

REVIEW ARTICLE

One Health in China

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As a result of rapid economic growth over the previous three decades, China has become the second largest economy worldwide since 2010. However, as a developing country with the largest population, this rapid economic growth primarily based on excessive consumption and waste of resources. Thus, China has been facing particularly severe ecological and environmental problems in speeding up industrialization and urbanization. The impact of the health risk factors is complex and difficult to accurately predict. Therefore, it is critical to investigate potential threats in the context of the human-animal-environment interface to protect human and animal health. The “One Health” concept recognizes that human health is connected to animal and environmental health. This review primarily discusses specific health problems in China, particularly zoonoses, and explains the origin and development of the One Health approach, as well as the importance of a holistic approach in China.

Keywords: *One Health approach; human–animal–environment interface; zoonosis; food safety; antimicrobial resistance*

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Consistent with the basic national policy of economic development as the central task, in combination with population growth, urbanization and industrial expansion, high energy consumption and serious pollution have made the ecological system more fragile in China. In the previous three decades, the contradictions among the environment, resources and economic growth have become increasingly prominent. The natural ecology has deteriorated, which not only restricts the long-term economic development but also impacts human interests and even threatens the survival of mankind. The balance between economic development and ecological conservation in China has become a critical issue in recent decades (1). Visible effects, such as emerging infectious diseases, SARS and MERS, indicate the necessity for close collaborations which is the advocacy by One Health include the national and local government, non-government agency, academia, research institute, interdisciplinary science community, the private sector, civil society and other stakeholder. One Health is a interdisciplinary approach suited to address health issues at the human-animal-environment interface (2). One Health

and Ecohealth (Ecosystem health), another holistic approach, despite the different origins, they appear to have increasing alignment regarding the aspects of vision and goals in recent years. However, compared with Ecohealth, One Health focuses more on network building, that's why we only focus on One Health here.

Health problems in China

Increasing health problems at the human–animal–environment interface in China

Currently, China has the largest population in the world, which accounts for 19.7% of the world's total population (1.393 billion/7.126 billion) (3). The population growth rate has declined since the 1970s, when the national ‘One-Child Policy’ was implemented. Nevertheless, the population in 1997 doubled compared with 1949 because of the momentum of population growth. According to the 2013 International Statistics Yearbook (4), China has also experienced substantial economic growth over the previous three decades. However, increasing demands or depletions of natural resources are always in companion

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with the rapid growth of both the population and the national economy.

Impact on environmental health

Worse situation of forest and wetland

Anthropogenic activities and their impacts, including agricultural encroachment, deforestation, road construction, dam building, irrigation, wetland modification, mining, the concentration or expansion of urban environments, and coastal zone degradation (5), have necessitated more contact and interactions among humans, domestic animals, wildlife, and undeveloped environments. These activities cause changes that threaten the capacity and resilience of ecosystems.

Currently, forest coverage is only 21.6% in China, whereas the global average is 31.0%, which indicates that the per capita forest area in China is only approximately one-quarter of the world average. The forest volume in China is 89 m³ per hectare, whereas it is 300 m³ per hectare in the developed countries in Europe. The forest area in China is only one-seventh of the world's average level (6). With accelerated urbanization and industrialization, the ecological restoration space has further been reduced.

Additionally, in the past 5 years, illegal construction has consumed more than 2 million acres of woodland every year, and half of this woodland area had forest coverage. Serious land reclamation issues in the local areas create pressure and challenges in reforestation and ecological restoration overload. According to the Ministry of Land and Resources of the People's Republic of China, the number of lakes has been reduced to 34% since the 1950s, whereas the number of rivers has been reduced by approximately 30,000, and the wetland loss rate has increased up to 21.6% in the previous 50 years (7). Many main wetlands have suffered from severe eutrophication, which leads to loss of wildlife habitat. Thus, wildlife or other domestic animals were compelled to migrate, which may increase human exposure to new pathogens that threaten public health.

Environmental pollution

With the fast-paced urbanization and increased energy consumption in modern China, the level of water, soil, and air pollution resulting from industry, heavy traffic, power generation, and coal smoke has been increasing at an alarming rate (8). According to the statistics of the Environmental Protection Department in 2013, the national wastewater emission was 69.54 billion tons, sulfur dioxide emission was 20.44 million tons, nitrogen oxide emission was 22.27 million tons, and the national industrial solid waste was 3.28 billion tons. (9). The Ministry of Land and Resources reported that the country has 3.33 million hectares of contaminated farmland that cannot be used for any constructive purpose (10). The report from *The Situation of Urban Living Garbage Management Survey* indicated that urban garbage has increased from 25.08

million tons in 1979 to 170.81 million tons in 2012. According to *The National Soil Pollution Condition Survey*, reported by the Environmental Protection Department and the Ministry of Land and Resources, the first investigation to assess the extent of soil pollution was conducted between April 2005 and December 2013, and suggested that the national soil condition was bleak. Nationally, soil in 16.2% of the whole landed area was polluted, with inorganic pollutants (e.g. cadmium, mercury, arsenic, copper, lead, chromium, zinc, and nickel) and organic pollutants (e.g. DDT and polycyclic aromatic hydrocarbons) contributing to 82.8 and 3.8%, respectively. These health risks have a serious influence on the quality of life of individuals with chronic exposure.

Climate change is no longer a distant threat (11). Global warming has been the most obvious phenomenon in countries all around the world. Warmer temperatures and extreme weather events reduce agricultural production and also directly affect human health through various diseases, such as heat-related disorders, mental health problems, vector-borne diseases, food-borne and water-borne diseases, and respiratory and allergic disorders (12). Relevant environmental regulations and laws have not yet solved air pollution in China, and the long-term effects of these measures remain obscure (13).

Furthermore, China has been labeled 'the largest greenhouse gases emitter and serious polluter in the world' (14). In 2012, according to the World Resources Institute (15), globally the total carbon dioxide emission was 33.84 billion tons, with carbon dioxide emission in China being 9.31 billion tons compared with 5.12 billion tons in America. Coal is the main source of energy in China. It has been reported that coal constitutes 67% of the total energy consumption in China, which accounted for half of the world's total coal consumption in 2012 (16). Additionally, the number of private vehicles has increased rapidly from 1.36 million in 1978 to 109.33 million in 2012 (17), and the greenhouse gases emission in China accounted for 57.7% of the total greenhouse gases emission globally (18). In recent years, the grave air pollution in China has attracted worldwide attention. According to the WHO, 16 of the 20 worst polluted cities worldwide are located in China. The negative impact of this serious pollution situation in China is the same or still worse than that of the SARS epidemic in 2003 (13), which in turn may increase the risk of health problems in the populace, including cardiovascular and cerebrovascular diseases (19, 20).

Impact on animal health

Wildlife

Human activities and their impacts, such as hunting and wildlife trade, the introduction of foreign species, urbanization, ecological tourism, construction of transportation infrastructure, climate change, pollution, and habitat destruction (5, 21–23), have direct or indirect impacts on

wildlife. These impacts include changes in behavior, population, distribution, community structure, reproductive capacity, biodiversity, and so on.

Private possession drives illegal wildlife trade in China. Wildlife resource demands have rapidly increased because of the high profits in wildlife businesses, especially with regard to conservation and endangered species. Under the lure of high profits, some individuals illegally hunt and sell wildlife. For example, the number of Tibetan antelopes decreased from 200,000 to 20,000 in the 1980s because Tibetan antelope fur was much sought after in markets; thus, the species has become an internationally endangered species. In addition, ecotourism endeavors, such as the highway in Changbai Mountain Nature Reserve's dense forest and the Qinghai-Tibet railway, has caused shrinkage and fragmentation of wildlife habitat, wildlife death, and changes in their migratory route, which has brought humans, domestic animals, and wild animals into close contact with each other and subsequently altered disease transmission. The role of wildlife in the transmission pathway of diseases has been described.

Climate change and/or habitat loss is a primary mechanism of biodiversity loss (24). Other factors have direct or indirect impact on biodiversity as well. According to the China Species Red List, which has recorded 10,211 species of animals (5,803) and plants (4,408), threatened invertebrates, including critically endangered, endangered, and dangerous, accounts for 34.74%, compared with 12.44% for threatened (nearly unstoppable). Threatened vertebrates account for 35.92%, whereas nearly unstoppable is 7.22%. Biodiversity loss plays a crucial role in the emergence and transmission of infectious diseases (22, 25, 26). The 'dilution effect' holds that biological diversity inhibits infectious diseases (27), which means that biodiversity loss may increase disease risks to humans.

Poultry, domestic animals, and pets

The demand for meat, eggs, and milk has rapidly increased because of the improved living conditions in China. According to 'Meat Consumption in China Now Double That in the United States', which was reported by the Earth Policy Institute, China's meat consumption was one-third of the US consumption in 1978. However, by 1992, China had exceeded the United States as the world's leading meat consumer. China's current annual meat consumption is more than double the consumption of United States. China's meat consumption continues to increase, whereas the corresponding data for the United States is showing a decline. Currently, China's per capita meat consumption is half of the United States; if it reaches the same level as that of the United States, China will end up consuming three-quarters of the beef and 80% of the chicken produced globally (28).

To meet the demand for meat, the animal husbandry industry has been unprecedentedly developed in China.

Livestock production currently accounts for 40% of the gross value of agricultural production in China (29). However, livestock and poultry rearing have become the second largest sources of pollution, immediately behind industries. One example is that of the substantial blue-green algae bloom in Tai Lake, which contaminated the drinking water of millions of people; ultimately, animal husbandry is also considered a main source of pollution. It was reported that domestic wastewater was the main source of pollution in the Yangtze Delta, followed by pollution from raising livestock and poultry, and industrial wastewater. Pigs and poultry produced approximately 90% of the total pollutants related to animal husbandry. It has been reported that the daily discharge of sewage from one pig is equivalent to wastewater from seven humans, and 100 pigs produce 10,000 to approximately 30,000 tons of sewage each year, including 107 tons of nitrogen and 31 tons of phosphorus, which drain off into soil and are subsequently converted to nitrate and phosphate, which in turn pollute both soil and water (30). A substantial number of odorous gases produced by poultry rearing, which contain many poisonous and harmful ingredients, such as ammonia, sulfur, and methane, negatively impact the air quality. In addition, the feces of livestock and poultry contain a substantial number of pathogenic microorganisms, including parasites that may spread zoonotic infectious diseases.

Pathogens carried by pets have gradually aroused public concern (31). Presently, the number of pets is substantial, and the species are also diverse. In addition to traditional pets, such as dogs and cats, there are also other rare species, such as guinea pigs, lizards, and other wildlife, which become members of the family. It was reported that the total number of pets had reached 150 million in a span of 10 years (2003–2013), an increase of 900% during the said period, and the pet economy has reached a staggering ¥90 billion (32). Direct contact with pets may lead to transmission of infectious diseases. Furthermore, the number of stray pets has further increased, and its carrying rate of viruses, bacteria, and parasites is higher than domestic pets. Humans may be infected with rabies, toxoplasmosis, leptospirosis, or salmonella disease via contact or by being bitten (33).

Impact on human health

Zoonosis

Zoonosis has comprised an increasing share of global public health events since the 21st century. Economic globalization, the development of the tourism industry, population growth, and environmental changes (including agricultural intensification, climate change, and biodiversity) objectively intensify the spread of diseases (34–36). It not only causes a serious threat to human health but also harms the development of animal husbandry, affects the

quality and safety of animal production, and leads to economic losses.

Epidemiological situation of zoonosis

It has been reported that 1,415 species of infectious organisms have been identified to be pathogenic to humans. Among these organisms, 868 are zoonotic, which may be transmitted between humans and animals (37). Of the emerging pathogens, 132 pathogens (75%) are zoonotic, and zoonotic pathogens are twice as likely to be associated with emerging diseases compared with non-zoonotic pathogens (38). There are 43 infectious diseases, such as SARS, MERS, H5N1, H7N9, Ebola, and Marburg that have newly emerged worldwide since the 1970s (39, 40). Twenty of these diseases were found in China. In addition, reemerging diseases, such as rabies, pulmonary tuberculosis, and brucellosis, cause additional threats to humans.

Wild animals are substantial natural reservoirs of pathogens (23, 37, 41, 42). Approximately 71.8% of zoonotic events occurring in humans can be traced to wildlife (43), including AIDS, avian flu, plague, foot and mouth disease, rabies, and dengue fever. Wildlife resources are very abundant in China where more than 5,300 types of vertebrates live (44). These wildlife species differ in their habits and also exist in diverse living environments, and the pathogens they carry are complex, which in turn forms a substantial natural pathogen reservoir. Generally, infected wild animals may not exhibit symptoms; however, they can transmit the pathogens to humans via specific mechanisms. Living environments, such as high-density breeding, make contact between captive wild animals and humans easier, which in turn increases the chance of cross-infection. For example, the avian influenza virus H7N9 has emerged with the capacity of cross-species infection; humans would get infected via exposure to the asymptomatic avian influenza virus and then exhibit a high fatality rate (45). Thus, the frequent trade of wildlife and its products has also increased the risk of infection, which clearly threatens public health.

Hazard of zoonosis

The features of emerging infectious diseases are as follows: a wider range of hosts, enhanced virulence during human infections, smaller regional differences, concealing of infected animals, rapid transmission rate, and higher morbidity and mortality. H5N1 has posed significant threats to both humans and animals since it re-emerged in South China in 1996, which caused an outbreak in goose in Guangdong Province. In 1997, 18 H5N1 patients were reported in Hong Kong, and six of them died (46–49). By the end of 2014, there were 42 human infections, with 27 fatalities, which indicated the mortality rate had increased to 64% (50). It has been reported that 5,327 cases with 349 deaths occurred in mainland China during the 2003 worldwide SARS epidemic (51). In 2009, the

outbreak of H1N1 caused 164,902 cases and 878 deaths in China (50, 52, 53). Since the first human H7N9 cases were reported in Guangdong Province in February 2013, up to April 2016, 750 confirmed human cases and 314 deaths have been reported. This could possibly be an even worse threat than H1N1 because H7N9 is a low pathogenic avian influenza virus. All pandemics so far have been caused by low pathogenic viruses, and not by high pathogenic viruses (54). In 2014, severe dengue fever outbreaks occurred, which posed a substantial socioeconomic burden, with 46,864 cases being reported nationwide (50).

Furthermore, resurging infectious diseases also threaten humans and animals. There were only 159 rabies cases in 1996 in China. The reappearance of the rabies epidemic has been continuous and became a rapid growth trend in the early 21st century. There were 2,000 rabies cases in 2003, whereas there were 3,300 deaths in 2007; the fatality rate is nearly 100%, and the rabies situation in China remains severe. Additionally, there are 4.99 million tuberculosis cases nationwide, and this incidence rate is the second highest worldwide (55). There are also approximately 1 million new cases of tuberculosis in China, which is in the forefront of infectious diseases in China.

Emerging and resurging infectious diseases appear to be a major public health problem, which calls for an interdisciplinary and holistic approach to respond to, identify, and manage the disease outbreaks rapidly.

Food safety and security

Globalization has triggered an increasing consumer demand for a wide variety of foods, which has resulted in an increasingly complex and longer global food chain, especially regarding animal products. Although corresponding laws and regulations have been implemented to control food safety issues, massive food safety events have been frequently exposed. Examples include the contamination of infant formula by melamine in 2008, which affected 300,000 infants and young children in China, including six children who died (www.who.int/media/centre/factsheets/fs399/en/).

The factors that cause food safety events include zoonoses (e.g. viruses, bacteria, and parasites), chemical pollutants (persistent organic pollutants), heavy metals, food additives, pesticide residues, and drug residues. Chemical fertilizers, pesticides, drugs, and growth-regulating agents originally had a substantial potential for food security problems. Around 0.5–0.6 million tons of pesticides are used in farm crops every year, and 80% of these pesticides directly enter the environment. Organophosphorus and organochlorine are left in animal meat because it is difficult to be decomposed and are thus eventually transmitted to humans (56). Zeng's study in 2012 demonstrated that fish in the South China Sea contained DDT, which was banned in 1985 (57). To prevent disease and promote growth, farmers use many antibiotics and hormone drugs,

which cause resistance in animal food. In addition, the abusive use of food additives in food processing remains common. Currently, 22 types of 1,812 class food additives in China are used illegally and cause potential threats to human health.

According to China's food safety public opinion report blue book, there were 1,942 food safety events in 2012, and 20,000 to 40,000 food poisoning cases occurred every year. Food poisoning caused by microorganisms accounted for 37.7% of total number of cases (www.nhfdc.gov.cn/zwgkzt/tjnj/list.shtml).

Antibiotic resistance

Antimicrobials are essential to treat bacterial infection (58–61). However, antibiotics abuse in both veterinary and human medicine has led to the emergence and spread of resistant bacteria, which bring about challenges to prevent and control diseases. According to the statistics of the China Pharmaceutical Industry Association, there are 210,000 tons of drug raw materials produced each year, including 97,000 tons used in the livestock industry. Overall, China has become one of the countries worldwide with a major issue of bacterial resistance. The most serious consequence of drug abuse is the emergence of superbugs. Resistant bacteria enter the food chain through animals (e.g. *Salmonella* through chickens) and are subsequently transmitted to humans. In addition, antimicrobial resistance is one of the main threats to modern medicine.

Bacterial resistance in animals may spread to humans, and the consequences are unimaginable. It is predicted that China will have 1 million human fatalities annually because of antibiotic resistance, and the economic losses would be as much as \$20 trillion by 2050 (62), whereas in the United States, an excess of \$20 billion would be spent on direct healthcare annually (63).

Chronic non-communicable diseases

The chronic, non-communicable diseases caused by environmental changes are clear. Accumulating evidence suggests that air pollution is linked with an increased risk of cancers, including lung cancer, breast cancer, and bladder cancer (64). Data from the Global Burden of Disease Study showed that, in 2010, air pollution led to more than 1.3 million premature deaths in China (64), the highest among 15 countries (65). Also, cities, such as Beijing, have been described as 'uninhabitable for human beings' (13).

Impact on social economy

Zoonoses have negative impacts on China's economy. The outbreak of SARS led to a total loss of \$25.3 billion to China's economy, and a 1–2% decrease in the growth rate of China's gross domestic product in 2003 (66). The emergence of the highly pathogenic avian influenza H5N1 virus in late 2003 has resulted in 140 million

poultry deaths and at least 92 human fatalities; it is reported to have cost the poultry industry US\$10 billion in Asia (67). The outbreak of H5N1 in Hong Kong resulted in 1.5 million poultry being slaughtered in 1997. Since the first H7N9 human cases appeared in China in 2003, the economic loss of the poultry industry was more than ¥40 billion by the end of June 2013. The global outbreak of H1N1 has added to the problem of an oversupply of pork in China, and the price of pork had fallen sharply because of the H1N1 outbreak, resulting in huge economic losses of intensive industry. To treat the MERS patients who came from Korea, it has cost more than ¥8 million within 15 days in the Guangdong Province.

One Health practice in China

Development of One Health in China and initial success

Faculties from the School of Public Health at Sun Yat-sen University and other research institutes are devoted to promoting the One Health approach in China. In 2014, an International Symposium on One Health Research was held in Guangzhou city (68); it was jointly hosted by Sun Yat-sen University, South China Agricultural University, the Academy of Military Medical Sciences, and Duke University. The conference topic was 'zoonosis, food safety and security, environment science, wildlife ecology, and antibiotics resistance'. Four Chinese academicians were invited to speak at the meeting. In addition, experts from America, Australia, Singapore, and other countries also attended. Two hundred international delegates involved in the disciplines of public health, clinical medicine, veterinary medicine, and environmental and agricultural science, from more than seven countries, discussed the complex interactions between human health; livestock, pet, and wildlife health; and environmental health during the 2-day conference.

The meeting provided a platform for international cooperation and established the first One Health website, 'One Earth, One World, One Health' (www.healthonly.cn/sunshine.asp?a_id=253), which promotes the development of One Health in China. The initial success of One Health in China is as follows:

First, with the help of the Zhongshan CDC, Guangzhou CDC, and animal husbandry and veterinary departments, Sun Yat-sen University and Duke University conducted a study of 'the relationship between occupational population and influenza virus infection'. The findings indicated that in terms of H3N2 infection, the risk for occupational individuals is 3.4 times higher than community residents, which suggested that occupational exposure may be a risk factor for H3N2 (69). Second, professor LU chose rural areas in Henan Province as the research field and conducted a baseline rabies investigation. Based on the baseline, a specific community intervention model of One

Health was formulated to analyze the residents exposed to rabies. The findings indicated that with the implementation of the One Health community intervention model, the rabies incidence in the residents decreased by 7.59% compared with the previous incidence, and community dog vaccination increased from 13.9 to 82.5%. Third, a study of dengue fever conducted by the Zhongshan CDC and veterinary departments together with the team of professor LU determined that a negative dengue infection is a potential factor in dengue fever outbreak. These findings indicated that One Health plays a vital role in disease prevention and control. This collaboration was beneficial, as it resulted in reduced risks, financial savings, reduced time to detect disease outbreaks, as well as improved plant health services.

Application of the One Health approach to address practical problems in China

Although the first One Health forum was held in China in 2014, the following approach has been applied to address the practical problems in China for many years: a schistosomiasis control program, based on the integration of case detection, health education, and morbidity control in humans; environmental management, such as molluscicide treatment; and livestock and farm management. Subsequently, cost–benefit analysis showed that the schistosomiasis control program generated a societal benefit of \$6.20 per \$1 invested. Additionally, the current mechanism to counter emerging diseases has been a substantial improvement in China concerning collaboration and cooperation, monitoring and decision-making, early warning system and organization since the SARS epidemic in 2003. This responding mechanism for emerging diseases has enabled China to successfully counter H5N1, H1N1, and H7N9 (70).

These examples suggest that interdisciplinary, cross-sectional, and cross-department cooperation can not only protect human health but also prevent unnecessary economic loss, and the loss reduction can be substantial. Additional benefits are likely to be generated through building new social contact networks and collaborative projects among multiple disciplines; however, it seems impossible to monetize these benefits.

Future research priorities

Food safety and security through the food production chain has been referred to as a ‘farm-to-fork’ issue, which is related to the different stages of food production (71), but often originates at the farm (72). Both wild and domestic animals are often regarded as sources of food contamination (73). For example, the general understanding is that the SARS epidemic in 2003 originated directly from human contact with and/or consumption of wildlife or indirectly through contact between wildlife and domestic animals (74, 75).

Each sector has its own responsibilities and priorities; thus, it is difficult to work together if there is no common understanding or mutual interest. However, food safety and security is a good example of the intricate link between humans, animals, and the surrounding environment. The question arises as to why we should first apply One Health in food safety. First, it is the central issue that many sectors pay more attention to, and One Health clearly formulates the benefits of cross-sectoral collaborations and sharing of data. Second, the experience of cross-sectoral collaboration already exists in this field. Finally, it involves food-borne diseases, zoonosis, and antimicrobial resistance, controlling of which may ensure food security and food safety.

It is necessary to establish collaborations between human and veterinary medicine, food authorities, and environmental sectors, and these different sectors should collect data from both humans and animals. These data include the emerging and reemerging zoonotic pathogens (viruses, bacteria, and parasites) and the prevalence, variation, genomic data, and the life cycle of the natural reservoir, as well as antibiotic use and antibiotic sensitivity. Moreover, a database is needed and should be available to scientists from different fields. One successful example in Denmark is an automated program referred to as Vetstat, which has been introduced to collect quantitative data regarding all prescribed animal medicines from veterinarians, pharmacies, and feed mills to control microbial resistance (76).

One Health mostly emphasized zoonosis in its early stage; however, in today’s globalized world, it has shifted to a broad paradigm, including ecology, sustainable development, economics, social justice, equity, and so on (77). For public health actors, a broader acceptance and understanding of One Health principles could influence their thought and values in practice.

Conclusion

Problems at the human–animal–environment interface have become acute and have involved resource waste, environmental disruption and pollution, biodiversity loss, food safety, antibiotic resistance, and emerging and re-emerging infectious diseases. These issues remind us that the health of humans, animals, and the ecosystem is closely interconnected. Addressing these problems at the interface requires collaborative, interdisciplinary, and cross-sectoral approaches. Using the One Health approach, the barriers between disciplines and sectors may be broken down and efforts to anticipate and combat serious challenges for the health of humans, animals, and the environment may be combined.

Authors’ contributions

JYW and LLL contributed to the literature review and manuscript writing. JHL guided writing of the manuscript

and provided the final approval of this version for publication.

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The authors declare that they have no conflict of interests.

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