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Stillbirth and Fine Particulate Matter Exposure in Ulaanbaatar Mongolia: July 2010 - April 2014

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by

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Stillbirth and Fine Particulate Matter Exposure in Ulaanbaatar Mongolia: July 2010 - April 2014

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ABSTRACT

Throughout the last decade, research on the relationship between fine particulate air pollution and fetal mortality has progressed in significant ways. This study contributes to the literature by exploring the impact of exposure to fine particulate matter ($PM_{2.5}$) pollution on stillbirth in Ulaanbaatar, Mongolia. It identifies the critical window of exposure – when fetuses are most vulnerable to the impact of pollution – during the last months of pregnancy. I utilize multiple ordinary least squares (OLS) regression analysis with a time-series design. Among the three time lags (no lag, 1- and 2-month lags) examined, I find a positively and statistically significant association between monthly stillbirth rates with 1-month lag and monthly average concentration levels of $PM_{2.5}$, while controlling for other ambient air pollutants and temperature. I find no statistically significant association between monthly average concentration levels of $PM_{2.5}$ and monthly stillbirth rate with no lag or 2-month lag.

Background

The World Health Organization (WHO) recently estimated that in 2012 there were 7 million premature deaths linked to air pollution, which means every eighth premature death around the world is a consequence of exposure to air pollution. Among these 7 million premature deaths, 3.7 million deaths relate to ambient (outdoor) air pollution, especially the most common ambient air pollutants, which are particulate matter (PM), nitrogen dioxide (NO_2), sulfur dioxide (SO_2), and ozone (O_3). Low- and middle-income countries are home to 88% of those whose deaths are related to these pollutants. This WHO report (2014) citing this information suggests that air pollution has become the world's largest single environmental health risk for human beings, with particulate matter impacting more people than all other pollutants.

The WHO defines particle pollution – or particulate matter (PM) – as "a complex mixture of solid and liquid particles of organic and inorganic substances suspended in the air." Particle pollution most commonly includes coarse particles (with a diameter between 2.5-10 micrometers) and fine particles (with diameters of 2.5 micrometers or less). Particulate pollution is usually measured in PM_{10} concentrations, which includes both coarse particles and fine particles, and in $PM_{2.5}$ concentrations (i.e. fine particles with diameters of 2.5 micrometers and less). Not all particle pollution is formed by exactly the same kinds of particles. Instead, it can be made up of hundreds of chemicals of different shapes with a particle size range of less than 10 micrometers in diameter (WHO, 2006). Particles are also categorized as primary particles and secondary particles based on whether they are emitted into the air directly from the source or formed through a complicated chemical reaction. Sources of primary particles involve construction sites, unpaved roads, fields, smokestacks or fires. In contrast, secondary particles, which make up most of the fine particle pollution (i.e. $PM_{2.5}$), are emitted from fuel combustion including power plants, industrial sites, and automobiles (Haywood & Boucher, 2000). These fine particles also tend to have a bigger influence on human health as the smaller size allows the particles to pass deep into the lungs, and even to pass through the lungs, entering directly into the blood stream and harming other organs (Dejmek, Solanský, Benes, Lenícek, & Srám, 2000; Ritz & Wilhelm, 2008). Lung cancer and cardiopulmonary mortality are two of the severe health outcomes that may occur (Pope et al., 2002: 1131-1141).

Besides contributing to premature deaths that are linked to cancer, cardio-vascular problems, and respiratory diseases in adults (Pope et al., 2002; Allen et al., 2013) and very young children (Woodruff, Grillo & Schoendorf, 1997; Son, Bell & Lee, 2010; Loomis, Castillejos, Gold, McDonnell, & Borja-Aburto, 1999; Chay & Greestone, 2003; Currie, Neidell & Schmieder, 2009; Ritz, Wilhelm & Zhao, 2006), many studies confirm that mothers who are exposed to high levels of ambient air pollution concentrations during pregnancy have a higher risk of having severe adverse birth outcomes, including early fetal loss (Hou et al., 2014) and stillbirth (Son et al., 2010; Choi, Wang, Lin, Spengler & Perera, 2012; Wu et al., 2009; Hou et al., 2014; Hwang, Lee & Jaakkola, 2011; Faiz et al., 2012, 2013).

WHO defines stillbirth as a baby born without any sign of life after or at 28 weeks of gestation age or with a birth weight of at least 1,000 grams. Some draw the boundary at 22 weeks or a birth weight of at least 500 grams, which is how stillbirth is defined in Mongolia. The Lancet Stillbirth Series report suggests that in 2009, there were more than 7200 babies stillborn every day around the world (Lawn, Gravett, Nunes, Rubens & Stanton, 2010). Even more than the percentage of premature deaths linked to ambient air pollution, 98% of these stillbirths occur in low- and middle-income countries. The Lancet report also reveals that only about 2% of the 7200 stillbirths are formally registered and that the global estimates of 7200 stillbirths per day is based on modeling and household surveys. Both the mechanism of how $PM_{2.5}$ -- or ambient air pollution as a broader category of pollutants -- causes or triggers stillbirth (Ritz & Wilhelm, 2008; Faiz et al., 2012) and the critical window of exposure that leads to stillbirth (Glinianaia, Rankin, Bell, Pless-Mulloli & Howel, 2002) remain largely unknown (Lawn et al., 2009; Yakoob et al., 2009; Salihu, 2008).

With respect to the causal relation between air pollution and stillbirth, some studies have shown that exposure to air pollution may restrict fetal growth (Lawn et al., 2009; Bruce, Perez-Padilla & Albalak, 2000). Other studies find that polycyclic aromatic hydrocarbons (PAHs), which are one particular kind of air pollutant, may be causing some of the adverse birth outcomes (Ritz & Wilhelm, 2008; Perera, Jedrychowski, Rauh, & Whyatt, 1999). A possible mechanism is that PAHs stick to particulate matter, especially ultra-fine particular matter, which makes it possible for these PAHs to penetrate through lung barriers of pregnant women and enter other organs including the brain and placenta through the bloodstream (Ritz & Wilhelm, 2008; Pereira et al., 1999). The particulate matter carrying PAHs can cause adverse birth outcomes including stillbirth by causing inflammation and interfering with placental development with PAH-DNA adducts, which may pose adverse impact on DNA (Ritz et al., 2006; Ritz & Wilhelm, 2008; Dejmek et al., 2000; Šrám, 1998; Perera et al., 1999; Shah & Balkhair, 2011).

With respect to the critical window of exposure, which I discuss further below, the existing literature on exposure to particulate air pollution and adverse birth outcomes has identified various time periods – or windows – during which exposure to air pollution is especially harmful to the fetus. For example, a study of examining the association between $PM_{2.5}$ exposure and intrauterine growth retardation (IUGR) in Czech Republic found the first month of pregnancy to be of critical impact on the likelihood of having babies with IUGR (Dejmek, Selevan, Benes, Solanský & Srám, 1999). In contrast, a study investigating the association between $PM_{2.5}$ exposure and birth weight in Sydney found the second trimester (4-6 months) of pregnancy and the last month of pregnancy to be of critical impact on the likelihood of having babies with low birth weight (Manns et al., 2005).

Although as many as 98% of stillbirths occur in low- and middle-income countries, most of the studies focusing on pregnancy exposure to particulate air pollution *and* fetal mortality have been done in high- and higher-middle-income countries and in regions including the United States (Chay & Greenstone, 1999, 2003; Lave & Seskin 1972; Ritz & Wilhelm, 2008; Faiz et al., 2012, 2013), Canada (Liu, Krewski, Shi, Chen & Burnett, 2007), United Kingdom (Pearce et al., 2010), South Korea (Son et al., 2011), Australia (Barnett &

Walkewitz, 2012), Czech Republic (Bobak & Leon, 1999), Taiwan (Hwang et al., 2011) , Brazil (Pereira et al., 1998), and Mainland China (Hou et al., 2014)[1]. However, most cities with worst air quality in the world are in developing countries in Asia (WHO, 2011); for instance, nineteen out of twenty most PM_{10} polluted cities in the world are located in developing countries in Asia including Iran, Mongolia, India, and Pakistan (WHO, 2011). Thus, most of the existing studies were not carried on where the most severe particulate pollution occurs. Of course, the lack of studies in these countries may be the result of unavailable or insufficient fetal mortality data in these low- and middle-income countries.

When the *Partnership for Maternal, Newborn & Child Health*, together with other organizations including WHO, called attention for stillbirths in low- and middle-income countries (2011), many in Mongolia also started to realize the prevalence of stillbirths in the capital city of Ulaanbaatar. TV9, one of the biggest TV stations in Mongolia, reported astonishing news in 2010 when it stated that every third pregnant mother had a fetal loss (either miscarriage or stillbirth), every seven out of ten births had complications after birth, and every one out of seven births produced a child with a birth defect. Another major newspaper, known as *Today*, also reported a similar story (2010).[2] According to *Today*, although doctors of obstetrics and gynecology said that up to 70% of fetal losses are caused

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[1] Countries and regions are categorized based the World Bank income economy groups.
[2] The electronic version of the article is accessible in Mongolian at http://www.mongolnews.mn/i/5087; last accessed on August 6, 2014.

by sexually transmitted diseases (STDs), pregnant women were more concerned about the air pollution impacting their babies' health in urban Ulaanbaatar (2010).

After these initial news stories, the topic of air pollution impacting fetus health disappeared from the headlines for a while. However, it has remained a major concern among residents of Ulaanbaatar, especially for mothers who are expecting. Earlier this year, the *UB Post* (2014) raised the issue of air pollution impacting unborn and newly born babies again, based on an interview with a maternal nurse. The article concluded with a quote from the nurse saying that "… we now advise women that the one and only way to give birth to a healthy child, and to ensure that they avoid giving birth to children with brain damage and heart problems, is to live in the fresh air – that is, as far from Ulaanbaatar as possible.[3]" While air pollution remains among the biggest concerns of people expecting to bring new lives into their families, there are no studies specifically examining the relationship between ambient air pollution and unborn babies in Ulaanbaatar.

Ulaanbaatar is known as the coldest capital city in the world, with a temperature that typically varies between -33.3°C (-28°F) and 27.2°C (81°F) across a year (WeatherSpark). It is the central hub of economic activity in Mongolia, which is one of these understudied low- and middle-income countries. Located in East and Centre Asia, Mongolia has a population of a little more than 2.8 million, and ranked at 130 among all countries in terms of gross domestic product (GDP) and a total economic income of 11,516 million US dollars in 2013

[3] The electronic version of the article is accessible in English at http://ubpost.mongolnews.mn/?p=7537; last accessed on August 6, 2014.

(World Bank, 2014). The capital city of Ulaanbaatar contains nearly half of the national population with more than 1.2 million people. It is the biggest and almost the only city with modern urban structure in Mongolia.

In recent decades, the huge immigration of Mongolians from rural areas to Ulaanbaatar for a "better" life has created a distinct settlement in the "ger" (traditional Mongolian house) areas surrounding the central city. Heating in the ger areas is the major cause of air pollution as most of the families in the ger areas use open-fire heating stoves to stay warm during the tough winter months. According to the *Urban outdoor air pollution database (2011)* that was released by the Department of Public Health and Environment of the WHO, Ulaanbaatar is listed as the world's most polluted city for year-round fine particulate matter pollution (annual $PM_{2.5}$)[4] and second most polluted city for year-round particulate matter (annual PM_{10}) [5](WHO, 2011). A report of *Air Quality Analysis of Ulaanbaatar –Improving Air Quality to Reduce Health Impacts* published by World Bank in 2011 confirmed that the air pollution in Ulaanbaatar, especially particulate matter pollution ($PM_{2.5}$ and PM_{10}), is much higher than other cities known to have polluted air, including Beijing, Cairo, and Los Angeles. According to a report by the World Bank in 2011, the concentration of both PM_{10} and $PM_{2.5}$ would have to be reduced by 80% to meet the WHO's suggested air quality standard (World Bank, 2011). In addition, the concentration of air pollution, especially the concentration of $PM_{2.5}$ in the ambient air in Ulaanbaatar varies

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[4] The $PM_{2.5}$ list includes 576 cities from 38 countries.
[5] The PM_{10} list includes 1100 cities from 91 countries.

across the duration of each year. As Figure 1 shows, the $PM_{2.5}$ concentration level during the winter can be as much as six to seven times the concentration level during the summer months.

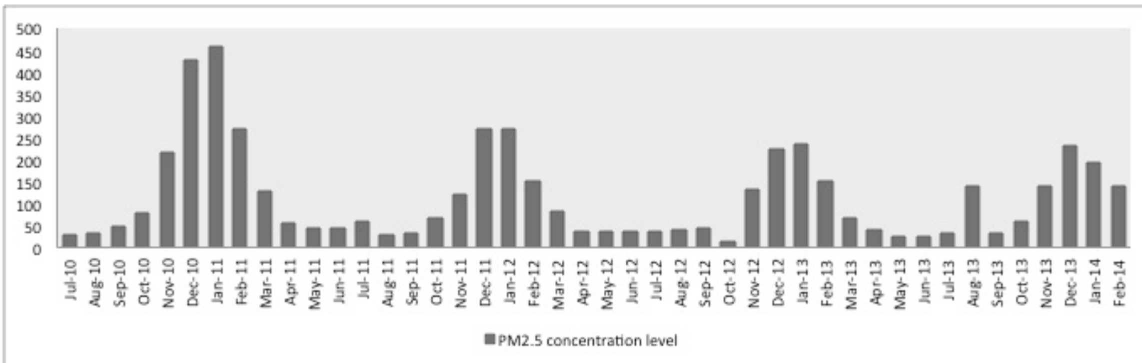

Figure 1 concentration trend of and PM_{10} in Ulaanbaatar, Mongolia from July 2010 to December 2013

In 2011, a group of eight researchers examined the ambient air pollution concentration and adverse health effects in Ulaanbaatar by assessing air pollution and its attributable mortality (Allen et al., 2013). It is the only published study that investigates the impact of ambient air pollution on adverse health effects in Ulaanbaatar. The study estimated that 29% of cardiopulmonary deaths and 40% of lung cancer deaths in the city are attributable to ambient air pollution and concluded that 9.7% of deaths of people over 30 years old are due to $PM_{2.5}$ pollution. It emphasized that the total mortality rate caused by $PM_{2.5}$ air pollution might be greater than 9.7% because infant mortality, which is a major contributor to total mortality, is not included in this study (Allen et al., 2013). Although this study confirms the ambient air pollution, particularly $PM_{2.5}$, has adverse impact on human health, further studies are required to understand the relationship of ambient air pollution to particular health effects such as adverse birth outcomes.

The research in this paper focuses on the relationship between exposure to fine particulate matter air pollution and stillbirth in Ulaanbaatar, Mongolia. For the year of 2009, *The Lancet* reported Mongolia as having the 96th lowest stillbirth rate among 193 countries (Cousens et al., 2011). While this positions Mongolia as having an unexceptional in terms of its overall stillbirth rate, we might expect Ulaanbaatar to be an ideal setting for exploring the relationship between air pollution and stillbirth, precisely because of the city's status as the "world's most polluted city." In particular, if air pollution does have an impact on the likelihood of stillbirth, then the high level of particulate matter air pollution in this area of the world suggests its impact on unborn fetuses will be pronounced. My specific aim is to identify a critical window of exposure to fine particulate matter pollution during which time the fetus is especially vulnerable to the impact of this kind of air pollution, making stillbirth more likely. Research on this topic is especially important because stillbirths account for at least one half of all perinatal deaths around the world (Yakoob et al., 2009). Furthermore, as I will discuss in the next section, there is a growing body of literature linking stillbirth to air pollutants including $PM_{2.5}$ (e.g. see Hwang et al., 2011; Hou et al., 2014; Bobak & Leon, 1999; Strand, Barnett & Tong, 2012; Pearce et al., 2010; Sakai, 1984; Pereira et al., 1998; Faiz et al., 2012, 2013). However, as a whole, this literature finds a great deal of variation in the windows of exposure during which time the fetus is most vulnerable to the impact of air pollution.

The Impact of Air Pollution on Adverse Birth Outcomes

Although a number of studies explore the relationship between ambient air pollution exposure during gestation and adverse birth outcomes, relatively few studies concentrate on fine particulate matter ($PM_{2.5}$), and especially on the relationship between $PM_{2.5}$ exposure and stillbirth. Current research has found that $PM_{2.5}$ exposure is associated with a variety of adverse birth outcomes, including intrauterine growth retardation (IUGR) (Dejmek et al., 1999; Liu et al., 2007), small for gestational age (SGA) (Parker, Woodruff, Basu & Schoendorf, 2005), lower birth weight (LBW) (Parker et al., 2005; Bell et al., 2010; Mannes et al., 2005), preterm birth (Wu et al., 2009; Huynh, Woodruff, Parker & Schoendorf, 2006; Ritz, Wilhelm, Hoggatt & Ghosh, 2007), and stillbirth (Faiz et al., 2013).

Intrauterine growth retardation (IUGR) refers to fetuses that weigh less than 90% of the weight of other babies of the same gestational age and gender when they are in their mothers' wombs (Šrám, 1999). The results of current studies exploring the association between $PM_{2.5}$ exposure and IUGR are not consistent. A study conducted in Northern Bohemia, Czech Republic between1994 and 1996 finds that $PM_{2.5}$ exposure is significantly associated with an increased risk of IUGR for fetuses whose mothers are exposed to high concentration level of $PM_{2.5}$ during the first month of pregnancy (Dejmek et al., 1999). Although a later study carried on in Canadian cities of Calgary, Edmonton, and Montreal during the time period 1985-2000 also found results confirming the statistically significant association between $PM_{2.5}$ exposure and increased risk of IUGR, the confirmed vulnerable exposure windows are not the same (Liu et al., 2007). Unlike the Czech research, the

Canadian study indicates that increased $PM_{2.5}$ exposures in first (1-3 months of pregnancy), second (4-6 months of pregnancy), and third (7-9 months of pregnancy) trimesters are associated with an increased risk of IUGR (Liu et al., 2007).

The definition of "small for gestational age (SGA)" is identical to IUGR. It also refers to fetuses that are smaller in their mothers' wombs than other babies of similar gestational age and gender (Šrám, 1999). A study exploring the impact of pregnant women's PM2.5 exposure on SGA in California, United States finds that infants whose mothers had the highest exposure to $PM_{2.5}$ concentrations during the entire duration of pregnancy had higher odds of being "small for gestational age" (SGA) than the infants whose mothers had lowest exposure to $PM_{2.5}$ concentrations during the entire term of pregnancy. They also find similar results when testing the association between SGA and $PM_{2.5}$ exposure during each of the three trimesters (Parker et al., 2005). Thus, taken together, current research on the relationship between fetal birth weight and exposure to particulate matter pollution suggests that there are multiple exposure "windows" during which exposure to particulate air pollution has been found to have significant impacts on fetal health: mothers exposed to higher $PM_{2.5}$ concentration levels during the first month of their pregnancy, or during any of the three trimesters of their pregnancy, or during the entire term of their pregnancy, have all been found to face a higher risk of having babies with IUGR or SGA conditions.

According to the WHO, low birth weight (LBW) refers to liveborn babies that weigh less than 2,500 grams (when normal weight should be between 2500 and 4200 grams) (ICD-10, 2010: P07). Similar to the studies exploring impact of $PM_{2.5}$ exposure on IUGR and SGA, existing research examining the association between gestational $PM_{2.5}$ exposure and

LBW do not reveal consistent results regarding the critical window of exposure to particulate matter pollution. Besides the confirmed impact of $PM_{2.5}$ exposure on SGA, Parker et al. also find statistically significant association between $PM_{2.5}$ exposure and LBW in their research conducted in California. Looking only at term births, they discover that the mean birth weight of infants in highest $PM_{2.5}$ gestational exposure category, where mothers are exposed to higher $PM_{2.5}$ concentrations across the entire pregnancy, is slightly higher than the birth weight of infants in lowest $PM_{2.5}$ gestational exposure category, where mothers are exposed to lower $PM_{2.5}$ concentrations across the entire pregnancy (Parker et al., 2005). A study examining four counties in Connecticut and Massachusetts, United States confirms the association between LBW and $PM_{2.5}$ exposures in the third trimester (Bell et al., 2010). In this study, Bell et al. find that pregnant women exposed to higher concentrations of $PM_{2.5}$, especially certain chemical constituents of $PM_{2.5}$, including road dust and related constituents such as silicon and aluminum, motor-vehicle-related species such as elemental carbon (also known as black carbon) and zinc, and oil-combustion-associated elements vanadium and nickel, are associated with babies with LBW (Bell et al., 2010). Another study confirming the association between $PM_{2.5}$ exposure and birth weight was carried on in Sydney, Australia between 1998 and 2000. The Sydney study reveals that exposure to $PM_{2.5}$ in the second trimester as well as in last month of pregnancy has a small but statistically significant adverse effect on birth weight (Mannes et al., 2005). In summary, like research on IUGR and SGA, studies on LBW show variation in the critical window of exposure, finding that LBW may be associated with mothers' $PM_{2.5}$ exposure during the entire pregnancy, during second and third trimester of pregnancy, and during the last month of pregnancy before delivery.

Similar variation in the critical window of exposure is also evident in research addressing the relationship between particulate matter pollution exposure and preterm birth. Preterm birth, also known as preterm labor, refers to births that occur before a fetus has reached 37 weeks of gestational age, when normal pregnancies last about 40 weeks (WHO, 2013). Various studies examine the association between preterm birth and $PM_{2.5}$ exposure (Wu et al., 2009; Huynh et al., 2006; Ritz et al., 2007). A study investigating this association in southern California concluded that pregnant women exposed to traffic-generated $PM_{2.5}$ pollution across the entire term of pregnancy faced and increased the risk of preterm birth (Wu et al., 2009). Likewise, another study linking $PM_{2.5}$ exposure to preterm birth in California shows an increase in preterm births for mothers experiencing high ambient air levels of $PM_{2.5}$ exposure over their entire pregnancy (Huynh et al., 2006). This study also finds the same association between $PM_{2.5}$ exposure and preterm birth in the when mothers are exposed to high levels of ambient particular pollution in only first month of pregnancy and the last two weeks of pregnancy (Huynh et al., 2006). A third and similar study in California suggests that preterm birth is associated with $PM_{2.5}$ exposure of pregnant women in the first trimester of their gestational period (Ritz et al., 2007).

In the context of a relatively broad body of research assessing the relationship between particulate matter air pollution and various birth outcomes, few examine stillbirth as one of these adverse birth outcomes, and those that have assessed it show inconsistent results regarding the critical window of exposure. A population based case control study examining air pollution and stillbirth in Taiwan found that exposure to inhalable particulate matter (PM_{10}) during first trimester is significantly associated with stillbirths among preterm births, which refer to stillbirths that happen before completing 37 weeks of gestational age (Hwang et al., 2011) However, this association does not hold for stillbirths of fetuses that come to term, which refers to stillbirth that occur for fetuses birthed after 37 weeks of gestational age (Hwang et al., 2011). Another study examining the association between ambient air pollution and fetal loss in early pregnancy in Tian Jin, China found that fetal loss within 14 weeks of gestational age was associated with higher exposure to total suspended particulates (TSP) during the first month of pregnancy (Hou et al., 2014).

Although these two studies find an association between fetal loss and $PM_{2.5}$ exposure during the first trimester and first month of pregnancy, several studies suggest there is no significant association between particulate matter exposure and stillbirth. For example, a study by Bobak and Leon did not find any significant association between TSP and stillbirth in Czech Republic during 1986-1988 (Bobak and Leon, 1999). Similarly, a study carried on in Brisbane, Australia did not find any significant association between PM_{10} and stillbirth (Barnett & Wolkewitz, 2012). A study examining of the relationship between black smoke (approximately equivalent to PM_4[6]) and stillbirth in northern England between 1962-1992, also did not find any association between exposure to black smoke exposure and stillbirth in any gestational trimester or across the whole pregnancy (Pearce et al., 2010). Finally, a study in Brazil suggests there is no significant association between air pollution exposure,

[6] PM_4: particulate matters with diameters less than 4 micrometers.

including PM_{10} exposure, and intrauterine mortality for fetuses over 22 weeks of pregnancy (Pereira et al., 1998).

Given this variation in the findings emerging from research on the impact of particulate pollution broadly defined, more recent research has directly looked into the relationship between $PM_{2.5}$ and stillbirth. For example, two important studies were done in New Jersey, United States for the time period of 1998-2004 (Faiz et al., 2012; 2013). Results of the first study (done in 2012) reveals that mean concentration levels of $PM_{2.5}$ in the ambient air during each of all three gestational trimesters and the entire length of pregnancy are higher for women whose pregnancies resulted in stillbirths than they are for women whose pregnancies resulted in live births. Although increased relative odds of stillbirth associated with exposure to higher mean $PM_{2.5}$ concentrations in each trimester is observed, none were statistically significant (Faiz et al., 2012). The second study (published in 2013, and building on the 2012 study) examines whether the mean $PM_{2.5}$ concentrations in the ambient air 2 days before delivery and the mean $PM_{2.5}$ concentrations in the ambient air 2 through 6 days before delivery are associated with stillbirth. This study found that the increase of mean $PM_{2.5}$ concentration level at both 2 days before delivery and at 2 through 6 days before delivery is significantly associated with the increase of stillbirth (Faiz et al., 2013).

To summarize: Among the few studies investigating the association between $PM_{2.5}$ exposure during pregnancy and stillbirth, the first research published by Faiz et al. in 2012 did not find any statistically significant association between stillbirth and average $PM_{2.5}$ concentration level during any of the three trimesters or throughout the entire pregnancy.

However, a positively and statistically significant association is observed in a later study in New Jersey that focuses on the impact of mean $PM_{2.5}$ concentrations several days before delivery. Since stillbirth can happen at any point during pregnancy from 22 week to around 40 weeks, it is more reasonable to conduct the research in the way the second New Jersey study does, which is to investigate if $PM_{2.5}$ is associated with stillbirths when pregnant women are exposed to high concentration levels of $PM_{2.5}$ in a certain time before stillbirth occurs; i.e. instead of investigating whether pregnant women are exposed to high $PM_{2.5}$ concentrations during a particular gestational age of the fetus.

Among studies investigating the impacts of $PM_{2.5}$ on adverse birth outcomes and the impacts of particulate matters on stillbirth, for research that find statistically significant associations, the critical windows of exposure – windows during which pregnant women's fetuses are most vulnerable – occur in two periods. One is the first trimester of pregnancy (Dejmek et al., 1999; Huynh et al., 2006; Ritz et al., 2007; Hwang et al., 2011), which includes the first month of pregnancy (Dejmek et al., 1999; Huynh et al., 2006). The other is the last month of pregnancy (Huynh et al., 2006; Mannes et al., 2005; Faiz et al., 2013), which includes the last two weeks (Huynh et al., 2006) and the last a few days (Faiz et al., 2013) before pregnancy terminated. Moreover, one of the only two studies directly linking stillbirth to $PM_{2.5}$ pollution in New Jersey suggests no statistically significant association between stillbirth and mean $PM_{2.5}$ concentrations during each of all three gestational trimesters and mean $PM_{2.5}$ concentrations during the entire gestation time. The other reveals a positive and statistically significant association between stillbirths and mean $PM_{2.5}$ concentrations 2 days and 2-6 days before stillbirth occurs. Thus, while this positive and statistically significant finding suggests that there is a critical window of exposure during the end of the last month of pregnancy, the association of high $PM_{2.5}$ concentrations and stillbirths at monthly intervals has not yet been investigated.

The present research seeks to contribute to this growing literature on the relationship between air pollution and fetal mortality by exploring the critical window of pregnancy during which $PM_{2.5}$ exposure has an impact on stillbirth in Ulaanbaatar, Mongolia. Given the high levels of particulate air pollution in Ulaanbaatar and the various studies and theoretical connections linking it to stillbirths, I hypothesize that *an increase of monthly average $PM_{2.5}$ concentration levels will be associated with an increase in the monthly stillbirth rate, when controlling for other ambient air pollutants and temperature.* To test this hypothesis, I use monthly average concentration levels of $PM_{2.5}$ of Ulaanbaatar, which is collected by one air quality monitoring station in the city, to measure the $PM_{2.5}$ exposure of all residences of Ulaanbaatar. I use monthly stillbirth rate among women giving birth in hospitals in Ulaanbaatar to measure stillbirths.[7] As the nature of the collected data does not allow me to investigate the critical window at the beginning of pregnancy, I only focus on investigating the second critical window during which $PM_{2.5}$ exposure may impact stillbirth, which is the period of time at the end of pregnancy.[8] However, by doing so I hope to add to the growing

[7] For this research, I collected stillbirth data on all "maternity" hospitals in Ulaanbaatar that report to the Health Department of Ulaanbaatar.

[8] The reports only include the information of how many stillbirths occurred in a calendar month. It does not reveal the gestational age of babies that are stillborn. Thus, I cannot determine when the pregnancy starts and what is the PM2.5 concentration level in beginning of pregnancy.

literature on particulate air pollution and stillbirth by assessing the relationship between $PM_{2.5}$ exposure and stillbirth on a monthly basis.

Analytic Strategy

In order to test whether the stillbirth rate in Ulaanbaatar, Mongolia directly associates with variation in the concentration level of fine particulate air pollution ($PM_{2.5}$), I utilize multiple ordinary least squares (OLS) regression analysis. This method is consistent with current comparative research that assesses the impact of air pollution on fetal health (Jedrychowski et al., 2004; Manns et al., 2005).

OLS regression has many advantages. It allows researchers to investigate the relationship between a dependent variable and an independent variable, while also controlling other variables. It is a common method used in causal analysis to isolate the affects of key variables (Allison, 1999). Thus, OLS can help to determine if the independent variable under investigation, $PM_{2.5}$ concentration, affects the dependent variable, monthly stillbirth rate, net of other pollutants. It can also help to determine how strong this relationship is. The general equation for a simple bi-variate linear equation that only takes into account one independent variable is: $y = a + bx$.

In this equation, y is the dependent variable, x is the independent variable, a represents the intercept (the value of y when x is 0), and b is the slope. The slope describes the nature of the relationship between the independent variable and dependent variable. When the slope is positive, it means the dependent variable increases with the increase of independent variable. When the slope is negative, however, the dependent variable decreases when the independent variable increases. A larger slope corresponds with a bigger change of dependent variable.

When there are supplementary independent variables to consider, additional terms are added to the equation. For example, Model 6 in this study includes one independent variable ($PM_{2.5}$) and six control variables (NO_2, O_3, PM_{10}, SO_2, CO, and temperature). Thus, the equation (including variable labels) for this model is:

Monthly Stillbirth Rate = $a + b_1PM_{2.5} + b_2NO_2 + b_3O_3 + b_4PM_{10} + b_5SO_2 + b_6CO + b_7Temprature$

In this equation, y is the monthly stillbirth rate in Ulaanbaatar as the dependent variable; $PM_{2.5}$, which represents the concentration level of $PM_{2.5}$ in the ambient air, is the independent variable; NO_2, O_3, PM_{10}, SO_2, and CO represent the concentration levels of each of the control variables that define other kinds of air pollution that may also have an impact on stillbirth. I use the statistical program STATA in analyzing the data.

Unlike other studies that use individual-level data in exploring the relationship between particulate matter air pollution and stillbirth, I examine time-series data of the monthly stillbirth rate and monthly average concentrations of fine particulate matter. I utilize a cross-sectional research design by treating months (from July 2010 to April 2014) as the units of analysis. This allows me to interrogate how the monthly stillbirth rate fluctuates with changes in $PM_{2.5}$ concentration. While other studies are inclusive in identifying the time lag between exposure to fine particulate matter and the occurrence of stillbirth, using monthly data will allow me to solely investigate which lag (no lag, 1-month, or 2-month lag, etc.) best describes the correlation between fine particulate matter and stillbirth rate. In other words, I am only investigating if a higher concentration of fine particulate matter is associated with a higher stillbirth rate across months; this eliminates potential confounding socio-economic factors of individuals or households that may impact the nature of the relationship between stillbirth and pollution, as well as the lag between exposure and experiencing a stillbirth (Pereira et al., 1998; Babbie, 2004; Gouveia, Bremner & Novaes, 2004; Ritz & Wilhelm, 2008; Faiz et al., 2013). Such a design reveals whether or not stillbirth rates increase following months of high $PM_{2.5}$ exposure.

Sample

Dependent Variable

The dependent variable of monthly stillbirth rate is calculated from the number of stillbirths and number of live births in Ulaanbaatar between July 2010 and April 2014, which were reported by the Ulaanbaatar Health Center.[9] The reports of Ulaanbaatar Health Center include the number of stillbirths and the number of live births in the form of aggregate numbers across the months. For instance, in the monthly report of July 2013, the reported number of stillbirths would be the sum of stillbirths in the first seven months, including months from January 2013 through July 2013. The January report, however, only includes

[9] Monthly reports including monthly stillbirth data are accessible in Mongolia at http://ubhealth.mn/index.php/2011-03-14-07-10-39/40-2011-03-14-07-10-06.html

the numbers of stillbirths within the month. The numbers of live births are also reported in the same way as the numbers of stillbirths. In order to obtain estimates for each month, I subtracted the aggregate numbers of stillbirths and live births from the preceding month. To transform the numbers into the monthly stillbirth rate, I divided the number of monthly stillbirths by the number of monthly live births, and then multiplied by 1000 in order to get the stillbirth rate of per 1000 live births. The monthly stillbirth rate in Ulaanbaatar is calculated as:

$$r_i = \frac{S_i - S_{i-1}}{L_i - L_{i-1}} \times 1000$$

Where:

r_i = Stillbirth Rate per 1000 live birth of month i (i=1, 2, …… 12)

S_i = The number of stillbirths occurring in the first i month(s) of the reported year (i=1, 2, ……, 12).

S_{i-1} = The number of stillbirths occurring in the first i-1 month(s) of the reported year (i=1, 2, …… , 12), when i=1, $S_{i-1} = 0$

L_i = The number of live births occurring in the first i month of the year (i=1, 2 …… 12).

L_{i-1} = The number of live births occurring in the first i-1 month of the year (i=1, 2 …… 12), when i=1, $L_{i-1} = 0$

Key Independent variable

The independent variable is the monthly average concentration level of fine particulate air pollution ($PM_{2.5}$). These data (gathered between July 2010 and February 2014) are obtained from National Agency for Meteorology Hydrology and Environmental Monitoring in the city of Ulaanbaatar, Mongolia. The $PM_{2.5}$ air pollution concentration levels are measured at the No. 2 air quality monitoring station in Ulaanbaatar in 15-minute intervals. The monthly average concentration levels are calculated using the daily average monitored concentration levels and are reported in unites of $\mu g/m^3$ (micrograms per cubic meter of air). Other air pollution control variables are measured and calculated in the same way unless specified.

Additional Control Variables

Nitrogen dioxide (NO_2): because it is an important component of ambient air pollution, other studies investigating the impact of ambient air pollution on fetal health included nitrogen dioxide (NO_2) as a key independent variable or control variable (Bell et al., 2007; Ha et al., 2001; Lee et al., 2003; Lin et al., 2004; Mannes et al., 2005; Faiz et al., 2012, 2013). Thus, I include nitrogen dioxide as a control variable in this study.

Ozone (O_3): this gas, comprised of three oxygen atoms, is another important component of ambient air pollution that studies examining the relationship between ambient air pollution and fetal health investigate (Ha et al., 2001; Lin et al., 2004; Mannes et al., 2005; Salam et al., 2005). Thus, I included ozone (O_3) concentration levels as another control variable in this study. The concentration level of ozone (O_3) included in this study is measured at the No.4 air quality monitoring station in Ulaanbaatar and was obtained through the National Agency Meteorology and the Environmental Monitoring of Mongolia. I included the ozone (O_3) monthly average concentration levels data for the same period of time from July 2010 to February 2014 as the key independent variable. The monthly average concentration levels for ozone (O_3) are based on the 8-hour average monitored concentration levels and are reported in unites of $\mu g/m^3$.

Sulfur dioxide (SO_2): this is another control variable I included in this study. A wide body of research confirms that sulfur dioxide (SO_2), as another primary component of ambient air pollution, has an influence on fetal health (Bobak, 2000; Rogers et al., 2000; Ha et al., 2001; Lee et al., 2003; Faiz et al., 2012, 2013).

Inhalable particulate matter (PM_{10}): it refers to particles that have diameters of 10μm (micrometers) or less. They are bigger particles than $PM_{2.5}$. Various research has confirmed that PM_{10} exposure has a direct influence on fetal health (Dejmek et al., 1999; Ritz, Yu, Chapa & Fruin, 2000; Hwang et al., 2011; Barnett & Wolkewitz, 2012). It is an additional control variable that I included in this study.

Carbon monoxide (CO): I included the monthly concentration levels of carbon monoxide (CO) as an additional control variable in this study. Comparable studies considered carbon monoxide (CO) as an important contributor to the impacts of ambient air pollution on fetal health (Ritz et al., 2000; Ha et al., 2001; Lee et al., 2003; Parker et al., 2005; Faiz et al., 2012, 2013).

Temperature: It is an important control variable because the key independent variable -- monthly average $PM_{2.5}$ concentration level varies across seasons. PM2.5 concentration levels are higher in winters in Ulaanbaatar because people burn solid fuels for heating in the cold weather. In addition, cold weather itself may have adverse impacts on fetal health. Thus, I included temperature as a control variable in testing dependent variables with different lags. I accessed the monthly average temperature data from monthly reports released by the Statistical Center of Ulaanbaatar city.

Results

Table 1 presents the univariate statistics for variables tested in this study. The univariate statistics for the dependent variable reveal that all the three dependent variables vary substantially across different months. The univariate statistics for the key independent variable, the monthly average concentration level of $PM_{2.5}$, and other control variables reveal that data for those variables also vary substantially across different months. The skewness presented in Table 1 reveals that all variables in this study are normally distributed.

Table 1. Univariate Statistics

	Mean	SD	Minimum	Maximum	Skewness
Stillbirth Rate without lagging (per 1000 live births)	5.624	1.358	2.827	9.718	0.3134
Stillbirth Rate with 1-month lag (per 1000 live births)	5.593	1.401	2.827	9.718	0.2176
Stillbirth Rate with 2-month lag (per 1000 live births)	5.75	1.894	2.827	14.184	2.0166
Fine particulate matter ($PM_{2.5}$) (µg/m^3)	113.955	107.066	14	459	1.5172
Nitrogen Dioxide (NO_2) (µg/m^3)	120.368	57.606	28	270	0.5963
Ozone (O_3)	21.42	15.21	4	66	1.0635
Sulfur Dioxide (SO_2) (µg/m^3)	24.545	19.255	2	66	0.686
Respirable particulate matter (PM_{10}) (µg/m^3)	203.205	100.729	92	513	1.2142
Carbon Monoxide (CO) (µg/m^3)	1489.682	912.271	1	3593	0.5741
Monthly Average Temperatures (°C)	-0.555	15.163	-25.5	24.4	-0.1285

N=44[10]

Table 1 presents that the mean of the key independent variable, the average monthly concentration level of $PM_{2.5}$, is 113.955 µg/m^3. It is important to emphasize that this number is much higher than the air pollution level recommended by the WHO’s air quality guidelines (10 µg/m^3 annual mean, 25 µg/m^3 daily mean). The standard deviation for monthly concentration level of $PM_{2.5}$ is 107.066, with the minimum and maximum statistics between 14µg/m^3 and 459µg/m$^{3.}$ These statistics thus confirm that Ulaanbaatar is a city that is highly polluted by $PM_{2.5}$ and that the $PM_{2.5}$ concentration levels vary widely across months.

Table 2 present the correlation matrix for all variables tested in this analysis. I included the dependent variable with three different lag periods—no lag, 1-month lag, and 2-

[10] A few data of the control variables, including nitrogen dioxide, ozone, sulfur dioxide, PM_{10}, and carbon monoxide are accessed and calculated from a different air pollution monitoring station. The monthly average concentration level of $PM_{2.5}$ is still found significant excluding those data.

month lag. Monthly Stillbirth Rate (0) refers to the monthly stillbirth rate as characterized by data from July 2010 through February 2014 (consistent with all other variables in this analysis). Monthly Stillbirth Rate (1) refers to the monthly stillbirth rate with a 1-month lag from August 2010 through March 2014. Monthly Stillbirth Rate (2) refers to monthly stillbirth rate with a 2-month lag from September 2010 through April 2014. Comparing these three lags, the 1-month lagged monthly stillbirth rate (Monthly Stillbirth Rate (1)) has the strongest correlation to the monthly average concentration level of $PM_{2.5}$ (0.24). However, all of the lags have a positive correlation with the monthly average concentration level of $PM_{2.5}$. Table 2 also suggests that the key independent variable, monthly average $PM_{2.5}$ concentration level, has high positive correlations with sulfur dioxide (0.83), PM_{10} (0.85), and carbon monoxide (0.78) and is negatively correlated with monthly average temperature (-0.79), and that these other pollutants are also highly correlated with one another. Thus to avoid problems of multicollinearity, I will build my models in a step-wise fashion, where I only add one additional pollutant at a time to models including concentration levels of $PM_{2.5}$, NO_2, and O_3 (these latter two are not highly correlated with the independent variable).

Although the correlation between independent variable and control variables does not confirm the existence of multicollinearity among the variables, it demonstrates a high probability that multicollinearity could be an issue in this analysis. Multicollinearity occurs when two or more independent and control variables have a linear relationship. When multicollinearity exists in a model, the influence of the variables that are highly correlated with each other may be incorrectly reported by OLS regression analysis. In this study, for example, the concentration levels of PM_{10} are highly correlated with the concentration levels of $PM_{2.5}$, because PM_{10}, which refers to particles with a diameter of 10μm or less, contains $PM_{2.5}$, which refers to particles with a diameter 2.5μm or less. Thus, including the concentration level of both $PM_{2.5}$ and PM_{10} in the same model, in a sense, is similar to counting the influence of $PM_{2.5}$ twice, or separating the influence of $PM_{2.5}$ concentration levels into two difference variables. To address the potential problem of multicollinearity, I investigated six different models when testing each dependent variable; by investigating these different models, it allows me to investigate if adding control variables, which may cause potential multicollinearity problem, affects the OLS results. I now turn to presenting my key regression findings.

Table 2. Correlation Matrix

		(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
(1)	Monthly Stillbirth Rate (0)	1.00									
(2)	Monthly Stillbirth Rate (1)		1.00								
(3)	Monthly Stillbirth Rate (2)			1.00							
(4)	$PM_{2.5}$	0.10	0.24	0.16	1.00						
(5)	Nitrogen Dioxide	-0.06	-0.03	0.08	0.41	1.00					
(6)	Ozone	0.08	0.08	0.06	-0.41	-0.43	1.00				
(7)	Sulfur Dioxide	0.00	-0.02	0.15	0.83	0.32	-0.39	1.00			
(8)	PM_{10}	0.07	0.08	0.14	0.85	0.39	-0.47	0.80	1.00		
(9)	Carbon Monoxide	0.05	-0.07	0.24	0.78	0.28	-0.48	0.91	0.75	1.00	
(10)	Monthly Average Temperature	0.03	0.02	-0.13	-0.79	-0.55	0.56	-0.89	-0.81	-0.87	1.00

The regression results are presented in Table 3, Table 4, and Table 5. Table 3 presents the results of monthly stillbirth rate with no lag, Table 4 presents the results of monthly stillbirth rate with 1-month lag, and Table 5 presents the results of monthly stillbirth rate with 2-month lag. In each of these tables, Model 1 represents the baseline model that includes $PM_{2.5}$, NO_2, and O_3. Additional pollutants are added one at a time in models 2 through 4. Model 5 includes the monthly average temperature as an additional control variable to the baseline model. Model 6 represents the saturated model that includes all the variables tested in the analysis. In Table 3, 4 and 5 I reported standardized coefficients with flagging for statistical significance, unstandardized coefficients in parentheses, standard errors in italics, and variance inflation factors in brackets. Although some of the variance inflation factors (VIFs) in Model 2 through 5, which are represented in Table 3, 4 and 5, are beyond the conventional standard, all VIFs in Model 1 in all three tables are well within the conventional standards, with the highest VIF reported at 1.34.

Table 3 presents the results for examining the relationship between the monthly stillbirth rate and the $PM_{2.5}$ monthly concentration level without imposing any lag. The results presented in Table 3 illustrate no significant association between monthly stillbirth rates and monthly average concentration levels of $PM_{2.5}$. This suggests that exposure to $PM_{2.5}$ does not have an immediate effect on stillbirth. In addition, the results presented in Table 3 demonstrate that none of the other predictors were significant in impacting the monthly stillbirth rate immediately.

Table 3. OLS Regression Predicting the Effect of $PM_{2.5}$ Concentrations on Monthly Stillbirth Rate without lagging in Ulaanbaatar

	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
$PM_{2.5}$	.178	.370	.314	.289	.324	.257
	(.002)	(.005)	(.004)	(.003)	(.004)	(.003)
	.002	*.004*	*.004*	*.004*	*.003*	*.005*
	[1.31]	[3.53]	[4.78]	[4.82]	[2.72]	[4.92]
NO_2	-.081	-.093	-.095	-.069	-.033	.020
	(-.002)	(-.002)	(-.002)	(-.002)	(-.001)	(-.000)
	.004	*.004*	*.004*	*.004*	*.004*	*.006*
	[1.34]	[1.34]	[1.35]	[1.39]	[1.49]	[2.18]
O_3	.121	.103	.115	.171	.072	.144
	(.011)	(.009)	(.010)	(.015)	(.006)	(.012)
	.016	*.016*	*.017*	*.018*	*.017*	*.019*
	[1.34]	[1.36]	[1.42]	[1.63]	[1.50]	[1.70]
SO_2		-.234	-.262	-.524		-.372
		(-.016)	(-.018)	(-.037)		(-.026)
		.20	*.021*	*.032*		*.037*
		[3.30]	[3.63]	[8.21]		[10.55]
PM_{10}			.103	.109		.164
			(.001)	(.001)		(.002)
			.004	*.004*		*.005*
			[4.09]	[4.09]		[4.40]
CO				.319		.418
				(.000)		(.001)
				.001		*.001*
				[6.83]		[7.82]
Monthly Temperatures					.234	.334
					(.021)	(.030)
					.027	*.048*
					[3.64]	[11.24]
Constant	5.365	5.560	5.392	4.9757	5.121	4.9757
R^2	.0320	.0486	.0512	.0661	.0471	.0661

Notes: Standardized coefficients flagged for statistical significance; unstandardized coefficients reported in parentheses; standard errors reported in italics; VIFs reported in brackets.
*P<0.1 **P<0.05 ***P<0.01

Table 4 presents the findings of the OLS regression analysis testing the association between the monthly average concentration levels of $PM_{2.5}$ and monthly stillbirth rates with a 1-month lag. In contrast to the results of Table 3 (of no lag), the results presented in Table 4 suggest that $PM_{2.5}$ is a notable predictor of the monthly stillbirth rate one month after the exposure (i.e. with a 1-month lag). $PM_{2.5}$ has a positively and statistically significant association with the monthly stillbirth rates with a

1-month lag, when controlling for the concentration levels of other air pollution components and monthly average temperatures. In Model 1 for example, the monthly stillbirth rate in Ulaanbaatar goes up when the monthly average concentration level of $PM_{2.5}$ from the previous month goes up. The unstandardized coefficient at .005 in Model 1 means that when the monthly average concentration level increases by 1 $\mu g/m^3$, the stillbirth rate (per 1000 live births) increases by .005. For instance, the monthly average $PM_{2.5}$ concentration levels are 27 $\mu g/m^3$ and 428 $\mu g/m^3$ in July 2010 and December 2010. According to the results presented in Table 4, we would predict the monthly stillbirth rate in January 2011 (the following month of December 2010) to be 2‰ (=0.014×(428-27)) higher than the monthly stillbirth rate in August 2010 (the following month of July 2010).

Model 2 through Model 4 sequentially increase the number of pollutants, which are included in the analysis at their monthly average concentration levels. All three models of Model 2 through Model 4 suggest a positively and statistically significant association between the dependent variable, monthly stillbirth rates with 1-month lag, and the key independent variable, monthly concentration levels of $PM_{2.5}$ at .01 levels. Table 4 also indicates that there is a negatively and statistically significant association between 1-month lagged monthly stillbirth rates and monthly average concentration levels of SO_2 in Model 2 and Model 3. It is important to point out that because some VIFs of the independent and control variables are beyond the conventional standard, multicollinearity may exist in Model 2 through Model 4.

Table 4. OLS Regression Predicting the Effects of $PM_{2.5}$ Concentration levels on Monthly Stillbirth Rate with 1-month Lag in Ulaanbaatar

	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
$PM_{2.5}$	.358** (.005) *.002* [1.31]	.943*** (.012) *.003* [3.53]	1.028*** (.013) *.004* [4.82]	1.058*** (.014) *.004* [5.01]	.700*** (.009) *.003* [2.72]	1.094*** (.014) *.004* [4.29]
NO_2	-.091 (-.002) *.004* [1.34]	-.126 (-.003) *.004* [1.34]	-.123 (-.003) *.004* [1.35]	-.158 (-.004) *.004* [1.39]	.023 (.001) *.004* [1.49]	-.252 (-.006) *.005* [2.18]
O_3	.188 (.017) *.016* [1.34]	.133 (.012) *.015* [1.36]	.114 (.011) *.015* [1.43]	.046 (.004) *.016* [1.63]	.073 (.007) *.016* [1.50]	.076 (.007) *.017* [1.70]
SO_2		-.713*** (-.052) *3.3* [3.31]	-.669** (-.049) *.019* [3.63]	-.346 (-.025) *.029* [8.21]		-.512 (-.037) *.033* [10.55]
PM_{10}			-.155 (-.002) *.004* [4.09]	-.162 (-.002) *.003* [4.09]		-.221 (.003) *.004* [4.40]
CO				-.394 (-.001) *.001* [6.83]		-.502 (-.001) *.001* [7.82]
Monthly Temperatures					.549* (.051) *.025* [3.64]	.364* (-.034) *.043* [11.24]
Constant	4.955	5.568	5.827	6.357	4.367	7.221
R^2	.1045	.2582	.2641	.2826	.1873	.2986

Notes: Standardized coefficients flagged for statistical significance; unstandardized coefficients reported in parentheses; standard errors reported in italics; VIFs reported in brackets.
*P<0.1 **P<0.05 ***P<0.01

Model 5 added the monthly average temperatures as a control variable to the baseline presented in Model 1. The association between the monthly concentration levels of $PM_{2.5}$ and 1-month lagged monthly stillbirth rate in Ulaanbaatar remained statistically significant. Thus, although the monthly average $PM_{2.5}$ concentration levels change widely and correlate closely with temperature variation because of coal burning for heating in winters, the $PM_{2.5}$ concentration level still directly influences monthly stillbirth rates in the following month, even when taking into account seasonal variation in temperature.

Model 6 is the model that includes all tested independent variables and control variables in this study. With a significant association between 1-month lagged monthly stillbirth rates and monthly average concentration levels of $PM_{2.5}$, Model 6 can explain almost 30% of the variation of monthly stillbirth rate of the following month. The unstandardized coefficient of monthly concentration level of $PM_{2.5}$ in Model 6 is 0.014. Thus, when the average monthly $PM_{2.5}$ concentration level increases by 1 $\mu g/m^3$, the monthly stillbirth rate of the next month would rise by .014‰. For the months compared in Model 1, where the monthly average concentration levels at 27 $\mu g/m^3$ in July 2010 and 428 $\mu g/m^3$ in December 2010, we can predict that the monthly stillbirth rate in August 2010 would be about 5.61‰ (=0.014×(428-27)) higher than the monthly stillbirth rate in January 2011. In other words, we can predict from Model 6 that there will be 5 to 6 more stillbirths per 1000 live births in the month following a highly $PM_{2.5}$ polluted winter month than stillbirths per 1000 live births in the month following a summer month with a lower $PM_{2.5}$ concentration level. However, similar to Model 2 through Model 4, high VIFs in Model 6 also indicates potential existence of multicollinearity.

When adding more control variables of other air pollutants and temperature, the R^2 number and coefficient numbers both increase. The increasing R^2 number indicates that each model of Model 1 through Model 4, and the saturated Model 6, explains a bigger portion of the 1-month lagged monthly stillbirth rate variation. The increasing coefficient numbers suggest that monthly $PM_{2.5}$ concentration levels have a stronger influence on the 1-month lagged monthly stillbirth rates in the models including more control variables. For instance, the baseline model of Model 1 only explains 10.45% (R^2= .1045) of 1-month lagged monthly stillbirth rate variation, while the saturated Model 6 can explain 29.86% (R^2= .2986) of the variation. This makes sense because with more variables accounted for in the models, we would expect them to predict a bigger portion of the examined dependent variable, which is the 1-month lagged monthly stillbirth rate in Ulaanbaatar.

Table 5 reports the finding from a test of the impact of monthly average $PM_{2.5}$ concentration levels on monthly stillbirth rates with a 2-month lag. Table 5 reveals no statistically significant association between monthly average $PM_{2.5}$ concentration levels and 2-month lagged monthly stillbirth rates in Ulaanbaatar during the studied period. However, Table 5 suggests a positively and statistically significant association between 2-month lagged monthly stillbirth rates and monthly average concentration levels of O_3 at the 0.1 levels in Model 4. Table 5 also suggests a positively and statistically significant association between 2-month lagged monthly stillbirth rates and monthly average concentration levels of CO in both Model 4 and Model 6. Similar to the other regression analyses results revealed in Table 3 and Table 4, high VIFs indicate a potential existence of multicollinearity in Model 2 through Model 6 in Table 5.

Table 5. OLS Regression Predicting the Effect of $PM_{2.5}$ Concentration Levels on Monthly Stillbirth Rate with 2-month lag in Ulaanbaatar

	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
$PM_{2.5}$	.199	.115	.088	.024	.134	-.011
	(.003)	(.002)	(.002)	(.000)	(.002)	(.000)
	.003	*.005*	*.006*	*.006*	*.005*	*.006*
	[1.31]	[3.53]	[4.78]	[4.82]	[2.72]	[4.92]
NO_2	.072	.077	.076	.146	.050	.242
	(.002)	(.003)	(.003)	(.005)	(.002)	(.008)
	.006	*.006*	*.006*	*.006*	*.006*	*.007*
	[1.34]	[1.34]	[1.35]	[1.39]	[1.49]	[2.18]
O_3	.171	.179	.185	.329*	.193	.300
	(.021)	(.022)	(.023)	(.041)	(.024)	(.037)
	.022	*.023*	*.023*	*.024*	*.024*	*.025*
	[1.34]	[1.36]	[1.42]	[1.63]	[1.50]	[1.70]
SO_2		.103	.090	-.596		-.431
		(.010)	(.009)	(-.059)		(-.042)
		.028	*.030*	*.043*		*.049*
		[3.30]	[3.63]	[8.21]		[10.55]
PM_{10}			.048	.063		.122
			(.001)	(.001)		(.002)
			.006	*.006*		*.006*
			[4.09]	[4.09]		[4.40]
CO				.836**		.943**
				(.002)		(.002)
				.001		*.001*
				[6.83]		[7.82]
Monthly Temperatures					-.106	.362
					(-.013)	(.045)
					.037	*.064*
					[3.64]	[11.24]
Constant	4.607	4.487	4.378	2.857	4.760	1.696
R^2	.0470	.0502	.0508	.1531	.0501	.1648

Notes: Standardized coefficients flagged for statistical significance; unstandardized coefficients reported in parentheses; standard errors reported in italics; VIFs reported in brackets.
*P<0.1 **P<0.05 ***P<0.01

Overall, the findings from Table 3 through Table 5 confirm my hypothesis that an increase of monthly average $PM_{2.5}$ concentration levels will be associated with an increase in stillbirths when controlling for other common ambient air pollutants and temperature. Specifically, the data reveal that among the three lags (no lag, 1-month and 2-month lag), a 1-month lag best describes the correlation between monthly average fine particulate matter ($PM_{2.5}$) concentration levels and monthly stillbirth rates. As such, the data confirms that the monthly average concentration level of $PM_{2.5}$ is an important predictor of the 1-month lagged monthly stillbirth rate in the city of Ulaanbaatar between July 2010 and April 2014. This means that the last month of pregnancy before delivery or stillbirth is a critical window that defines the vulnerability of fetuses whose mothers are exposed to high $PM_{2.5}$ concentration levels. In other words, pregnant women that are exposed to a higher $PM_{2.5}$ concentration level during their last month of pregnancy are more likely to experience stillbirth than pregnant women who are exposed to a lower $PM_{2.5}$ concentration level during their last month of pregnancy.

For the city of Ulaanbaatar, where the $PM_{2.5}$ concentration levels vary largely according to the burning activities in the ger areas, this research has particular implications. Women whose last month of pregnancy is during the winter, when the households in ger areas burn large amounts of coal for heating, and $PM_{2.5}$ concentration levels are higher, are more likely to have stillborn babies than women whose last month of pregnancy is during the summer, when there is much less coal burning going on in ger areas and the $PM_{2.5}$ concentration levels are lower. It is important to point out that stillbirths, as well as live births, can happen anytime between the 23rd and 40th week pregnancy (i.e. usually the expected delivery date). When I say the last month of pregnancy is a critical window, I do not mean that the 35th through the 40th week of pregnancy is the critical time of vulnerability (i.e. which is the last month of pregnancy for a full term pregnancy). By critical window, I mean the last month of pregnancy before the child's actual birth or stillbirth, wherever that may fall after the 22nd week of pregnancy.

Discussion

In assessing the relationship between fine particulate matter air pollution and the incidence of stillbirth in Ulaanbaatar, Mongolia, I found a positively and statistically significant association between monthly stillbirth rate with 1-month lag and monthly average concentration levels of $PM_{2.5,}$ while controlling for other ambient air pollutants and temperature. The monthly stillbirth rate in Ulaanbaatar is positively associated with the monthly average concentration level of $PM_{2.5}$ in the preceding month. I found no statistically significant association between monthly average concentration levels of $PM_{2.5}$ and monthly stillbirth rate with either no lag or a 2-month lag. This suggests that the entire month preceding the occurrence of stillbirth should be assessed as a critical window during which pregnant women who are exposed to high levels of $PM_{2.5}$ are at an increased risk of have a stillborn child. Thus, while the New Jersey studies found an acute association between stillbirth and an increase of in $PM_{2.5}$ concentrations just a few days before stillbirth occurs, the research in the present study suggests that particulate matter pollution exposure during the entire final month of pregnancy may influence the likelihood of stillbirth.

Several features of this study make it unique. Unlike the second New Jersey study, which used individual data that included the exact dates on which stillbirths occurred and the mothers' $PM_{2.5}$ exposure during several days prior to stillbirths, I use aggregate data on stillbirth rates and calendar months. Individual data, such as which day of the month a stillbirth occurs and the mothers' socio-economic status, cannot change the stillbirth rates of each natural month. Thus, by using monthly data, this research is able to solely investigate which lag (no lag, 1-month, or 2-month lag) best describes the association between $PM_{2.5}$ concentrations and stillbirth rate and eliminates potential confounding socio-economic factors that may influence the nature of the association between $PM_{2.5}$ exposure and stillbirth. Additionally, no study has yet examined if the association between particulate matter pollution and stillbirth exists on monthly basis except the present one. Moreover, this study is conducted in Ulaanbaatar, which is the capital city with high $PM_{2.5}$ pollution of a low-income country. Thus, the result of present study adds to the growing body of literature by studying a distinct interval basis and important location.

When interpreting the results of present study, certain limitations in the analysis should be considered. Firstly, the models can only explain 10.5% to 30% of why stillbirths happen following a month of high $PM_{2.5}$ exposure. Many variables that may also predict the fluctuation of stillbirth rate are not included here. These variables have the potential to explain a larger percent of monthly stillbirth rate fluctuation when added to the models in this study. For example, variables that may be influenced by temperature variation such as prenatal care, access to doctors, and access to clean water and nutrition are particularly important in this context. Although additional socioeconomic factors like maternal age, income, mother's education level, and perinatal care are not controlled here (as this data represents monthy time-series estimates), future study should include socioeconomic factors that can be compared across individuals.

Secondly, the average $PM_{2.5}$ concentration level for each month is gathered from the No. 2 government air pollution monitoring station, which is the only air pollution monitoring station among 10 in Ulaanbaatar that gathered $PM_{2.5}$ concentration levels during observed period in the city of Ulaanbaatar. Thus, the monthly $PM_{2.5}$ concentration level does not tell us about inter-individual variation in individual $PM_{2.5}$ exposure. To address this and the limitation previously discussed, further studies are suggested, especially those using individual level data for accurate exposure measurement and socio-economic control variables.

Lastly, in this study, some ambient pollutants already known to be significantly associated with stillbirths were not found to influence stillbirths, including PM_{10} (Hwang et al., 2011), NO_2 (Faiz et al., 2012, 2013), SO_2 (Hwang et al., 2011; Faiz et al., 2012, 2013), and CO (Faiz et al., 2012, 2013). This may because of the unique characteristics of Ulaanbaatar: for example, this city has extremely high concentrations of particulate matter, cold temperatures and a high altitude. However, further studies should investigate the relationship between stillbirth and other ambient air pollutants, as well how the association between different air pollutants (e.g. the influence of SO_2 concentrations on $PM_{2.5}$ concentrations) influences overall air pollution concentrations and stillbirths.

To Summarize: The primary finding of this study is that increased monthly average $PM_{2.5}$ concentration levels are positively associated with the following month's stillbirth rates. Further studies with that use individual-level hospital records, information on socio-economic status, and more individually specific air pollution exposure measurement should be carried out to confirm and further refine these findings and also to investigate the role of air pollution in other important critical windows for risk of stillbirth, such as the beginning period of pregnancy.

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