | 0.382  | 4.482| 1.174| 0.181| 0.964| 14.24 |
| 10     | 41.695| 75.587     | 0.905     | 1.457  | 0.375  | 5.101| 1.166| 0.178| 0.962| 14.269|

3.3. Granger Causality Test

The Granger causality tests reported in table 4. Wind speed, Precipitation Granger causes PM$_{2.5}$ at the 10% level. Temperature difference Granger causes PM$_{2.5}$ at the 1% level. There is two-way granger causality relationship between $O_3$ and PM$_{2.5}$. And NO$_2$ Granger Causes PM$_{2.5}$.

**Table 4.** Granger Causality Test.

| Null Hypothesis                  | Obs | F-Statistic | Prob. |
|----------------------------------|-----|-------------|-------|
| PM$_{10}$ does not Granger Cause PM$_{2.5}$ | 1077 | 0.401 | 0.752 |
| PM$_{2.5}$ does not Granger Cause PM$_{10}$ | 1.663 | 0.173 |
| $O_3$ does not Granger Cause PM$_{2.5}$ | 23.881 | 0.000*** |
| PM$_{2.5}$ does not Granger Cause $O_3$ | 7.207 | 0.000*** |
| NO$_2$ does not Granger Cause PM$_{2.5}$ | 12.536 | 0.000*** |
| PM$_{2.5}$ does not Granger Cause NO$_2$ | 0.340 | 0.797 |
| FF does not Granger Cause PM$_{2.5}$ | 2.276 | 0.078* |
| PM$_{2.5}$ does not Granger Cause FF | 1.073 | 0.360 |
| CO does not Granger Cause PM$_{2.5}$ | 1.128 | 0.337 |
| PM$_{2.5}$ does not Granger Cause CO | 4.198 | 0.006*** |
| RR does not Granger Cause PM$_{2.5}$ | 2.280 | 0.078* |
| PM$_{2.5}$ does not Granger Cause RR | 1.742 | 0.157 |
| SO$_2$ does not Granger Cause PM$_{2.5}$ | 0.056 | 0.983 |
| PM$_{2.5}$ does not Granger Cause SO$_2$ | 10.772 | 0.000*** |
4. Discussions

Based on VAR model, this paper researched on the influencing factors of PM$_{2.5}$ in Chengdu through the impulse response function, variance decomposition and Granger causality test, conclusions and recommendations are as follows:

(1) From the perspective of impulse response function, PM$_{10}$, CO and SO$_2$ have negative influence on PM$_{2.5}$, and O$_3$ has positive effects on PM$_{2.5}$ only in short-time, NO$_2$ has positive effects on PM$_{2.5}$ both in short-term and long-term perspective. Therefore, prevention and control of PM$_{2.5}$ should be taken together with that of NO$_2$. And in terms of climate conditions, only wind has a negative effect on PM$_{2.5}$ in the short term. Since Chengdu is located in the Sichuan basin and with less windy weather, it is difficult to control PM$_{2.5}$ through changing climate conditions.

(2) For the variance decomposition results, PM$_{2.5}$ variance contribution is the biggest. Therefore, the key for the control of PM$_{2.5}$ must be based on the cause and formation rules of PM$_{2.5}$. In addition, temperature difference, O$_3$ and NO$_2$ also have obvious influence on PM$_{2.5}$. On one hand, control of O$_3$ and NO$_2$ can decrease the harm of PM$_{2.5}$, on the other hand, temperature difference changes also can help to give more accurate warning for PM$_{2.5}$.

(3) Through the results of Granger causality test, climate conditions are Granger causes for PM$_{2.5}$. But in air pollutants, only NO$_2$ and O$_3$ are Granger causes for PM$_{2.5}$. Combined with the results of impulse response function and variance decomposition, NO$_2$ and O$_3$ have close relationship with PM$_{2.5}$. A further study on air pollutants as O$_2$ and O$_3$ may play an important role in finding out the real source and formation reasons of PM$_{2.5}$.

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