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Air pollution: A systematic review of its psychological, economic, and social effects

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This review (178 published articles) is the first to systematically examine the psychological (affective, cognitive, behavioral), economic, and social effects of air pollution *beyond* its physiological and environmental effects. Affectively, air pollution decreases happiness and life satisfaction, and increases annoyance, anxiety, mental disorders, self-harm, and suicide. Cognitively, it impairs cognitive functioning and decision making. Behaviorally, air pollution triggers avoidance behavior, defensive expenditure, and migration as coping strategies. Economically, it hurts work productivity and stock markets. Socially, it exacerbates criminal activities and worsens perception of the government. Importantly, both actual and perceived air pollution levels matter. Limitations of past research and future directions are discussed.

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Air pollution is a grave problem that impacts billions of people across the globe. For example, it is the primary cause of death in India, killing over 1.6 million people a year [1]. According to the Environmental Protection Agency (EPA), in 2017 about 111 million Americans (about 35% of the U.S. population) were living in counties with unhealthy air [2]. Along with the rise of social ecology, social science research on air pollution has been proliferating in recent decades. However, there has yet to be a systematic review of its psychological (affective, cognitive, behavioral), economic, and social effects beyond its physiological and environmental effects.

The present review surveyed 178 published papers in English. The literature search was conducted in the following databases: Google Scholar, PsycINFO, ProQuest, PubMed, Science Direct, Scopus, and Web of Science. Moreover, the corresponding authors of these papers were contacted to ensure that no relevant or unpublished papers had been overlooked. Table 1 presents the papers by category, outcome, and year. Importantly, it details both the pollutants measured and the pollutants found to have a significant effect.

Air pollution is a mixture of particulate matter (e.g. $PM_{2.5}$, PM_{10}), gases (e.g. carbon monoxide [CO], nitrogen dioxide [NO_2], ozone [O_3], sulfur dioxide [SO_2]), organic compounds (e.g. polycyclic aromatic hydrocarbon [PAH]), and metals (e.g. lead). Composite measures include the air pollution index (API) and air quality index (AQI). As shown in Table 1, $PM_{2.5}$ and PM_{10} were the most widely studied pollutants.

Psychological effects

Happiness and life satisfaction (subjective well-being)

A wealth of research shows that air pollution negatively predicts people's happiness and life satisfaction. This effect has been observed across the world, including Australia [3], Canada [4], China [5–9,10••], USA [11], and Europe [12–23]. While most studies relied on self-report measures of happiness and life satisfaction, recent research has begun to leverage unobtrusive social media data. For example, through an analysis of 210 million geotagged Weibo tweets in China, Zheng *et al.* [10••] revealed that air pollution was associated with lower happiness expressed in tweets. Importantly, analyzing data from 48 countries (1990–2006), Menz [24] estimated that people's life satisfaction generally does not habituate to air pollution over time.

Annoyance, anxiety, mental disorders, self-harm, and suicide

Air pollution is also associated with increased annoyance [25–29] and anxiety [30–37,38•]. For example, in an assessment of 71,271 elderly women, Power *et al.* [33] found that exposure to $PM_{2.5}$ — especially recent exposure — predicted increased anxiety symptoms. Physiologically, exposure to air pollutants can trigger anxiety by increasing oxidative stress and systemic inflammation [39]. Psychologically, perceived air pollution can trigger existential anxiety about one's health and future [38•].

More devastatingly, air pollution is associated with increased mental disorders, such as depression [7,34,35,40–55], schizophrenia [56,57], and autism [58–65]. In addition to self-report measures of depression [7,34,35,49,41–55], several studies have leveraged

Table 1

Published studies on the psychological, economic, and social effects of air pollution

Category	Outcome	Author(s), year	Pollutants measured	Pollutants with significant effects	Location
Psychological (affective)	Happiness and life satisfaction	Welsch [12]	NO_2, Pb, TSP	NO_2, Pb	10 European countries
		Di Tella and MacCulloch [13]	SO_x	SO_x	12 OECD countries
		Rehdanz and Maddison [16]	Perceived pollution	Perceived pollution	Germany
		Smyth *et al.* [5]	SO_2	SO_2	China (30 cities)
		Luechinger [17]	SO_2	SO_2	Germany (445 counties)
		MacKerron and Mourato [18]	NO_2, PM_{10}, perceived pollution	NO_2, PM_{10}, perceived pollution	UK (London)
		Ferreira and Moro [19]	PM_{10}	PM_{10}	Ireland
		Menz [24]	PM_{10}	PM_{10}	48 countries
		Levinson [11]	PM_{10}	PM_{10}	USA (10,193 counties)
		Menz and Welsch [20]	NO_2, SO_2	NO_2, SO_2	10 European countries
		Ferreira *et al.* [21]	SO_2	SO_2	23 European countries (248 regions)
		Ambrey *et al.* [3]	PM_{10}	PM_{10}	Australia (South East Queensland)
		Dolan and Laffan [22]	$PM_{2.5}$	$PM_{2.5}$	UK
		Giovanis and Ozdamar [23]	CO, NO_2, O_3, PM_{10}, SO_2	CO, NO_2, O_3, PM_{10}, SO_2	Switzerland
		Orru *et al.* [14]	PM_{10}	PM_{10}	Estonia
		Xu and Li [6]	Perceived pollution	Perceived pollution	China
		Barrington-Leigh and Behzadnejad [4]	CO, NO_2, $PM_{2.5}$, SO_2	SO_2	Canada
		Ozdamar and Giovanis [15]	CO, NO_x, O_3,	NO_x, O_3	UK
		Zhang *et al.* [7]	API (NO_2, PM_{10}, SO_2)	API (NO_2, PM_{10}, SO_2)	China (162 counties)
		Zhang *et al.* [8]	CO, NO_2, O_3, $PM_{2.5}$, PM_{10}, SO_2	$PM_{2.5}$	China (162 counties)
		Yuan *et al.* [9]	AQI	AQI	China (281 cities)
		Zheng *et al.* [10••]	AQI, $PM_{2.5}$	AQI, $PM_{2.5}$	China (144 cities)
	Annoyance and anxiety	Rotko *et al.* [25]	NO_2, $PM_{2.5}$	NO_2, $PM_{2.5}$	Athens, Basel, Milan, Oxford, Prague, Helsinki
		Jacquemin *et al.* [26]	$PM_{2.5}$, S	$PM_{2.5}$, S	12 European countries (25 centers)
		Modig and Forsberg [27]	NO_2	NO_2	Sweden (Umeå; Uppsala; Gothenburg)
		Llop *et al.* [28]	NO_2	NO_2	Spain (Valencia)
		Heaney *et al.* [30]	H_2S from landfill	H_2S from landfill	USA (Orange County, North Carolina)
		Claeson *et al.* [29]	Perceived pollution, odorants	Perceived pollution	Sweden (Värnamo)
		Cho *et al.* [31]	CO, NO_2, O_3, PM_{10}, SO_2	O_3	South Korea (Seoul)
		Mehta *et al.* [32]	Black carbon, NO_2, O_3, $PM_{2.5}$, particle number counts, SO_4^{2-}	Black carbon, NO_2, $PM_{2.5}$, particle number counts	USA (Greater Boston area, Massachusetts)
		Power *et al.* [33]	$PM_{2.5}$, $PM_{2.5\text{-}10}$	$PM_{2.5}$	USA (48 continental states)
		Lin *et al.* [34]	NO_2, PM_{10}, SO_2	NO_2, PM_{10}, SO_2	China (Shanghai)
		Pun *et al.* [35]	$PM_{2.5}$	$PM_{2.5}$	USA
		Sass *et al.* [36]	$PM_{2.5}$	$PM_{2.5}$	USA
		Vert *et al.* [53]	NO_2, NO_x, $PM_{2.5}$, $PM_{2.5}$ absorbance, PM_{10}, PM_{coarse}	n.s.	Spain (Barcelona)

Table 1 (*Continued*)

Category	Outcome	Author(s), year	Pollutants measured	Pollutants with significant effects	Location
		Xu *et al.* [37]	Perceived haze	Perceived haze	China (Nanjing, Jiangsu Province)
		Lu *et al.* [38*]	Perceived pollution	Perceived pollution	USA (9360 cities)
	Mental disorders	Pedersen *et al.* [56]	Benzene, CO, NO_x, NO_2	Benzene, CO	Denmark
		Szyszkowicz [40]	CO, NO_2, O_3, $PM_{2.5}$, PM_{10}, SO_2	Warm season: CO, NO_2, SO_2, O_3; cold season: $PM_{2.5}$, PM_{10}	Canada (Edmonton, Alberta)
		Szyszkowicz *et al.* [41]	CO, NO_2, O_3, $PM_{2.5}$, PM_{10}, SO_2	CO, NO_2, PM_{10}, SO_2	Canada (Edmonton; Halifax; Montreal; Ottawa; Toronto; Vancouver)
		Szyszkowicz [42]	SO_2	SO_2	Canada (Toronto)
		Szyszkowicz and Tremblay [43]	CO, NO_2, SO_2	NO_2, SO_2	Canada (Edmonton, Alberta)
		Lim *et al.* [49]	CO, NO_2, O_3, PM_{10}, SO_2	NO_2, O_3, PM_{10}	South Korea (Seoul)
		Becerra *et al.* [58]	CO, NO, NO_2, O_3, $PM_{2.5}$, PM_{10}	NO, NO_2, O_3, $PM_{2.5}$	USA (Los Angeles)
		Volk *et al.* [59]	NO_2, O_3, $PM_{2.5}$, PM_{10}, traffic-related pollution	NO_2, $PM_{2.5}$, PM_{10}, traffic-related pollution	USA (California)
		Cho *et al.* [44]	CO, NO_2, O_3, PM_{10}, SO_2	CO, NO_2, PM_{10}, SO_2	South Korea (Seoul)
		Gong *et al.* [60]	NO_x, PM_{10}	n.s.	Sweden (Stockholm)
		Kalkbrenner *et al.* [61]	PM_{10}	PM_{10}	USA (North Carolina; California)
		Raz *et al.* [62]	$PM_{2.5}$, $PM_{2.5\text{-}10}$	$PM_{2.5}$	USA
		Talbott *et al.* [63]	$PM_{2.5}$	$PM_{2.5}$	USA (southwestern Pennsylvania)
		Kim *et al.* [45]	$PM_{2.5}$	$PM_{2.5}$	South Korea
		Szyszkowicz *et al.* [46]	NO_2, O_3, $PM_{2.5}$, SO_2	NO_2, O_3, $PM_{2.5}$, SO_2	Canada (9 urban areas in Ontario)
		Zijlema *et al.* [47]	NO_2, $PM_{2.5}$, $PM_{2.5}$ absorbance, PM_{10}	n.s.	Finland, Germany, Netherlands, Norway
		Gao *et al.* [57]	CO, NO_2, O_3, $PM_{2.5}$, $PM_{2.5\text{-}10}$, PM_{10}, SO_2	$PM_{2.5}$, $PM_{2.5\text{-}10}$, PM_{10}	China (Beijing)
		Ha [50]	$PM_{2.5}$	$PM_{2.5}$	USA (48 contiguous states)
		Kioumourtzoglou *et al.* [51]	O_3, $PM_{2.5}$	O_3, $PM_{2.5}$	USA (48 continental states)
		Lin *et al.* [52]	$PM_{2.5}$	$PM_{2.5}$	China, Ghana, India, Mexico, Russia, South Africa
		Lin *et al.* [34]	NO_2, PM_{10}, SO_2	SO_2	China (Shanghai)
		Pun *et al.* [35]	$PM_{2.5}$	$PM_{2.5}$	USA
		Raz *et al.* [65]	NO_2	NO_2	Israel (central costal area)
		Vert *et al.* [53]	NO_2, NO_x, $PM_{2.5}$, $PM_{2.5}$ absorbance, PM_{10}, PM_{coarse}	NO_2, NO_x, $PM_{2.5}$, $PM_{2.5}$ absorbance, PM_{10}	Spain (Barcelona)
		Zhang *et al.* [7]	API (NO_2, PM_{10}, SO_2)	API (NO_2, PM_{10}, SO_2)	China (162 counties)
		Chen *et al.* [48]	CO, NO_2, O_3, $PM_{2.5}$, PM_{10}, SO_2	CO, PM_{10}, SO_2	China (Shanghai)
		Kerin *et al.* [64]	NO_2, O_3, $PM_{2.5}$, PM_{10}, near-roadway pollution	NO_2	USA (California)
		Oudin *et al.* [183]	NO_2, O_3, PM_{10}	PM_{10} (during warm season)	Sweden (Gothenburg)
		Shin *et al.* [54]	CO, NO_2, PM_{10}, SO_2	CO, NO_2, PM_{10}	South Korea
		Wang *et al.* [55]	$PM_{2.5}$	$PM_{2.5}$	China (158 prefectures)
	Self-harm and suicide	Biermann *et al.* [68]	O_3	O_3	Germany (Middle Franconia, Bavaria)
		Kim *et al.* [69]	$PM_{2.5}$, PM_{10}	$PM_{2.5}$, PM_{10}	South Korea (Seoul; Busan; Incheon; Daejeon; Daegu; Gwangju; Ulsan)

Table 1 (*Continued*)

Category	Outcome	Author(s), year	Pollutants measured	Pollutants with significant effects	Location
		Szyszkowicz *et al.* [72]	CO, NO_2, O_3, $PM_{2.5}$, PM_{10}, SO_2	CO, NO_2, $PM_{2.5}$, PM_{10}, SO_2 (for cold period)	Canada (Vancouver)
		Yang *et al.* [73]	CO, NO_x, O_3, PM_{10}, SO_2	CO, O_3, PM_{10}, SO_2	Taipei City
		Bakian *et al.* [74]	NO_2, $PM_{2.5}$, PM_{10}, SO_2	NO_2, $PM_{2.5}$	USA (Salt Lake County, Utah)
		Kim *et al.* [75]	CO, NO_2, O_3, PM_{10}, SO_2	O_3, PM_{10}	South Korea (16 administrative regions)
		Lin *et al.* [76]	NO_2, PM_{10}, SO_2	NO_2, PM_{10}, SO_2 (cool seasons only)	China (Guangzhou, Guangdong Province)
		Ng *et al.* [77]	NO_2, $PM_{2.5}$, SO_2, SPM	NO_2, $PM_{2.5}$, SO_2	Japan (Tokyo)
		Casas *et al.* [78]	O_3, PM_{10}	O_3, PM_{10}	Belgium
		Liu *et al.* [67]	CO, NO_2, O_3, $PM_{2.5}$, SO_2	CO, O_3, $PM_{2.5}$	China (Jiangsu Province)
		Kim *et al.* [79]	NO_2, $PM_{2.5}$, $PM_{2.5\text{-}10}$, PM_{10}, SO_2	NO_2, $PM_{2.5\text{-}10}$, PM_{10}, SO_2	10 Cities in Northeast Asia
		Lee *et al.* [70]	CO, NO_2, O_3, PM_{10}, SO_2	CO, NO_2, PM_{10}, SO_2	South Korea (26 cities)
		Min *et al.* [71]	NO_2, PM_{10}, SO_2	NO_2, PM_{10}, SO_2	South Korea
		Szyszkowicz *et al*. [66]	CO, NO_2, O_3, $PM_{2.5}$, PM_{10}, SO_2	CO, NO_2, $PM_{2.5}$, PM_{10}	Canada (Edmonton, Alberta)
Psychological (cognitive)	Cognitive functioning (prenatal)	Perera *et al.* [80]	PAHs	PAHs	USA (New York City, New York)
		Perera *et al.* [81]	PAHs	PAHs	USA (New York City, New York)
		Edwards *et al.* [84]	PAHs	PAHs	Poland (Krakow)
		Sanders [85]	TSP	TSP	USA (Texas)
		Vrijheid *et al.* [86]	Gas cooking	Gas cooking	Spain
		Guxens *et al.* [87]	NO_2, NO_x, $PM_{2.5}$, PM_{10}, PM_{coarse}	NO_2, $PM_{2.5}$	France, Germany, Greece, Italy, Netherlands, Spain
		Harris *et al.* [88]	Black carbon, $PM_{2.5}$, residential proximity to major roadways, near-residence traffic density	Residential proximity to major roadways, near-residence traffic density	USA (Massachusetts)
		Jedrychowski *et al.* [89]	PAHs	PAHs	Poland (Krakow)
		Lertxundi *et al.* [90]	NO_2, $PM_{2.5}$, benzene	NO_2, $PM_{2.5}$	Spain (Guipúzcoa)
		Yorifuji *et al.* [91]	NO_2, SPM, SO_2	NO_2, SPM, SO_2	Japan
		Bharadwaj *et al.* [82]	AQI (CO, O_3, PM_{10})	AQI (CO, O_3, PM_{10})	Chile (Santiago)
		Isen *et al.* [83]	TSP	TSP	USA
	Cognitive functioning (children and youths)	Coscia *et al.* [92]	Pb	Pb	USA (Cincinnati, Ohio)
		Braun *et al.* [123]	Pb	Pb	USA
		Pastor *et al.* [100]	Respiratory hazard ratio	Respiratory hazard ratio	USA (Los Angeles, California)
		Suglia *et al.* [102]	Black carbon	Black carbon	USA (Boston, Massachusetts)
		Calderón-Garcidueñas *et al.* [101]	O_3, $PM_{2.5}$, PM_{10}	O_3, $PM_{2.5}$, PM_{10}	Mexico (Mexico City; Polotitlán)
		Tang *et al.* [103]	Hg, PAHs, Pb	PAHs, Pb	China (Chongqing)
		Froehlich *et al.* [124]	Pb	Pb	USA
		Morales *et al.* [104]	NO_2	NO_2	Spain (Menorca)
		Wang *et al.* [105]	NO_2	NO_2	China (Quanzhou, Fujian Province)
		Freire *et al.* [106]	NO_2	n.s.	Spain (Granada)

Table 1 (*Continued*)

Category	Outcome	Author(s), year	Pollutants measured	Pollutants with significant effects	Location
		Mohai *et al.* [107]	EPA's risk-screening environmental indicator	EPA's risk-screening environmental indicator	USA (Michigan)
		Siddique *et al.* [125]	NO_x, PM_{10}, SO_x	PM_{10}	India (Delhi)
		van Kempen *et al.* [93]	NO_2	NO_2	Netherlands (Amsterdam)
		Chiu *et al.* [94]	Black carbon	Black carbon	USA (Boston, Massachusetts)
		Harris *et al.* [88]	Black carbon, $PM_{2.5}$, residential proximity to major roadways, near-residence traffic density	Residential proximity to major roadways, near-residence traffic density	USA (Massachusetts)
		Kicinski *et al.* [95]	Traffic exposure	Traffic exposure	Belgium (Flanders)
		Stafford [96]	Indoor air quality	Indoor air quality	USA (Texas)
		Sunyer *et al.* [97]	Elemental carbon, NO_2, UFP	Elemental carbon, NO_2, UFP	Spain (Barcelona)
		Ebenstein *et al.* [98•]	$PM_{2.5}$	$PM_{2.5}$	Israel
		Min and Min [129]	NO_2, PM_{10}	NO_2, PM_{10}	South Korea
		Wang *et al.* [99]	$PM_{2.5}$	$PM_{2.5}$	USA (Los Angeles)
	Cognitive functioning (young and old adults)	Sun and Gu [108]	API (CO, NO_2, O_3, PM_{10}, SO_2)	API (CO, NO_2, O_3, PM_{10}, SO_2)	China (171 cities)
		Chen and Schwartz [109]	O_3, PM_{10}	O_3	USA
		Ranft *et al.* [115]	PM_{10}, residential distance to the next busy road	Residential distance to the next busy road	Germany (the Ruhr area)
		Zeng *et al.* [116]	API	API	China (866 counties)
		Power *et al.* [117]	Black carbon	Black carbon	USA (Greater Boston area, Massachusetts)
		Wellenius *et al.* [118]	Residential distance to the nearest major roadway	Residential distance to the nearest major roadway	USA (Boston, Massachusetts)
		Weuve *et al.* [119]	$PM_{2.5}$, $PM_{2.5\text{-}10}$, PM_{10}	$PM_{2.5}$, $PM_{2.5\text{-}10}$	USA
		Loop *et al.* [184]	$PM_{2.5}$		USA (48 states)
		Ailshire and Crimmins [121]	$PM_{2.5}$	$PM_{2.5}$	USA
		Ailshire and Clarke [120]	$PM_{2.5}$	$PM_{2.5}$	USA
		Gatto *et al.* [122]	NO_2, O_3, $PM_{2.5}$	$PM_{2.5}$	USA (Los Angeles, California)
		Tonne *et al.* [110]	$PM_{2.5}$, PM_{10}	$PM_{2.5}$, PM_{10}	UK (London)
		Schikowski *et al.* [111]	NO_2, NO_x, $PM_{2.5}$, $PM_{2.5}$ absorbance, PM_{10}	NO_2, NO_x, $PM_{2.5}$, $PM_{2.5}$ absorbance, PM_{10}	Germany (Southern Muensterland)
		Kioumourtzoglou *et al.* [112]	$PM_{2.5}$	$PM_{2.5}$	USA (50 northeastern cities)
		Oudin *et al.* [126]	NO_x	NO_x	Sweden (Umeå)
		Cacciottolo *et al.* [127]	$PM_{2.5}$	$PM_{2.5}$	USA (48 states)
		Chen *et al.* [128]	NO_2, $PM_{2.5}$	NO_2, $PM_{2.5}$	Canada (Ontario)
		Zhang *et al.* [113••]	API (NO_2, PM_{10}, SO_2)	API (NO_2, PM_{10}, SO_2)	China (162 counties)
		Heyes *et al.* [114]	$PM_{2.5}$	$PM_{2.5}$	Canada (Ottawa)
	Decision making	Archsmith *et al.* [131]	CO, O_3, $PM_{2.5}$	CO, $PM_{2.5}$	USA
		Huang *et al.* [133]	AQI (CO, NO_2, O_3, $PM_{2.5}$, PM_{10}, SO_2)	AQI (CO, NO_2, O_3, $PM_{2.5}$, PM_{10}, SO_2)	China (34 cities)
		Dong *et al.* [130]	AQI	AQI	China (105 cities)

Table 1 (*Continued*)

Category	Outcome	Author(s), year	Pollutants measured	Pollutants with significant effects	Location
Psychological (behavioral)	Avoidance behavior	Bresnahan *et al.* [134]	CO, NO_2, O_3, SO_2	O_3	USA (Los Angeles, California)
		Mansfield *et al.* [135]	AQI	AQI	USA (35 metropolitan areas)
		Currie *et al.* [142]	CO, O_3, PM_{10}	CO	USA (Texas)
		Graff Zivin and Neidell [136]	O_3 alert	O_3 alert	USA (Southern California)
		Neidell [140]	O_3 alert	O_3 alert	USA (Southern California)
		Wen *et al.* [137]	AQI alert	AQI alert	USA (Colorado; Florida; Indiana; Kansas; Massachusetts; Wisconsin)
		Moretti and Neidell [138]	O_3	O_3	USA (Los Angeles, California)
		Noonan [141]	O_3 alert	O_3 alert	USA (Atlanta, Georgia)
		Hales *et al.* [143]	$PM_{2.5}$, PM_{10}	$PM_{2.5}$, PM_{10}	USA (Utah)
		Saberian *et al.* [139]	AQI alert	AQI alert	Australia (Sydney)
		Liu and Salvo [144]	$PM_{2.5}$	$PM_{2.5}$	China (a major urban center)
	Defensive expenditure	Sun *et al.* [145]	$PM_{2.5}$	$PM_{2.5}$	China
		Chang *et al.* [148*]	AQI	AQI	China
		Liu *et al.* [147]	$PM_{2.5}$ alert	$PM_{2.5}$ alert	China (Beijing; Tianjin; Shanghai; Guangzhou; Chengdu; Chongqing; Shenyang; Xi'an)
		Zhang and Mu [146]	AQI	AQI	China (190 cities)
	Migration	Kahn [185]	O_3	O_3	USA (California counties)
		Lu *et al.* [149]	Smog risk perception	Smog risk perception	China (Beijing–Tianjin–Hebei region)
		Qin and Zhu [150]	AQI	AQI	China (153 cities)
Economic	Work productivity (absenteeism)	Ostro [151]	Sulfate, TSP	TSP	USA (84 metropolitan statistical areas)
		Hansen and Selte [152]	NO_2, PM_{10}, SO_2,	PM_{10}	Norway (Oslo)
		Hanna and Oliva [153]	SO_2	SO_2	Mexico (Mexico City)
		Aragón *et al.* [154]	NO_2, $PM_{2.5}$, PM_{10}, SO_2	NO_2, $PM_{2.5}$	Peru (Lima)
		Jans *et al.* [155]	PM_{10}	PM_{10}	Sweden
	Work productivity (presenteeism)	Graff Zivin and Neidell [156]	O_3	O_3	USA (Central Valley, California)
		Chang *et al.* [157]	$PM_{2.5}$	$PM_{2.5}$	USA (Northern California)
		Chang *et al.* [158*]	API	API	China (Shanghai; Nantong, Jiangsu Province)
		He *et al.* [159]	$PM_{2.5}$, SO_2	$PM_{2.5}$, SO_2	China (Henan Province; Jiangsu Province)
	Stock markets	Levy and Yagil [160]	AQI	AQI	USA (New York; Philadelphia)
		Levy and Yagil [165]	AQI	AQI	Australia, Canada, China, Netherlands, USA
		Demir and Ersan [164]	PM_{10}	PM_{10}	Turkey (Istanbul; Ankara; Izmir)
		Lepori [163]	PM, NO_x, SO_2	PM, NO_x, SO_2	Italy (Milan)
		Li and Peng [161]	AQI	AQI	China
		He and Liu [162]	AQI	AQI	China (Shanghai)
Social	Crime and unethical behavior	Nevin [166]	Pb	Pb	USA
		Dietrich *et al.* [170]	Pb	Pb	USA (Cincinnati, Ohio)
		Stretesky and Lynch [171]	Pb	Pb	USA (all counties in the contiguous 48 states)
		Gong *et al.* [172]	AQI, perceived pollution	AQI, perceived pollution	China
		Nevin [173]	Pb	Pb	Australia, Canada, Finland, France, West Germany, Italy, New Zealand, UK, USA

Table 1 (*Continued*)

Category	Outcome	Author(s), year	Pollutants measured	Pollutants with significant effects	Location
		Reyes [174]	Pb	Pb	USA (50 states and DC)
		Haynes *et al.* [175]	Hg, Mn, Pb, $PM_{2.5}$, PM_{10}	Hg, Mn, $PM_{2.5}$, PM_{10}	USA (all 88 Ohio counties)
		Reyes [176]	Pb	Pb	USA (50 states and DC)
		Fehr *et al.* [177•]	$PM_{2.5}$, perceived pollution	Perceived pollution	China (Wuhan, Hubei Province)
		Lu *et al.* [38•]	Composite (CO, NO_2, $PM_{2.5}$, PM_{10}, SO_2, TSP),	Composite (CO, NO_2, $PM_{2.5}$, PM_{10}, SO_2, TSP), perceived pollution	USA (9360 cities)
		Younan *et al.* [167]	$PM_{2.5}$	$PM_{2.5}$	USA (Southern California)
		Burkhardt *et al.* [168]	O_3, $PM_{2.5}$	O_3, $PM_{2.5}$	USA
	Perception of the government	Huang *et al.* [181]	NO, N_2O, PM_{10}, SO_2, dust, smoke, perceived pollution	PM_{10}, dust, smoke, perceived pollution	China (36 cities) and 56 countries
		Shi and Guo [180]	AQI	AQI	China (157 cities)

Pollutant abbreviations: API, air pollution index; AQI, air quality index; CO, carbon monoxide; H_2S, hydrogen sulfide; Hg, mercury; Mn, manganese; NO, nitric oxide; NO_2, nitrogen dioxide; NO_x, nitrogen oxides; N_2O, nitrous oxide; O_3, ozone; PAH, polycyclic aromatic hydrocarbons; Pb, lead; PM, particulate matter; PM_{10}, particulate matter with an aerodynamic diameter less than 10 μm; $PM_{2.5}$, particulate matter with an aerodynamic diameter less than 2.5 μm; SO_2, sulfur dioxide; SPM, suspended particulate matter; TSP, total suspended particulate; UFP, ultrafine particulate matter.

objective measures from hospitals [40–48]. In a series of studies, Szyszkowicz *et al.* found that there tended to be more emergency department visits for depression on more polluted days [40–43,46].

Even worse, air pollution may be a risk factor for substance abuse [66], non-suicidal self-harm [67], and suicide [68–79]. Notably, the effects of air pollution on suicide were found to be stronger for men than for women [67,69,70,72,74–76].

Cognitive functioning

Besides its negative effects on affective well-being, air pollution also harms cognitive functioning across all life stages, from prenatal development [80–91], childhood and youth [88,92–97,98•,99–107], to young and old adults [108–112,113••,114–122]. The impacted cognitive outcomes include attention, visuo-construction, memory, math ability, reading comprehension, verbal intelligence, and non-verbal intelligence. For example, Ebenstein *et al.* [98•], by exploiting variation across the same students taking multiple matriculation exams, found that contemporaneous $PM_{2.5}$ exposure negatively predicted performance; remarkably, $PM_{2.5}$ exposure during these exams also negatively predicted post-secondary educational attainment and earnings in the long run. Using a nationally representative longitudinal dataset from China, Zhang *et al.* [113••] found that, controlling for contemporaneous exposure, cumulative exposure to air pollution impeded cognitive performance in standardized math and verbal tests. More seriously, air pollution may lead to cognitive disorders like dementia and attention deficit hyperactivity disorder [59,60,123–129]. For example, Cacciottolo *et al.* [127] found that living in places with $PM_{2.5}$ exceeding EPA standards increased the risk for dementia by 92%. Again, several of these studies found that the harmful effects of air pollution on human cognition were worse for men than for women [94,97–99,113••].

Decision making

In light of the negative effects of air pollution on cognitive performance, it is unsurprising that air pollution impairs decision-making quality [130]. For example, professional baseball umpires were more likely to make incorrect calls when ambient CO and $PM_{2.5}$ were at high levels [131]. In addition to reducing decision *quality*, air pollution may alter decision-making *tendencies*. For example, Chew *et al.* [132] found that on highly polluted days, individuals exhibited increased risk aversion, ambiguity aversion, and impatience in temporal decision making. A recent study [133] found that air pollution exacerbated the disposition bias, or investors' tendency to sell winning assets while retaining failing assets.

Avoidance behavior, defensive expenditure, and migration

Behaviorally, people react to air pollution in several ways. First, when air pollution is high, people tend to avoid outdoor activities [134–138] such as cycling [139], zoo and observatory attendance [140], park usage [141], and school attendance [142–144].

Second, air pollution increases defensive expenditure, with individuals spending more on facemasks [145,146], air purifiers [145,147], and health insurance [148•]. For example, Zhang and Mu [146] found that in China a 100-point increase in AQI increased the consumption of all masks by 54.5% and anti-$PM_{2.5}$ masks by 70.6%. Using transaction-level data from a Chinese insurance company, Chang *et al.* [148•] found that a one-standard-deviation increase in daily air pollution led to a 7.2% increase in the number of health insurance contracts purchased that day. Interestingly, a one-standard-deviation decrease in air pollution from the purchase date increased the probability of cancellation during the cost-free period by 4.0%.

Third, residents in polluted regions show increased interest in emigration. A study on air pollution in the capital region of China (Beijing-Tianjin-Hebei) found that perceived physical health risk, mental health risk, and government control predicted skilled workers' migration intention [149]. Moreover, Qin and Zhu [150] found that a 100-point increase in AQI predicted a 2.3%–4.8% increase in internet searches for 'emigration' the next day.

Economic effects

Work productivity

Related to the negative effects of air pollution on affective well-being and cognitive functioning, a growing body of work suggests that air pollution can reduce work productivity in two ways. First, air pollution decreases labor supply by increasing *absenteeism* [151–155]. For example, Aragón *et al.* [154] found that moderate levels of $PM_{2.5}$ reduced the working hours of adults, likely because of their need to care for susceptible dependents (e.g. small children and elderly adults). Second, air pollution decreases productivity at work by increasing *presenteeism* [156,157,158•,159]. For example, Graff Zivin and Neidell [156] found that a 10-ppb increase in ozone decreased the productivity of outdoor crop harvest workers by 5.5%. Similarly, studying the largest call center in China, Chang *et al.* [158•] found that a 10-unit increase in API decreased the number of daily calls handled by a worker by 0.35% on average.

Stock markets

Mounting evidence suggests that air pollution hurts stock markets. In their examination of four U.S. stock exchanges, Levy and Yagil [160] found that air pollution negatively predicted stock returns; this effect was weaker the more distant air pollution was from a stock exchange. Similar findings have been observed in stock exchanges in China [161,162], Italy [163], Turkey [164], Canada, the Netherlands, and Australia [165].

Social effects

Crime and unethical behavior

An extensive body of research demonstrates that air pollution is associated with increased criminal and unethical behavior [38•,166–176,177•]. For example, analyzing a nine-year panel of 9360 U.S. cities, Lu *et al.* [38•] found that air pollution predicted both violent crimes (murder, rape, robbery, assault) and property crimes (burglary, motor vehicle theft). Similarly, Bondy *et al.* [169] provided quasi-experimental evidence for the effects of air pollution on both violent and property crimes in London by exploiting daily wind direction as an exogenous source of random variation in air pollution.

Regarding the mechanism, evidence suggests that the psychological experience of air pollution can increase unethical behavior by elevating anxiety, possibly because the induced anxiety depletes individuals' self-control and narrows their focus on their own interests rather than moral principles [38•,177•,178,179]. Consistent with these findings, Chew *et al.* [132] found that on days of high air pollution, individuals were more selfish and less prosocial (e.g. giving less in a dictator game, contributing less in a public goods game, reciprocating less in a sequential prisoner's dilemma, demanding more in an ultimatum game).

Perception of the government

Because the government plays an important role in regulating air pollution, it is plausible that citizens would have a negative perception of the government on highly polluted days. For example, Shi and Guo [180] found that pollution levels predicted more online searches for the word 'corruption'. Likewise, Huang *et al.* [181] provided experimental evidence for the psychological experience of air pollution on perceived corruption: When individuals recalled hazy (versus cloudy) days, they were more likely to perceive the government as corrupt.

Limitations of past research and future directions

Data versus theory driven

One limitation of past research is that many studies on air pollution were data driven rather than theory driven. Researchers tend to collect data on all pollutants accessible without specifying *a priori* which pollutants would influence the outcome variable(s). As a result, it is common to read sentences like 'pollutant X, but not pollutant Y, had a significant effect'. Similarly, although the detrimental effects of air pollution are consistent across studies, estimates of magnitude vary considerably. To achieve greater theoretical and empirical precision, future research could benefit from two practices. First, pre-registering the hypothesized results could reduce Type I error and the file-drawer problem. Second, understanding how pollutants differ (e.g. in size, color, odor, physiological effects) can inform *why* some pollutants but not others should influence a given outcome. For example, small pollutants (e.g. $PM_{2.5}$) can travel indoors and thus affect indoor work productivity, whereas large pollutants cannot [157]. Likewise, colored and malodorous pollutants (e.g. NO_2) may influence *perceived* pollution more strongly than colorless and odorless pollutants.

Actual versus perceived air pollution

Relatedly, for the varied outcomes reviewed above, it is often unclear whether the effect of air pollution is more physiological or psychological. To date, only a small percentage of studies have assessed both actual and perceived pollution levels [29,139,140,149,182]. These studies suggest that the *perception* of air pollution levels matters. For example, Neidell [140] found that zoo attendance dropped by 13% and observatory attendance dropped by 6% when a smog alert was issued relative to days with similar levels of air pollution but no smog alert. Similarly, Fehr *et al.* [177•] found that employees' *perception* of air pollution levels — but not actual air pollution levels — predicted their unethical behavior at work. To ascertain whether the effect of air pollution on a given outcome is more psychological or physiological, future studies should measure both actual and perceived pollution levels and assess the effects of one while controlling for the other.

Conclusion

Research on the psychological, economic, and social effects of air pollution is booming. Air pollution corrupts not only the health of individuals, but also the health of society.

Conflict of interest statement

None declared.

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References and recommended reading

Papers of particular interest, published within the period of review, have been highlighted as:

- • of special interest
- •• of outstanding interest

1. *Air pollution in India: breathe uneasy*. The Economist; 2015 https://www.economist.com/asia/2015/02/05/breathe-uneasy.

2. *Air Quality – National Summary*. Environmental Protection Agency; 2018 https://www.epa.gov/air-trends/air-quality-national-summary.

3. Ambrey CL, Fleming CM, Chan AY: **Estimating the cost of air pollution in South East Queensland: an application of the life satisfaction non-market valuation approach**. *Ecol Econ* 2014, **97**:172-181 http://dx.doi.org/10.1016/j.ecolecon.2013.11.007.

4. Barrington-Leigh C, Behzadnejad F: **Evaluating the short-term cost of low-level local air pollution: a life satisfaction approach**. *Environ Econ Policy Stud* 2017, **19**:269-298 http://dx.doi.org/10.1007/s10018-016-0152-7.

5. Smyth R, Mishra V, Qian X: **The environment and well-being in urban China**. *Ecol Econ* 2008, **68**:547-555 http://dx.doi.org/10.1016/j.ecolecon.2008.05.017.

6. Xu J, Li J: **Tax payment, social contribution for pollution prevention and happiness**. *Probl Ekorozwoju* 2016, **11**:59-64.

7. Zhang X, Zhang X, Chen X: **Happiness in the air: how does a dirty sky affect mental health and subjective well-being?** *J Environ Econ Manage* 2017, **85**:81-94 http://dx.doi.org/10.1016/j.jeem.2017.04.001.

8. Zhang X, Zhang X, Chen X: **Valuing air quality using happiness data: the case of China**. *Ecol Econ* 2017, **137**:29-36 http://dx.doi.org/10.1016/j.ecolecon.2017.02.020.

9. Yuan L, Shin K, Managi S: **Subjective well-being and environmental quality: the impact of air pollution and green coverage in China**. *Ecol Econ* 2018, **153**:124-138 http://dx.doi.org/10.1016/j.ecolecon.2018.04.033.

10. •• Zheng S, Wang J, Sun C, Zhang X, Kahn ME: **Air pollution lowers Chinese urbanites' expressed happiness on social media**. *Nat Hum Behav* 2019, **3**:237-243 http://dx.doi.org/10.1038/s41562-018-0521-2.

Through an analysis of 210 million geotagged Weibo tweets for 144 Chinese cities, this paper revealed that air pollution was associated with lower happiness expressed in tweets. These results were substantiated by comprehensive robustness checks (e.g. using wind direction as an instrumental variable).

11. Levinson A: **Valuing public goods using happiness data: the case of air quality**. *J Public Econ* 2012, **96**:869-880 http://dx.doi.org/10.1016/j.jpubeco.2012.06.007.

12. Welsch H: **Environment and happiness: valuation of air pollution using life satisfaction data**. *Ecol Econ* 2006, **58**:801-813 http://dx.doi.org/10.1016/j.ecolecon.2005.09.006.

13. Di Tella R, MacCulloch R: **Gross national happiness as an answer to the Easterlin Paradox?** *J Dev Econ* 2008, **86**:22-42 http://dx.doi.org/10.1016/j.jdeveco.2007.06.008.

14. Orru K, Orru H, Maasikmets M, Hendrikson R, Ainsaar M: **Well-being and environmental quality: does pollution affect life satisfaction?** *Qual Life Res* 2016, **25**:699-705 http://dx.doi.org/10.1007/s11136-015-1104-6.

15. Ozdamar O, Giovanis E: **The causal effects of income support and housing benefits on mental well-being: an application of a Bayesian network**. *Metroeconomica* 2017, **68**:398-424 http://dx.doi.org/10.1111/meca.12131.

16. Rehdanz K, Maddison D: **Local environmental quality and life-satisfaction in Germany**. *Ecol Econ* 2008, **64**:787-797 http://dx.doi.org/10.1016/j.ecolecon.2007.04.016.

17. Luechinger S: **Valuing air quality using the life satisfaction approach**. *Econ J* 2009, **119**:482-515 http://dx.doi.org/10.1111/j.1468-0297.2008.02241.x.

18. Mackerron G, Mourato S: **Life satisfaction and air quality in London**. *Ecol Econ* 2009, **68**:1441-1453 http://dx.doi.org/10.1016/j.ecolecon.2008.10.004.

19. Ferreira S, Moro M: **On the use of subjective well-being data for environmental valuation**. *Environ Resour Econ* 2010, **46**:249-273 http://dx.doi.org/10.1007/s10640-009-9339-8.

20. Menz T, Welsch H: **Life-cycle and cohort effects in the valuation of air quality: evidence from subjective well-being data**. *Land Econ* 2012, **88**:300-325 http://dx.doi.org/10.3368/le.88.2.300.

21. Ferreira S, Akay A, Brereton F, Cuñado J, Martinsson P, Moro M, Ningal TF: **Life satisfaction and air quality in Europe**. *Ecol Econ* 2013, **88**:1-10 http://dx.doi.org/10.1016/j.ecolecon.2012.12.027.

22. Dolan P, Laffan K: **Bad air days: the effects of air quality on different measures of subjective well-being**. *J Benefit-Cost Anal* 2016, **7**:147-195 http://dx.doi.org/10.1017/bca.2016.7.

23. Giovanis E, Ozdamar O: **Structural equation modelling and the causal effect of permanent income on life satisfaction: the case of air pollution valuation in Switzerland**. *J Econ Surv* 2016, **30**:430-459 http://dx.doi.org/10.1111/joes.12163.

24. Menz T: **Do people habituate to air pollution? Evidence from international life satisfaction data**. *Ecol Econ* 2011, **71**:211-219 http://dx.doi.org/10.1016/j.ecolecon.2011.09.012.

25. Rotko T, Oglesby L, Künzli N, Carrer P, Nieuwenhuijsen MJ, Jantunen M: **Determinants of perceived air pollution annoyance and association between annoyance scores and air pollution ($PM_{2.5}$, NO_2) concentrations in the European EXPOLIS study**. *Atmos Environ* 2002, **36**:4593-4602 http://dx.doi.org/10.1016/S1352-2310(02)00465-X.

26. Jacquemin B, Sunyer J, Forsberg B, Götschi T, Bayer-Oglesby L, Ackermann-Liebrich U, de Marco R, Heinrich J, Jarvis D, Torén K, Künzli N: **Annoyance due to air pollution in Europe**. *Int J Epidemiol* 2007, **36**:809-820 http://dx.doi.org/10.1093/ije/dym042.

27. Modig L, Forsberg B: **Perceived annoyance and asthmatic symptoms in relation to vehicle exhaust levels outside home: a cross-sectional study**. *Environ Health A Glob Access Sci Source* 2007, **6**:29 http://dx.doi.org/10.1186/1476-069X-6-29.

28. Llop S, Ballester F, Estarlich M, Esplugues A, Fernández-Patier R, Ramón R, Marco A, Aguirre A, Sunyer J, Iñiguez C: **Ambient air pollution and annoyance responses from pregnant women**. *Atmos Environ* 2008, **42**:2982-2992 http://dx.doi.org/10.1016/j.atmosenv.2007.12.049.

29. Claeson AS, Lidén E, Nordin M, Nordin S: **The role of perceived pollution and health risk perception in annoyance and health symptoms: a population-based study of odorous air pollution**. *Int Arch Occup Environ Health* 2013, **86**:367-374 http://dx.doi.org/10.1007/s00420-012-0770-8.

30. Heaney CD, Wing S, Campbell RL, Caldwell D, Hopkins B, Richardson D, Yeatts K: **Relation between malodor, ambient hydrogen sulfide, and health in a community bordering a landfill**. *Environ Res* 2011, **111**:847-852 http://dx.doi.org/10.1016/j.envres.2011.05.021.

31. Cho J, Choi YJ, Sohn J, Suh M, Cho SK, Ha KH, Kim C, Shin DC: **Ambient ozone concentration and emergency department visits for panic attacks**. *J Psychiatr Res* 2015, **62**:130-135 http://dx.doi.org/10.1016/j.jpsychires.2015.01.010.

32. Mehta AJ, Kubzansky LD, Coull BA, Kloog I, Koutrakis P, Sparrow D, Spiro A, Vokonas P, Schwartz J: **Associations between air pollution and perceived stress: the Veterans Administration Normative Aging Study**. *Environ Health A Glob Access Sci Source* 2015, **14**:10 http://dx.doi.org/10.1186/1476-069X-14-10.

33. Power MC, Kioumourtzoglou MA, Hart JE, Okereke OI, Laden F, Weisskopf MG: **The relation between past exposure to fine particulate air pollution and prevalent anxiety: observational cohort study**. *BMJ* 2015, **350**:h1111 http://dx.doi.org/10.1136/bmj.h1111.

34. Lin Y, Zhou L, Xu J, Luo Z, Kan H, Zhang J, Yan C, Zhang J: **The impacts of air pollution on maternal stress during pregnancy**. *Sci Rep* 2017, **7**:40956 http://dx.doi.org/10.1038/srep40956.

35. Pun VC, Manjourides J, Suh H: **Association of ambient air pollution with depressive and anxiety symptoms in older adults: results from the NSHAP study**. *Environ Health Perspect* 2017, **125**:342-348 http://dx.doi.org/10.1289/EHP494.

36. Sass V, Kravitz-Wirtz N, Karceski SM, Hajat A, Crowder K, Takeuchi D: **The effects of air pollution on individual psychological distress**. *Health Place* 2017, **48**:72-79 http://dx.doi.org/10.1016/j.healthplace.2017.09.006.

37. Xu W, Ding X, Zhuang Y, Yuan G, An Y, Shi Z, Goh PH: **Perceived haze, stress, and negative emotions: an ecological momentary assessment study of the affective responses to haze**. *J Health Psychol* 2017 http://dx.doi.org/10.1177/1359105317717600.

38. • Lu JG, Lee JJ, Gino F, Galinsky AD: **Polluted morality: air pollution predicts criminal activity and unethical behavior**. *Psychol Sci* 2018, **29**:340-355 http://dx.doi.org/10.1177/0956797617735807.

Analyses of a nine-year panel of 9360 U.S. cities found that air pollution predicted six major categories of crime; these analyses accounted for a comprehensive set of control variables (e.g. city and year fixed effects, population, law enforcement) and survived various robustness checks (e.g. balanced panel, nonparametric bootstrapped standard errors). Three subsequent experiments involving American and Indian participants provided further evidence for the effect of psychologically experiencing a polluted (versus clean) environment on unethical behavior.

39. Brook RD, Rajagopalan S, Pope CA, Brook JR, Bhatnagar A, Diez-Roux AV, Holguin F, Hong Y, Luepker RV, Mittleman MA *et al.*: **Particulate matter air pollution and cardiovascular disease: an update to the scientific statement from the American Heart Association**. *Circulation* 2010, **121**:2331-2378 http://dx.doi.org/10.1161/CIR.0b013e3181dbece1.

40. Szyszkowicz M: **Air pollution and emergency department visits for depression in Edmonton, Canada**. *Int J Occup Med Environ Health* 2007, **20**:241-245.

41. Szyszkowicz M, Rowe B, Colman I: **Air pollution and daily emergency department visits for depression**. *Int J Occup Med Environ Health* 2009, **22**:355-362.

42. Szyszkowicz M: **Ambient sulfur dioxide and female ED visits for depression**. *Air Qual Atmos Health* 2011, **4**:259-262 http://dx.doi.org/10.1007/s11869-010-0081-8.

43. Szyszkowicz M, Tremblay N: **Case-crossover design: air pollution and health outcomes**. *Int J Occup Med Environ Health* 2011, **24**:249-255 http://dx.doi.org/10.2478/s13382-011-0034-y.

44. Cho J, Choi YJ, Suh M, Sohn J, Kim H, Cho SK, Ha KH, Kim C, Shin DC: **Air pollution as a risk factor for depressive episode in patients with cardiovascular disease, diabetes mellitus, or asthma**. *J Affect Disord* 2014, **157**:45-51 http://dx.doi.org/10.1016/j.jad.2014.01.002.

45. Kim KN, Lim YH, Bae HJ, Kim M, Jung K, Hong YC: **Long-term fine particulate matter exposure and major depressive disorder in a community-based urban cohort**. *Environ Health Perspect* 2016, **124**:1547-1553 http://dx.doi.org/10.1289/EHP192.

46. Szyszkowicz M, Kousha T, Kingsbury M, Colman I: **Air pollution and emergency department visits for depression: a multicity case-crossover study**. *Environ Health Insights* 2016, **10**:155-161 http://dx.doi.org/10.4137/ehi.s40493.

47. Zijlema WL, Wolf K, Emeny R, Ladwig KH, Peters A, Kongsgård H, Hveem K, Kvaløy K, Yli-Tuomi T, Partonen T *et al.*: **The association of air pollution and depressed mood in 70,928 individuals from four European cohorts**. *Int J Hyg Environ Health* 2016, **219**:212-219 http://dx.doi.org/10.1016/j.ijheh.2015.11.006.

48. Chen C, Liu C, Chen R, Wang W, Li W, Kan H, Fu C: **Ambient air pollution and daily hospital admissions for mental disorders in Shanghai, China**. *Sci Total Environ* 2018, **613-614**:324-330 http://dx.doi.org/10.1016/j.scitotenv.2017.09.098.

49. Lim YH, Kim H, Kim JH, Bae S, Park HY, Hong YC: **Air pollution and symptoms of depression in elderly adults**. *Environ Health Perspect* 2012, **120**:1023-1028 http://dx.doi.org/10.1289/ehp.1104100.

50. Ha H: **Geographic variation in mentally unhealthy days: air pollution and altitude perspectives**. *High Alt Med Biol* 2017, **18**:258-266 http://dx.doi.org/10.1089/ham.2016.0137.

51. Kioumourtzoglou MA, Power MC, Hart JE, Okereke OI, Coull BA, Laden F, Weisskopf MG: **The association between air pollution and onset of depression among middle-aged and older women**. *Am J Epidemiol* 2017, **185**:801-809 http://dx.doi.org/10.1093/aje/kww163.

52. Lin H, Guo Y, Kowal P, Airhihenbuwa CO, Di Q, Zheng Y, Zhao X, Vaughn MG, Howard S, Schootman M *et al.*: **Exposure to air pollution and tobacco smoking and their combined effects on depression in six low- and middle-income countries**. *Br J Psychiatry* 2017, **211**:157-162 http://dx.doi.org/10.1192/bjp.bp.117.202325.

53. Vert C, Sánchez-Benavides G, Martínez D, Gotsens X, Gramunt N, Cirach M, Molinuevo JL, Sunyer J, Nieuwenhuijsen MJ, Crous-Bou M, Gascon M: **Effect of long-term exposure to air pollution on anxiety and depression in adults: a cross-sectional study**. *Int J Hyg Environ Health* 2017, **220**:1074-1080 http://dx.doi.org/10.1016/j.ijheh.2017.06.009.

54. Shin J, Park JY, Choi J: **Long-term exposure to ambient air pollutants and mental health status: a nationwide population-based cross-sectional study**. *PLoS One* 2018, **13**:e0195607 http://dx.doi.org/10.1371/journal.pone.0195607.

55. Wang R, Xue D, Liu Y, Liu P, Chen H: **The relationship between air pollution and depression in China: is neighbourhood social**

capital protective? *Int J Environ Res Public Health* 2018, **15**:1160 http://dx.doi.org/10.3390/ijerph15061160.

56. Pedersen CB, Raaschou-Nielsen O, Hertel O, Mortensen PB: **Air pollution from traffic and schizophrenia risk**. *Schizophr Res* 2004, **66**:83-85 http://dx.doi.org/10.1016/S0920-9964(03)00062-8.

57. Gao Q, Xu Q, Guo X, Fan H, Zhu H: **Particulate matter air pollution associated with hospital admissions for mental disorders: a time-series study in Beijing, China**. *Eur Psychiatry* 2017, **44**:68-75 http://dx.doi.org/10.1016/j.eurpsy.2017.02.492.

58. Becerra TA, Wilhelm M, Olsen J, Cockburn M, Ritz B: **Ambient air pollution and autism in Los Angeles county, California**. *Environ Health Perspect* 2013, **121**:380-386 http://dx.doi.org/10.1289/ehp.1205827.

59. Volk HE, Lurmann F, Penfold B, Hertz-Picciotto I, McConnell R: **Traffic-related air pollution, particulate matter, and autism**. *Arch Gen Psychiatry* 2013, **70**:71-77 http://dx.doi.org/10.1001/jamapsychiatry.2013.266.

60. Gong T, Almqvist C, Bölte S, Lichtenstein P, Anckarsäter H, Lind T, Lundholm C, Pershagen G: **Exposure to air pollution from traffic and neurodevelopmental disorders in Swedish twins**. *Twin Res Hum Genet* 2014, **17**:553-562 http://dx.doi.org/10.1017/thg.2014.58.

61. Kalkbrenner AE, Windham GC, Serre ML, Akita Y, Wang X, Hoffman K, Thayer BP, Daniels JL: **Particulate matter exposure, prenatal and postnatal windows of susceptibility, and autism spectrum disorders**. *Epidemiology* 2015, **26**:30-42 http://dx.doi.org/10.1097/EDE.0000000000000173.

62. Raz R, Roberts AL, Lyall K, Hart JE, Just AC, Laden F, Weisskopf MG: **Autism spectrum disorder and particulate matter air pollution before, during, and after pregnancy: a nested case-control analysis within the Nurses' Health Study II Cohort**. *Environ Health Perspect* 2015, **123**:264-270 http://dx.doi.org/10.1289/ehp.1408133.

63. Talbott EO, Arena VC, Rager JR, Clougherty JE, Michanowicz DR, Sharma RK, Stacy SL: **Fine particulate matter and the risk of autism spectrum disorder**. *Environ Res* 2015, **140**:414-420 http://dx.doi.org/10.1016/j.envres.2015.04.021.

64. Kerin T, Volk H, Li W, Lurmann F, Eckel S, McConnell R, Hertz-Picciotto I: **Association between air pollution exposure, cognitive and adaptive function, and ASD severity among children with autism spectrum disorder**. *J Autism Dev Disord* 2018, **48**:137-150 http://dx.doi.org/10.1007/s10803-017-3304-0.

65. Raz R, Levine H, Pinto O, Broday DM, Yuval, Weisskopf MG: **Traffic-related air pollution and autism spectrum disorder: a population-based nested case-control study in Israel**. *Am J Epidemiol* 2018, **187**:717-725 http://dx.doi.org/10.1093/aje/kwx294.

66. Szyszkowicz M, Thomson EM, Colman I, Rowe BH: **Ambient air pollution exposure and emergency department visits for substance abuse**. *PLoS One* 2018, **13**:e0199826 http://dx.doi.org/10.1371/journal.pone.0199826.

67. Liu W, Sun H, Zhang X, Chen Q, Xu Y, Chen X, Ding Z: **Air pollution associated with non-suicidal self-injury in Chinese adolescent students: a cross-sectional study**. *Chemosphere* 2018, **209**:944-949 http://dx.doi.org/10.1016/j.chemosphere.2018.06.168.

68. Biermann T, Stilianakis N, Bleich S, Thürauf N, Kornhuber J, Reulbach U: **The hypothesis of an impact of ozone on the occurrence of completed and attempted suicides**. *Med Hypotheses* 2009, **72**:338-341 http://dx.doi.org/10.1016/j.mehy.2008.09.042.

69. Kim C, Jung SH, Kang DR, Kim HC, Moon KT, Hur NW, Shin DC, Suh I: **Ambient particulate matter as a risk factor for suicide**. *Am J Psychiatry* 2010, **167**:1100-1107 http://dx.doi.org/10.1176/appi.ajp.2010.09050706.

70. Szyszkowicz M, Willey JB, Grafstein E, Rowe BH, Colman I: **Air pollution and emergency department visits for suicide attempts in Vancouver, Canada**. *Environ Health Insights* 2010, **4**:79-86 http://dx.doi.org/10.4137/ehi.s5662.

71. Yang AC, Tsai SJ, Huang NE: **Decomposing the association of completed suicide with air pollution, weather, and unemployment data at different time scales**. *J Affect Disord* 2011, **129**:275-281 http://dx.doi.org/10.1016/j.jad.2010.08.010.

72. Bakian AV, Huber RS, Coon H, Gray D, Wilson P, McMahon WM, Renshaw PF: **Acute air pollution exposure and risk of suicide completion**. *Am J Epidemiol* 2015, **181**:295-303 http://dx.doi.org/10.1093/aje/kwu341.

73. Kim Y, Myung W, Won HH, Shim S, Jeon HJ, Choi J, Carroll BJ, Kim DK: **Association between air pollution and suicide in South Korea: a nationwide study**. *PLoS One* 2015, **10**:e0117929 http://dx.doi.org/10.1371/journal.pone.0117929.

74. Lin GZ, Li L, Song YF, Zhou YX, Shen SQ, Ou CQ: **The impact of ambient air pollution on suicide mortality: a case-crossover study in Guangzhou, China**. *Environ Health A Glob Access Sci Source* 2016, **15**:90 http://dx.doi.org/10.1186/s12940-016-0177-1.

75. Ng CFS, Stickley A, Konishi S, Watanabe C: **Ambient air pollution and suicide in Tokyo, 2001–2011**. *J Affect Disord* 2016, **201**:194-202 http://dx.doi.org/10.1016/j.jad.2016.05.006.

76. Casas L, Cox B, Bauwelinck M, Nemery B, Deboosere P, Nawrot TS: **Does air pollution trigger suicide? A case-crossover analysis of suicide deaths over the life span**. *Eur J Epidemiol* 2017, **32**:973-981 http://dx.doi.org/10.1007/s10654-017-0273-8.

77. Kim Y, Ng CFS, Chung Y, Kim H, Honda Y, Guo YL, Lim YH, Chen BY, Page LA, Hashizume M: **Air pollution and suicide in 10 cities in Northeast Asia: a time-stratified case-crossover analysis**. *Environ Health Perspect* 2018, **126**:037002 http://dx.doi.org/10.1289/EHP2223.

78. Lee H, Myung W, Kim SE, Kim DK, Kim H: **Ambient air pollution and completed suicide in 26 South Korean cities: effect modification by demographic and socioeconomic factors**. *Sci Total Environ* 2018, **639**:944-951 http://dx.doi.org/10.1016/j.scitotenv.2018.05.210.

79. Min JY, Kim HJ, Min KB: **Long-term exposure to air pollution and the risk of suicide death: a population-based cohort study**. *Sci Total Environ* 2018, **628–629**:573-579 http://dx.doi.org/10.1016/j.scitotenv.2018.02.011.

80. Perera FP, Rauh V, Whyatt RM, Tsai WY, Tang D, Diaz D, Hoepner L, Barr D, Tu YH, Camann D, Kinney P: **Effect of prenatal exposure to airborne polycyclic aromatic hydocarbons on neurodevelopment in the first 3 years of life among inner-city children**. *Environ Health Perspect* 2006, **114**:1287-1292 http://dx.doi.org/10.1289/ehp.9084.

81. Perera FP, Li Z, Whyatt R, Hoepner L, Wang S, Camann D, Rauh V: **Prenatal airborne polycyclic aromatic hydrocarbon exposure and child IQ at age 5 years**. *Pediatrics* 2009, **124**:e195-202 http://dx.doi.org/10.1542/peds.2008-3506.

82. Bharadwaj P, Gibson M, Graff Zivin J, Neilson C: **Gray matters: fetal pollution exposure and human capital formation**. *J Assoc Environ Resour Econ* 2017, **4**:505-542 http://dx.doi.org/10.1086/691591.

83. Isen A, Rossin-Slater M, Walker R: **Every breath you take—every dollar you'll make: the long-term consequences of the Clean Air Act of 1970**. *J Polit Econ* 2017, **125**:848-902 http://dx.doi.org/10.1086/691465.

84. Edwards SC, Jedrychowski W, Butscher M, Camann D, Kieltyka A, Mroz E, Flak E, Li Z, Wang S, Rauh V, Perera F: **Prenatal exposure to airborne polycyclic aromatic hydrocarbons and children's intelligence at 5 years of age in a prospective cohort study in Poland**. *Environ Health Perspect* 2010, **118**:1326-1331 http://dx.doi.org/10.1289/ehp.0901070.

85. Sanders NJ: **What doesn't kill you makes you weaker: prenatal pollution exposure and educational outcomes**. *J Hum Resour* 2012, **47**:826-850 http://dx.doi.org/10.1353/jhr.2012.0018.

86. Vrijheid M, Martinez D, Aguilera I, Bustamante M, Ballester F, Estarlich M, Fernandez-Somoano A, Guxens M, Lertxundi N, Martinez MD *et al.*: **Indoor air pollution from gas cooking and infant neurodevelopment**. *Epidemiology* 2012, **23**:23-32 http://dx.doi.org/10.1097/EDE.0b013e31823a4023.

87. Guxens M, Garcia-Esteban R, Giorgis-Allemand L, Forns J, Badaloni C, Ballester F, Beelen R, Cesaroni G, Chatzi L, De Agostini M *et al.*: **Air pollution during pregnancy and childhood cognitive and psychomotor development: six European birth cohorts**. *Epidemiology* 2014, **25**:636-647 http://dx.doi.org/10.1097/EDE.0000000000000133.

88. Harris MH, Gold DR, Rifas-Shiman SL, Melly SJ, Zanobetti A, Coull BA, Schwartz JD, Gryparis A, Kloog I, Koutrakis P *et al.*: **Prenatal and childhood traffic-related pollution exposure and childhood cognition in the project viva cohort (Massachusetts, USA)**. *Environ Health Perspect* 2015, **123**:1072-1078 http://dx.doi.org/10.1289/ehp.1408803.

89. Jedrychowski WA, Perera FP, Camann D, Spengler J, Butscher M, Mroz E, Majewska R, Flak E, Jacek R, Sowa A: **Prenatal exposure to polycyclic aromatic hydrocarbons and cognitive dysfunction in children**. *Environ Sci Pollut Res* 2015, **22**:3631-3639 http://dx.doi.org/10.1007/s11356-014-3627-8.

90. Lertxundi A, Baccini M, Lertxundi N, Fano E, Aranbarri A, Martínez MD, Ayerdi M, Álvarez J, Santa-Marina L, Dorronsoro M, Ibarluzea J: **Exposure to fine particle matter, nitrogen dioxide and benzene during pregnancy and cognitive and psychomotor developments in children at 15 months of age**. *Environ Int* 2015, **80**:33-40 http://dx.doi.org/10.1016/j.envint.2015.03.007.

91. Yorifuji T, Kashima S, Higa Diez M, Kado Y, Sanada S, Doi H: **Prenatal exposure to traffic-related air pollution and child behavioral development milestone delays in Japan**. *Epidemiology* 2016, **27**:57-65 http://dx.doi.org/10.1097/EDE.0000000000000361.

92. Coscia JM, Ris MD, Succop PA, Dietrich KN: **Cognitive development of lead exposed children from ages 6 to 15 years: an application of growth curve analysis**. *Child Neuropsychol* 2003, **9**:10-21 http://dx.doi.org/10.1076/chin.9.1.10.14498.

93. van Kempen E, Fischer P, Janssen N, Houthuijs D, van Kamp I, Stansfeld S, Cassee F: **Neurobehavioral effects of exposure to traffic-related air pollution and transportation noise in primary school children**. *Environ Res* 2012, **115**:18-25 http://dx.doi.org/10.1016/j.envres.2012.03.002.

94. Chiu YHM, Bellinger DC, Coull BA, Anderson S, Barber R, Wright RO, Wright RJ: **Associations between traffic-related black carbon exposure and attention in a prospective birth cohort of urban children**. *Environ Health Perspect* 2013, **121**:859-864 http://dx.doi.org/10.1289/ehp.1205940.

95. Kicinski M, Vermeir G, Van Larebeke N, Den Hond E, Schoeters G, Bruckers L, Sioen I, Bijnens E, Roels HA, Baeyens W *et al.*: **Neurobehavioral performance in adolescents is inversely associated with traffic exposure**. *Environ Int* 2015, **75**:136-143 http://dx.doi.org/10.1016/j.envint.2014.10.028.

96. Stafford TM: **Indoor air quality and academic performance**. *J Environ Econ Manage* 2015, **70**:34-50 http://dx.doi.org/10.1016/j.jeem.2014.11.002.

97. Sunyer J, Esnaola M, Alvarez-Pedrerol M, Forns J, Rivas I, López-Vicente M, Suades-González E, Foraster M, Garcia-Esteban R, Basagaña X *et al.*: **Association between traffic-related air pollution in schools and cognitive development in primary school children: a prospective cohort study**. *PLoS Med* 2015, **12**:e1001792 http://dx.doi.org/10.1371/journal.pmed.1001792.

98. • Ebenstein A, Lavy V, Roth S: **The long-run economic consequences of high-stakes examinations: evidence from transitory variation in pollution**. *Am Econ J Appl Econ* 2016, **8**:36-65 http://dx.doi.org/10.1257/app.20150213.

By exploiting variation across the same students taking multiple matriculation exams, the authors found that contemporaneous $PM_{2.5}$ exposure negatively predicted performance; remarkably, $PM_{2.5}$ exposure during these exams also negatively predicted post-secondary educational attainment and earnings in the long run.

99. Wang P, Tuvblad C, Younan D, Franklin M, Lurmann F, Wu J, Baker LA, Chen JC: **Socioeconomic disparities and sexual dimorphism in neurotoxic effects of ambient fine particles on youth IQ: a longitudinal analysis**. *PLoS One* 2017, **12**:e0188731 http://dx.doi.org/10.1371/journal.pone.0188731.

100. Pastor M, Morello-Frosch R, Sadd JL: **Breathless: schools, air toxics, and environmental justice in California**. *Policy Stud J* 2006, **34**:337-362 http://dx.doi.org/10.1111/j.1541-0072.2006.00176.x.

101. Calderón-Garcidueñas L, Mora-Tiscareño A, Ontiveros E, Gómez-Garza G, Barragán-Mejía G, Broadway J, Chapman S, Valencia-Salazar G, Jewells V, Maronpot RR *et al.*: **Air pollution, cognitive deficits and brain abnormalities: a pilot study with children and dogs**. *Brain Cogn* 2008, **68**:117-127 http://dx.doi.org/10.1016/j.bandc.2008.04.008.

102. Suglia SF, Gryparis A, Wright RO, Schwartz J, Wright RJ: **Association of black carbon with cognition among children in a prospective birth cohort study**. *Am J Epidemiol* 2008, **167**:280-286 http://dx.doi.org/10.1093/aje/kwm308.

103. Tang D, Li T, Liu JJ, Zhou Z, Yuan T, Chen Y, Rauh VA, Xie J, Perera F: **Effects of prenatal exposure to coal-burning pollutants on children's development in China**. *Environ Health Perspect* 2008, **116**:674-679 http://dx.doi.org/10.1289/ehp.10471.

104. Morales E, Julvez J, Torrent M, De Cid R, Guxens M, Bustamante M, Künzli N, Sunyer J: **Association of early-life exposure to household gas appliances and indoor nitrogen dioxide with cognition and attention behavior in preschoolers**. *Am J Epidemiol* 2009, **169**:1327-1336 http://dx.doi.org/10.1093/aje/kwp067.

105. Wang S, Zhang J, Zeng X, Zeng Y, Wang S, Chen S: **Association of traffic-related air pollution with children's neurobehavioral functions in Quanzhou, China**. *Environ Health Perspect* 2009, **117**:1612-1618 http://dx.doi.org/10.1289/ehp.0800023.

106. Freire C, Ramos R, Puertas R, Lopez-Espinosa MJ, Julvez J, Aguilera I, Cruz F, Fernandez MF, Sunyer J, Olea N: **Association of traffic-related air pollution with cognitive development in children**. *J Epidemiol Commun Health* 2010, **62**:223-228 http://dx.doi.org/10.1136/jech.2008.084574.

107. Mohai P, Kweon BS, Lee S, Ard K: **Air pollution around schools is linked to poorer student health and academic performance**. *Health Aff* 2011, **30**:852-862 http://dx.doi.org/10.1377/hlthaff.2011.0077.

108. Sun R, Gu D: **Air pollution, economic development of communities, and health status among the elderly in urban China**. *Am J Epidemiol* 2008, **168**:1311-1318 http://dx.doi.org/10.1093/aje/kwn260.

109. Chen JC, Schwartz J: **Neurobehavioral effects of ambient air pollution on cognitive performance in US adults**. *Neurotoxicology* 2009, **30**:231-239 http://dx.doi.org/10.1016/j.neuro.2008.12.011.

110. Tonne C, Elbaz A, Beevers S, Singh-Manoux A: **Traffic-related air pollution in relation to cognitive function in older adults**. *Epidemiology* 2014, **25**:674-681 http://dx.doi.org/10.1097/EDE.0000000000000144.

111. Schikowski T, Vossoughi M, Vierkötter A, Schulte T, Teichert T, Sugiri D, Fehsel K, Tzivian L, Bae IS, Ranft U *et al.*: **Association of air pollution with cognitive functions and its modification by APOE gene variants in elderly women**. *Environ Res* 2015, **142**:10-16 http://dx.doi.org/10.1016/j.envres.2015.06.009.

112. Kioumourtzoglou MA, Schwartz JD, Weisskopf MG, Melly SJ, Wang Y, Dominici F, Zanobetti A: **Long-term $PM_{2.5}$ exposure and neurological hospital admissions in the northeastern United States**. *Environ Health Perspect* 2016, **124**:23-29 http://dx.doi.org/10.1289/ehp.1408973.

113. •• Zhang X, Chen X, Zhang X: **The impact of exposure to air pollution on cognitive performance**. *Proc Natl Acad Sci* 2018, **115**:9193-9197 http://dx.doi.org/10.1073/pnas.1809474115.

Using a nationally representative longitudinal dataset from China, the authors found that controlling for contemporaneous exposure, cumulative exposure to air pollution impeded cognitive performance in standardized math and verbal tests. This study was among the first to investigate the cognitive impact of cumulative exposure while controlling for contemporaneous exposure.

114. Heyes A, Rivers N, Schaufele B: **Pollution and politician productivity: the effect of PM on MPs**. *Land Econ* 2019, **95**:157-173 http://dx.doi.org/10.3368/le.95.2.157.

115. Ranft U, Schikowski T, Sugiri D, Krutmann J, Krämer U: **Long-term exposure to traffic-related particulate matter impairs**

cognitive function in the elderly. *Environ Res* 2009, **109**:1004-1011 http://dx.doi.org/10.1016/j.envres.2009.08.003.

116. Zeng Y, Gu D, Purser J, Hoenig H, Christakis N: **Associations of environmental factors with elderly health and mortality in China**. *Am J Public Health* 2010, **100**:298-305 http://dx.doi.org/10.2105/AJPH.2008.154971.

117. Power MC, Weisskopf MG, Alexeeff SE, Coull BA, Spiro A III, Schwartz J: **Traffic-related air pollution and cognitive function in a cohort of older men**. *Environ Health Perspect* 2011, **119**:682-687 http://dx.doi.org/10.1289/ehp.1002767.

118. Wellenius GA, Boyle LD, Coull BA, Milberg WP, Gryparis A, Schwartz J, Mittleman MA, Lipsitz LA: **Residential proximity to nearest major roadway and cognitive function in community-dwelling seniors: results from the mobilize Boston study**. *J Am Geriatr Soc* 2012, **60**:2075-2080 http://dx.doi.org/10.1111/j.1532-5415.2012.04195.x.

119. Weuve J, Puett RC, Schwartz J, Yanosky JD, Laden F, Grodstein F: **Exposure to particulate air pollution and cognitive decline in older women**. *Arch Intern Med* 2012, **172**:219-227 http://dx.doi.org/10.1001/archinternmed.2011.683.

120. Ailshire JA, Clarke P: **Fine particulate matter air pollution and cognitive function among U.S. older adults**. *J Gerontol—Ser B Psychol Sci Soc Sci* 2015, **70**:322-328 http://dx.doi.org/10.1093/geronb/gbu064.

121. Ailshire JA, Crimmins EM: **Fine particulate matter air pollution and cognitive function among older US adults**. *Am J Epidemiol* 2014, **180**:359-366 http://dx.doi.org/10.1093/aje/kwu155.

122. Gatto NM, Henderson VW, Hodis HN, St. John JA, Lurmann F, Chen JC, Mack WJ: **Components of air pollution and cognitive function in middle-aged and older adults in Los Angeles**. *Neurotoxicology* 2014, **40**:1-7 http://dx.doi.org/10.1016/j.neuro.2013.09.004.

123. Braun JM, Kahn RS, Froehlich T, Auinger P, Lanphear BP: **Exposures to environmental toxicants and attention deficit hyperactivity disorder in U.S. children**. *Environ Health Perspect* 2006, **114**:1904-1909 http://dx.doi.org/10.1289/ehp.9478.

124. Froehlich TE, Lanphear BP, Auinger P, Hornung R, Epstein JN, Braun J, Kahn RS: **Association of tobacco and lead exposures with attention-deficit/hyperactivity disorder**. *Pediatrics* 2009, **124**:e1054-e1063 http://dx.doi.org/10.1542/peds.2009-0738.

125. Siddique S, Banerjee M, Ray MR, Lahiri T: **Attention-deficit hyperactivity disorder in children chronically exposed to high level of vehicular pollution**. *Eur J Pediatr* 2011, **170**:923-929 http://dx.doi.org/10.1007/s00431-010-1379-0.

126. Oudin A, Forsberg B, Adolfsson AN, Lind N, Modig L, Nordin M, Nordin S, Adolfsson R, Nilsson LG: **Traffic-related air pollution and dementia incidence in northern Sweden: a longitudinal study**. *Environ Health Perspect* 2016, **124**:306-312 http://dx.doi.org/10.1289/ehp.1408322.

127. Cacciottolo M, Wang X, Driscoll I, Woodward N, Saffari A, Reyes J, Serre ML, Vizuete W, Sioutas C, Morgan TE *et al.*: **Particulate air pollutants, APOE alleles and their contributions to cognitive impairment in older women and to amyloidogenesis in experimental models**. *Transl Psychiatry* 2017, **7**:e1022 http://dx.doi.org/10.1038/tp.2016.280.

128. Chen H, Kwong JC, Copes R, Tu K, Villeneuve PJ, van Donkelaar A, Hystad P, Martin RV, Murray BJ, Jessiman B *et al.*: **Living near major roads and the incidence of dementia, Parkinson's disease, and multiple sclerosis: a population-based cohort study**. *Lancet* 2017, **389**:718-726 http://dx.doi.org/10.1016/S0140-6736(16)32399-6.

129. Min J, Min K: **Exposure to ambient PM_{10} and NO_2 and the incidence of attention-deficit hyperactivity disorder in childhood**. *Environ Int* 2017, **99**:221-227 http://dx.doi.org/10.1016/j.envint.2016.11.022.

130. Dong R, Fisman R, Wang Y, Xu N: **Air pollution, affect, and forecasting bias: evidence from Chinese financial analysts**. *J Financ Econ* 2019.

131. Archsmith J, Heyes A, Saberian S: **Air quality and error quantity: pollution and performance in a high-skilled, quality-focused occupation**. *J Assoc Environ Resour Econ* 2018, **5**:827-863 http://dx.doi.org/10.1086/698728.

132. Chew SH, Huang W, Li X: **Does haze cloud decision making? A natural laboratory experiment**, n.d.

133. Huang J, Xu N, Yu H: **Pollution and performance: do investors make worse trades on hazy days?** *Manage Sci* 2019.

134. Bresnahan BW, Dickie M, Gerking S: **Averting behavior and urban air pollution**. *Land Econ* 1997, **73**:340-357 http://dx.doi.org/10.2307/3147172.

135. Mansfield C, Johnson FR, Van Houtven G: **The missing piece: valuing averting behavior for children's ozone exposures**. *Resour Energy Econ* 2006, **28**:215-228 http://dx.doi.org/10.1016/j.reseneeco.2006.02.002.

136. Graff Zivin J, Neidell M: **Days of haze: environmental information disclosure and intertemporal avoidance behavior**. *J Environ Econ Manage* 2009, **58**:119-128 http://dx.doi.org/10.1016/j.jeem.2009.03.001.

137. Wen XJ, Balluz L, Mokdad A: **Association between media alerts of air quality index and change of outdoor activity among adult asthma in six states, BRFSS, 2005**. *J Commun Health* 2009, **34**:40-46 http://dx.doi.org/10.1007/s10900-008-9126-4.

138. Moretti E, Neidell M: **Pollution, health, and avoidance behavior: evidence from the ports of Los Angeles**. *J Hum Resour* 2011, **46**:154-175 http://dx.doi.org/10.1353/jhr.2011.0012.

139. Saberian S, Heyes A, Rivers N: **Alerts work! Air quality warnings and cycling**. *Resour Energy Econ* 2017, **49**:165-185 http://dx.doi.org/10.1016/j.reseneeco.2017.05.004.

140. Neidell M: **Information, avoidance behavior, and health: the effect of ozone on asthma hospitalizations**. *J Hum Resour* 2009, **44**:450-478 http://dx.doi.org/10.1353/jhr.2009.0018.

141. Noonan DS: **Smoggy with a chance of altruism: the effects of ozone alerts on outdoor recreation and driving in Atlanta**. *Policy Stud J* 2014, **42**:122-145 http://dx.doi.org/10.1111/psj.12045.

142. Currie J, Hanushek E, Kahn EM, Neidell M, Rivkin S: **Does pollution increase school absences?** *Rev Econ Stat* 2009, **91**:682-694 http://dx.doi.org/10.1162/rest.91.4.682.

143. Hales NM, Barton CC, Ransom MR, Allen RT, Pope CA: **A quasi-experimental analysis of elementary school absences and fine particulate air pollution**. *Medicine* 2016, **95**:e2916 http://dx.doi.org/10.1097/MD.0000000000002916.

144. Liu H, Salvo A: **Severe air pollution and child absences when schools and parents respond**. *J Environ Econ Manage* 2018, **92**:300-330 http://dx.doi.org/10.1016/j.jeem.2018.10.003.

145. Sun C, Kahn ME, Zheng S: **Self-protection investment exacerbates air pollution exposure inequality in urban China**. *Ecol Econ* 2017, **131**:468-474 http://dx.doi.org/10.1016/j.ecolecon.2016.06.030.

146. Zhang J, Mu Q: **Air pollution and defensive expenditures: evidence from particulate-filtering facemasks**. *J Environ Econ Manage* 2018, **92**:517-536 http://dx.doi.org/10.1016/j.jeem.2017.07.006.

147. Liu T, He G, Lau A: **Avoidance behavior against air pollution: evidence from online search indices for anti-$PM_{2.5}$ masks and air filters in Chinese cities**. *Environ Econ Policy Stud* 2018, **20**:325-363 http://dx.doi.org/10.1007/s10018-017-0196-3.

148. • Chang TY, Huang W, Wang Y: **Something in the air: pollution and the demand for health insurance**. *Rev Econ Stud* 2018, **85**:1609-1634 http://dx.doi.org/10.1093/restud/rdy016.
Using transaction-level data from a Chinese insurance company, the authors found that a one-standard-deviation increase in daily air pollution led to a 7.2% increase in the number of health insurance contracts purchased that day. Interestingly, a one-standard-deviation decrease in air pollution from the purchase date increased the probability of cancellation during the cost-free period by 4.0%.

149. Lu H, Yue A, Chen H, Long R: **Could smog pollution lead to the migration of local skilled workers? Evidence from the Jing-Jin-Ji region in China**. *Resour Conserv Recy* 2018, **130**:177-187 http://dx.doi.org/10.1016/j.resconrec.2017.11.024.

150. Qin Y, Zhu H: **Run away? Air pollution and emigration interests in China**. *J Popul Econ* 2018, **31**:235-266 http://dx.doi.org/10.1007/s00148-017-0653-0.

151. Ostro BD: **The effects of air pollution on work loss and morbidity**. *J Environ Econ Manage* 1983, **10**:371-382 http://dx.doi.org/10.1016/0095-0696(83)90006-2.

152. Hansen AC, Selte HK: **Air pollution and sick-leaves: a case study using air pollution data from Oslo**. *Environ Resour Econ* 2000, **16**:31-50 http://dx.doi.org/10.1023/A:1008318004154.

153. Hanna R, Oliva P: **The effect of pollution on labor supply: evidence from a natural experiment in Mexico City**. *J Public Econ* 2015, **122**:68-79 http://dx.doi.org/10.1016/j.jpubeco.2014.10.004.

154. Aragón FM, Miranda JJ, Oliva P: **Particulate matter and labor supply: the role of caregiving and non-linearities**. *J Environ Econ Manage* 2017, **86**:295-309 http://dx.doi.org/10.1016/j.jeem.2017.02.008.

155. Jans J, Johansson P, Nilsson JP: **Economic status, air quality, and child health: evidence from inversion episodes**. *J Health Econ* 2018, **61**:220-232 http://dx.doi.org/10.1016/j.jhealeco.2018.08.002.

156. Graff Zivin J, Neidell M: **The impact of pollution on worker productivity**. *Am Econ Rev* 2012, **102**:3652-3673 http://dx.doi.org/10.1257/aer.102.7.3652.

157. Chang TY, Graff Zivin J, Gross T, Neidell M: **Particulate pollution and the productivity of pear packers**. *Am Econ J Econ Policy* 2016, **8**:141-169 http://dx.doi.org/10.1257/pol.20150085.

158. • Chang TY, Graff Zivin J, Gross T, Neidell M: **The effect of pollution on worker productivity: evidence from call center workers in China**. *Am Econ J Appl Econ* 2019, **11**:151-172 http://dx.doi.org/10.1257/app.20160436.
Studying the largest call center in China, the authors found that a 10-unit increase in API decreased the number of daily calls handled by a worker by 0.35% on average.

159. He J, Liu H, Salvo A: **Severe air pollution and labor productivity: evidence from industrial towns in China**. *Am Econ J Appl Econ* 2019, **11**:173-201 http://dx.doi.org/10.1257/app.20170286.

160. Levy T, Yagil J: **Air pollution and stock returns in the US**. *J Econ Psychol* 2011, **32**:374-383 http://dx.doi.org/10.1016/j.joep.2011.01.004.

161. Li Q, Peng CH: **The stock market effect of air pollution: evidence from China**. *Appl Econ* 2016, **48**:3442-3461 http://dx.doi.org/10.1080/00036846.2016.1139679.

162. He X, Liu Y: **The public environmental awareness and the air pollution effect in Chinese stock market**. *J Clean Prod* 2018, **185**:446-454 http://dx.doi.org/10.1016/j.jclepro.2018.02.294.

163. Lepori GM: **Air pollution and stock returns: evidence from a natural experiment**. *J Empir Financ* 2016, **35**:25-42 http://dx.doi.org/10.1016/j.jempfin.2015.10.008.

164. Demir E, Ersan O: **When stock market investors breathe polluted air**. *Entrepreneurship, Business and Economics* 2016, **2**:705-720 https://doi.org/10.1007/978-3-319-27573-4_46.

165. Levy T, Yagil J: **Air pollution and stock returns – extensions and international perspective**. *Int J Eng Bus Enterp Appl* 2013, **32**:374-383.

166. Nevin R: **How lead exposure relates to temporal changes in IQ, violent crime, and unwed pregnancy**. *Environ Res* 2000, **83**:1-22 http://dx.doi.org/10.1006/enrs.1999.4045.

167. Younan D, Tuvblad C, Franklin M, Lurmann F, Li L, Wu J, Berhane K, Baker LA, Chen JC: **Longitudinal analysis of particulate air pollutants and adolescent delinquent behavior in Southern California**. *J Abnorm Child Psychol* 2018, **46**:1283-1293 http://dx.doi.org/10.1007/s10802-017-0367-5.

168. Burkhardt J, Bayham J, Wilson A, Berman JD, O'Dell K, Ford B, Fischer EV, Pierce JR: **The relationship between monthly air pollution and violent crime across the United States**. *J Environ Econ Policy* 2019:1-18 http://dx.doi.org/10.1080/21606544.2019.1630014.

169. Bondy M, Roth S, Sager L: **Crime is in the air: the contemporaneous relationship between air pollution and crime**, n.d.

170. Dietrich KN, Douglas RM, Succop PA, Berger OG, Bornschein RL: **Early exposure to lead and juvenile delinquency**. *Neurotoxicol Teratol* 2001, **23**:511-518 http://dx.doi.org/10.1016/S0892-0362(01)00184-2.

171. Stretesky PB, Lynch MJ: **The relationship between lead exposure and homicide**. *Arch Pediatr Adolesc Med* 2001, **155**:579-582 http://dx.doi.org/10.1001/archpedi.155.5.579.

172. Gong S, Lu JG, Schaubroeck JM, Li Q, Zhou Q, Qian X: **Is the effect of air pollution on unethical behavior physiological or psychological?** n.d.

173. Nevin R: **Understanding international crime trends: the legacy of preschool lead exposure**. *Environ Res* 2007, **104**:315-336 http://dx.doi.org/10.1016/j.envres.2007.02.008.

174. Reyes JW: **Environmental policy as social policy? The impact of childhood lead exposure on crime**. *BE J Econ Anal Policy* 2007, **7**:51 http://dx.doi.org/10.2202/1935-1682.1796.

175. Haynes EN, Chen A, Ryan P, Succop P, Wright J, Dietrich KN: **Exposure to airborne metals and particulate matter and risk for youth adjudicated for criminal activity**. *Environ Res* 2011, **111**:1243-1248 http://dx.doi.org/10.1016/j.envres.2011.08.008.

176. Reyes JW: **Lead exposure and behavior: effects on antisocial and risky behavior among children and adolescents**. *Econ Inq* 2015, **53**:1580-1605 http://dx.doi.org/10.1111/ecin.12202.

177. • Fehr R, Yam KC, He W, Chiang JTJ, Wei W: **Polluted work: a self-control perspective on air pollution appraisals, organizational citizenship, and counterproductive work behavior**. *Organ Behav Hum Decis Process* 2017, **143**:98-110 http://dx.doi.org/10.1016/j.obhdp.2017.02.002.
A two-week diary study found that Chinese employees' *perceived* air pollution — but not actual air pollution — predicted their unethical behavior at work.

178. Hirsh JB, Lu JG, Galinsky AD: **Moral Utility Theory: understanding the motivation to behave (un)ethically**. *Res Organ Behav* 2018, **38**:43-59 http://dx.doi.org/10.1016/j.riob.2018.10.002.

179. Lu JG, Zhang T, Rucker DD, Galinsk AD: **On the distinction between unethical and selfish behavior**. *Atlas of Moral Psychology*. 2018:465-474.

180. Shi Q, Guo F: **Do people have a negative impression of government on polluted days? Evidence from Chinese cities**. *J Environ Plan Manag* 2018, **62**:797-817 http://dx.doi.org/10.1080/09640568.2018.1443801.

181. Huang Z, Zheng W, Tan X, Zhang X, Liu L: **Polluted air increases perceived corruption**. *J Pac Rim Psychol* 2016, **10**:e13 http://dx.doi.org/10.1017/prp.2016.10.

182. Zeidner M, Shechter M: **Psychological responses to air pollution: some personality and demographic correlates**. *J Environ Psychol* 1988, **8**:191-208 http://dx.doi.org/10.1016/S0272-4944(88)80009-4.

183. Oudin A, Åström DO, Asplund P, Steingrimsson S, Szabo Z, Carlsen HK: **The association between daily concentrations of air pollution and visits to a psychiatric emergency unit: a case-crossover study**. *Environ Health* 2018, **17**:4 http://dx.doi.org/10.1186/s12940-017-0348-8.

184. Loop MS, Kent ST, Al-Hamdan MZ, Crosson WL, Estes SM, Estes MG Jr, Quattrochi DA, Hemmings SN, Wadley VG, McClure LA: **Fine particulate matter and incident cognitive impairment in the REasons for Geographic and Racial Differences in Stroke (REGARDS) cohort**. *PLoS One* 2013, **8**:e75001 http://dx.doi.org/10.1371/journal.pone.0075001.

185. Kahn ME: **Smog reduction's impact on California county growth**. *J Reg Sci* 2000, **40**:565-582 http://dx.doi.org/10.1111/0022-4146.00188.