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Compound natural and human disasters: Managing drought and COVID-19 to sustain global agriculture and food sectors

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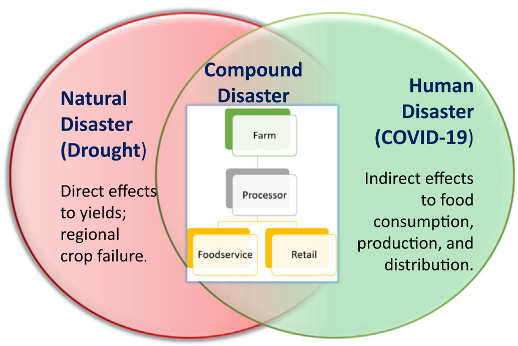
GRAPHICAL ABSTRACT



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ABSTRACT

Individually, both droughts and pandemics cause disruptions to global food supply chains. The 21st century has seen the frequent occurrence of both natural and human disasters, including droughts and pandemics. Together their impacts can be compounded, leading to severe economic stress and malnutrition, particularly in developing countries. Understanding how droughts and pandemics interact, and identifying appropriate policies to address them together and separately, is important for maintaining a robust global food supply. Herein we assess the impacts of each of these disasters in the context of food and agriculture, and then discuss their compounded effect. We discuss the implications for policy, and suggest opportunities for future research.

1. Implications of drought for agriculture and the food sector

Agricultural drought is a period with declining soil moisture and consequent crop failure (Mishra and Singh, 2010). Droughts affect both rain-fed and irrigated agriculture. In the case of rain-fed agriculture, severe droughts may directly reduce or eliminate yields, resulting in crop failure and nutritional and revenue deficits. In the case of irrigated agriculture, the impact of drought depends on the availability of water from storage facilities. Three quarters of the globally harvested land from 1983 to 2009 (454 million hectares) experienced drought-induced yield losses, translating to a loss of approximately $166 billion (Kim et al., 2019). Nearly 10% of the total land area of the United States was subject to either severe or extreme droughts at any given time during the last century. Several studies indicate that droughts are the most expensive natural disasters to strike the U.S. with wide ranging

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effects over many sectors, but most particularly agriculture (Mishra and Singh, 2010). In addition, climate change is likely to impact the spatio-temporal distribution of water availability (Konapala et al., 2020), including green water availability (Veettil and Mishra, 2020), which may significantly increase water stress in agricultural lands worldwide.

Farmers have the ability to adapt to drought conditions. Adaptations include obtaining access to alternative water sources, modifying agronomical practices (Burke and Emerick, 2016, Olen et al., 2016, Hagerty, 2020), or adopting water-conservation technologies (Schoengold et al., 2007). These adaptations have reduced the adverse effects of drought upon yields and revenue (Sumner et al., 2015a, 2015b). Zilberman et al. (2002) reviewed California's response to the 1987–91 droughts and showed that during the first two years of the drought, when sufficient reservoir and groundwater supplies were available, its impact on agriculture was minimal. During the fourth year of the drought, farmers received much-reduced surface water deliveries from storage facilities. Groundwater pumping replaced a third of the reduced supplies; conservation efforts saved a third, and the fallowing of land reduced the need for the remaining third. The drought led to institutional changes, including a "water bank" that introduced trading among regions. Similarly, Sumner et al.'s (2015a, 2015b) assessment of the impact of the severe 2015 drought in California showed that farmers adapted through an increased reliance on groundwater, the fallowing of land, and the growing of lower-value crops. As a result of these adaptations, farm income declined by only 4%, and the impact on employment and agricultural prices was modest. The key in both cases was the heavy reliance on groundwater pumping, which came at a major cost to aquifer supplies, and would have posed a threat to the viability of California agriculture had the drought persisted. However, not everyone was impacted the same; some producers and workers in specific sectors and regions in the state were affected substantially. Farmers and farmworkers can lose significantly from drought, mainly severe, long-lasting ones, like the 2001–2009 drought in Australia (Edwards et al., 2009).

Droughts can have devastating effects on poor developing countries (Morton, 2007). Rural areas in many developing countries are producing their own food and feeding nearby cities. With poor harvests, these countries may need to import food, but may lack either the infrastructure or income to do so. Without global trade, local or regional droughts can be catastrophic for the entire food supply (Wilhite et al., 2007; Mishra et al., 2015). Severe and prolonged drought may lead to hunger and poverty, depletion of natural resources including deforestation, and ultimately, migration from affected areas and a shift from agricultural production (Gleick, 2014; Blakeslee et al., 2020). The combination of limited land and water resources and an increase in extreme weather events will likely pose a significant threat to the sustainability of the agricultural sector. Adaptation strategies must address the likely increased frequency and severity of droughts with climate change (Rodell et al., 2018; Mukherjee et al., 2018, 2020).

Although droughts can affect large regions, they rarely coincide globally. While droughts have significantly impacted the revenues of those living in the affected regions (Liu et al., 2014), they seldom result in a substantial increase in agricultural commodity prices. Indeed, world trade and adaptation protocols have served to mitigate the impacts of droughts on commodity prices, meaning the effects on consumers in the developed world have been mild. Liu et al. (2014) estimate only modest welfare losses from future expected irrigation water shortages using a global general equilibrium model, demonstrating the buffer capacity of global markets to irrigation water scarcity.

Studies have shown that in the developing world, drought may lead to increased malnourishment (Cooper et al., 2019) and contribute to migration, conflicts, and instability (Hsiang et al., 2013, Gleick, 2014). Since droughts are likely to become more frequent and/or severe with climate change (Rodell et al., 2018, Swain et al., 2018, Mukherjee et al., 2020), strategies are needed to address the food supply and revenue disruptions that droughts may cause. Among the solutions to address the challenges of drought include the development and adoption of drought- and disease-tolerant crop varieties (Huffman et al., 2018), improved agricultural practices (Hornbeck and Keskin, 2014), improved water allocation mechanisms (Gleick, 2014), and markets (Anderson et al., 2019).

2. Implications of pandemics for agriculture and the food sector

Large epidemics and pandemics may occur randomly and feature great uncertainty, which raises several urgent challenges. The first challenge is to identify the factors driving the pandemic and solutions to control and eliminate it. In particular, research is needed to identify the cause of the epidemic, the factors that affect its diffusion, the testing mechanism to identify victims, and the medical treatments to cure victims and prevent spread. The second challenge comes with implementing the solution. Developing and manufacturing effective tests, establishing procedures for testing, tracing, isolating, and treating infected individuals, and manufacturing and distributing a vaccine, once one is available, is time-consuming. In the meantime, slowing or stopping the spread requires the implementation of social isolation procedures, including the closure of restaurants, bars, and theatres, which can cause disruptions to food consumption, production, and distribution (CDC, 2020).

Much of the economic cost of a pandemic may occur during the period of constrained activities before finding a solution or extinguishing the disease (Fernandes, 2020). Constrained activities may be due to isolation policies, self-policing, or an economic recession. According to Guan et al. (2020), most countries aimed to stop the spread of COVID-19 by restricting commercial activities and movement with travel restrictions, lockdowns, and other restrictions on businesses. The study found that countries that acted earlier and implemented more drastic measures were able to shorten the duration of the restrictions and reduce the economic damage. The patterns of the spread of the disease across countries indicate mutual dependency, and the reduction of economic activities and control of the disease in one country benefits others. Most countries have already experienced drastic reductions in GNP, which will likely reduce demand for food away from home and shift consumption from high-value foods and luxury products to necessities (Okrent and Alston, 2012).

Even though the COVID-19 pandemic is still ongoing, it has already provided some generalizable lessons on how pandemics can affect the agri-food sector.[1] For example, restrictions on movement among regions and social distancing (shelter-in-place) policies affect the functionality of the food supply chain through short-run shocks to supply and demand in agricultural and food markets. Hobbs (2020) suggests that the introduction of social distancing reduced food consumption away from home (restaurants, schools, events) and shifted consumption towards meals prepared at home. Social distancing also led to panic buying, stockpiling, and increased consumption of basic foods such as eggs and flour. Galanakis (2020) suggests that the pandemic may also increase demand for food products that are believed to boost immune systems. Altogether, though, demand for agricultural commodities may decline, as institutions like restaurants tend to have a higher willingness-to-pay for produce.

Simultaneously, there have been significant changes in supply. Some regions may be experiencing a reduction in migrant farm labor, which can impact harvesting and reduce the supply of fruits and vegetables (Siche, 2020). In other regions, farm labor availability could increase as a result of higher unemployment in cities. Some processing facilities of milk and other products were closed to meet social distancing requirements (Bruno et al., 2020). Restrictions on trade and slower

[1] We do not focus on transmission of the virus itself through the food supply chain. Rizou et al. (2020) focuses on pathways of transmission within foods and food supply chains concluding that the possibility of transmission through the food sector, while possible, is of very low risk and low priority.

movement across borders also reduced supply. The transition from purchases of food from restaurants and other establishments to home requires adaptation by food processors and retailers, including adjustments to packaging. Farmers were forced to respond to changing labor conditions and changing markets. Restaurants, processors, and other links in the food supply chain that could not or cannot adapt to changing demand or meet social distancing requirements will suffer large losses. On the other hand, food delivery services have expanded, so some parts of the food sector may gain from these changes.

One possible outcome of the COVID-19 pandemic is increased concentration in the food sector. At the same time, unemployment among food sector workers has significantly increased. Since many around the world are informal workers, their ability to benefit from compensation schemes enacted in response to COVID-19 is limited. Overall, the longer social distancing continues, it is expected that many businesses in the food sector will accumulate losses which will increase the likelihood of defaults and bankruptcies, resulting in more unemployment. Hobbs (2020) found that food prices in Canada did not change much as a result of COVID-19 and the resulting policies. Bruno et al. (2020) suggest that the prices of some commodities, like eggs, had increased in response, particularly at the wholesale level in California, but altogether prices at retail have not changed much. On the other hand, there have been shortages of some commodities and of some fruits and vegetables, and some retailers have rationed supplies in response.

Food insecurity in the U.S. has increased, in part because of challenges in accessing food from the National School Lunch Program due to school closures (Ambrozek and Beatty, 2020). The Brooking Institute (2020) estimates that one in five U.S. households were food insecure by the end of April 2020, with the greatest levels seen among households with children. Mahajan and Tomar (2020) suggest that in India, the supply of vegetables, fruit and oil has declined by 10% but with a minimal impact on prices. The farther the origin of the product from the market, the lower is the availability. Altogether, the evidence suggests that private supply chains were able to adapt to much of the COVID-19 shock. The decline in demand that resulted from a reduction in economic activities is likely to harm the farm sector. Unlike droughts, pandemics can affect food demand in addition to supply, putting increased strain on the food supply chain.

3. Compound natural and human disasters: drought and Covid-19

A compound disaster arises when the adverse consequences resulting from different disaster agents occur simultaneously. Compound disasters can severely weaken the resilience of multiple sectors, including agriculture, energy, and the environment. In this study, the compound disaster impacting agriculture and the food sector is based on a combination of two different agents: drought (natural disaster) and COVID-19 (human disaster).

The co-occurrence of drought and COVID-19 has occurred across all continents to different degrees. The map in Fig. 1 indicates the extent of drought and intensity of COVID-19 cases around the world. The Western United States, Southeastern Australia, Southeast Asia, and many regions of South America, Africa, and Europe experienced both disasters. The drought will further increase the hardship experienced by those in the farming sector who have been unable to sell their produce due to COVID-19 restrictions. Droughts reduce crop yields and farm revenues, and COVID-19 further disrupts food distribution and demand. Losses associated with the compounded effects of the drought and the pandemic may lead to bankruptcies and unemployment in the rural sector, requiring the injection of credit and other resources to revitalize the rural economies of severely impacted regions.

The drought conditions in the U.S are likely to continue throughout the summer. California agriculture is becoming more vulnerable to drought conditions, which combined with climate change and pandemics, reduces its overall resilience. Similarly, the anticipated drought in Texas will significantly affect the farming sector. Both the lockdown and the most arid spring in half a century severely reduced Italy's agricultural production (the third largest in Europe) (Thelocal, 2020). Across Eastern and Southern Africa, the pandemic is exacerbating food insecurity (EU Science Hub, 2020). This reduction in agricultural

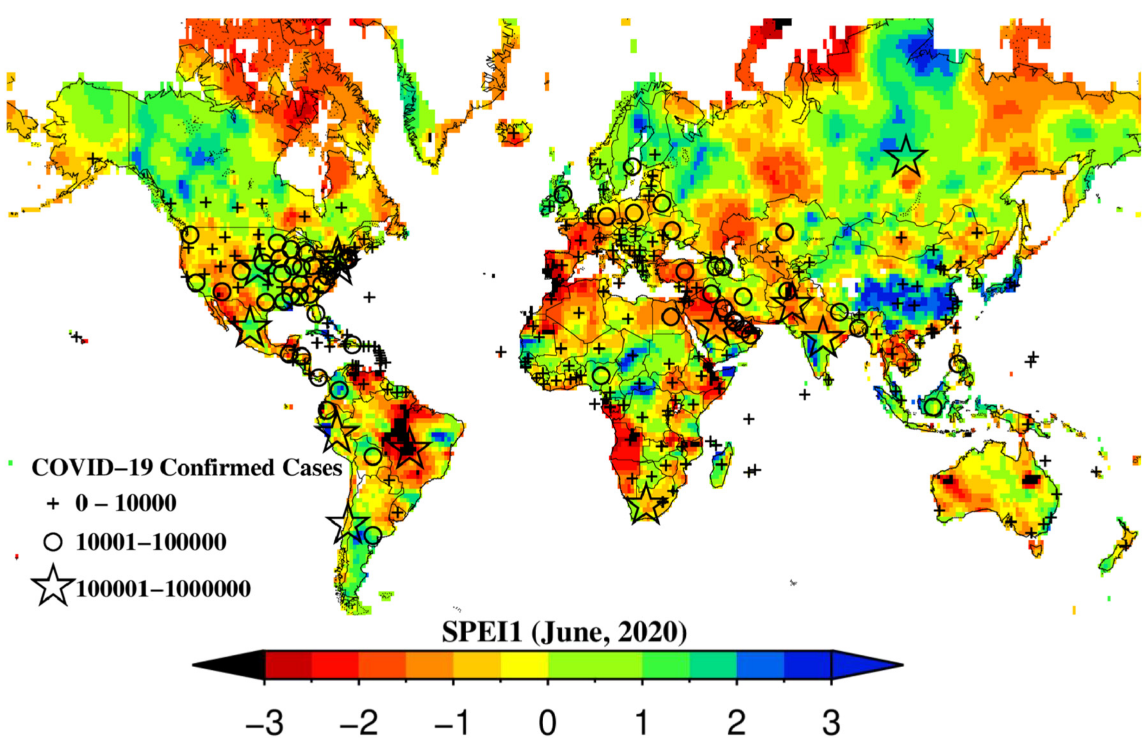

Fig. 1. Global map showing drought condition and COVID-19 cases during the months of June 2020. The co-occurrence of drought and COVID-19 occurs in different geographical regions worldwide. Drought map is based on the Standardised Precipitation-Evapotranspiration Index (SPEI1), and the negative value associated with SPEI1 represents different magnitudes of drought severity; COVID-19 numbers were obtained from Johns Hopkins University (https://coronavirus.jhu.edu/map.html).

production from COVID-19 will likely intensify different food security threats (e.g., conflicts and desert locusts) in East Africa, and the drought that affected Zimbabwe's agricultural output in 2019–2020 will likely trigger an economic downturn (EU Science Hub, 2020).

Although the most severe impacts of COVID-19 and drought have occurred in different regions, COVID-19 indirectly aggravates the impact the drought, with developing nations most affected. Because developed nations, who are suffering significantly from COVID-19, finance most relief efforts, the recession and decrease of the social safety net from the virus will reduce their capacity to contribute to that relief, and developing countries may lack sufficient social safety nets of their own (Laborde et al., 2020).

3.1. The direct and indirect effects of shocks

Both pandemics and droughts are shocks that affect agricultural and food systems. The effects of drought are mostly direct through reduced agricultural output. A pandemic, on the other hand, is a shock to the health system mitigated by vaccines or effective cures. Without a cure, societies must adapt through social distancing and travel restrictions, which results in indirect effects on both food supply and food demand through reduced income, social distancing, and restrictions on movement. Societies have experienced drought for millennia and have developed i) long-term adaptation strategies, including the establishment of irrigation systems, water storage, water conservation, and drought-resistant crops, and ii) transportation infrastructure, and trade and aid mechanisms to direct food to where it is most needed.

The impacts of these shocks vary across locations due to spatial heterogeneity (e.g. differences in climate and biophysical conditions, population density and other demographics, economic activity). So far, the direct effects of COVID-19 (deaths per millions) have been proportionally more substantial in the developed north and in cities than in developing countries and rural areas. The direct effects of drought have been more significant in the developing south than in the north, with bigger impacts in rural areas than in urban regions. The indirect effects of COVID-19, however, have been very substantial in the rural agri-food sector, affected by the recession, social isolation measures, decline in food demand, and reduced labor and constraints on the movement of food products. Drought indirectly affects cities and more developed countries through increased migration and relocation, in some cases leading to social unrest (Hsiang et al., 2013).

Heterogeneity across countries and populations may require differentiated policy interventions. For example, older and health-compromised individuals and concentrated populations are more vulnerable to COVID-19, necessitating more stringent social distancing restrictions than for younger individuals and dispersed populations. Similarly, the impact of drought may vary among regions. Regions with sufficient water reserves may actually benefit because of increased prices. Policies must recognize this heterogeneity.

3.2. Impact on agri-food supply chains

The pandemic is a global problem that affects the supply and demand of food, with impacts all along the agri-food supply chain (Garnett et al., 2020). Agri-food supply chains include upstream producers (farmers); intermediaries including processors, wholesalers and retailers; and consumers. Intermediaries may include traditional, small-scale operations and mom-and-pop stores, as well as modern processors and supermarkets. Although the direct effects on farmers are relatively small, mostly through lower output prices and constraints on labor and transportation, traditional food service processors and retailers are losing substantially due to social isolation. Modern processors may adjust more easily to social distancing constraints, and become stronger because of the pandemic. The market share of supermarkets and food delivery systems is likely to increase, with the net effect being a modernization of agri-food supply chains. Drought is mostly local, affecting farmers upstream and their associated intermediaries and farmworkers, which means that wholesalers and retailers linked to the global market, may obtain supply from alternate sources and avoid the worst affects. Societies have developed mechanisms (i.e. dams, water storage facilities, and drought-resistant crops) to adapt to drought and the resilience of different regions may reflect their investment in these adaptation strategies.

Vulnerable populations suffer the most from the effects of both pandemics and drought. Traditional food intermediaries and the food service sector rely on a low-income, informal workforce that may lose their income in affected drought regions due to the pandemic and its consequences. Further, farmers with junior water rights are likely to be hit hardest during times of drought. Water systems in many places allocate resources according to rules whereby holders of senior rights gain access to the amount that they are entitled to first (Schoengold et al., 2007). During droughts, junior rights owners may end up without water, and if there are limited opportunities for water trade, junior rights owners may lose significantly, and will not be able to obtain water to grow their crops. In this case, a safety net policy that provides emergency aid, as well as international aid, needs to be introduced in the same way that it needs to be introduced in the case of a pandemic. Food protectionism and export restrictions on agricultural products stirred by the pandemic make it even more challenging for water-scarce regions to buffer the negative consequences of drought (Espitia et al., 2020; Kerr, 2020).

Both droughts and pandemics may also result in certain regions and populations facing severe food security problems. In Zimbabwe, for example, the population was already suffering from unemployment, and now must deal with the coronavirus, as well as the consequences of the drought last year (Mukeredzi, 2020). Similarly, 45 million people in 13 Southern African countries became food insecure as a result of combined drought, flood, and the coronavirus (SADC, 2020).

4. Crisis triggers change

Crises like drought and pandemics trigger innovation and technological and institutional change Adaptation to a crisis softens its blow and enhances future resilience. Droughts have led to the increased use of water conservation technologies (ward 2014), to increased reliance on water trading throughout the world, especially in Australia (Grafton et al., 2014), as well as the monitoring and regulation of groundwater in California (Aladjem and Sunding, 2015). The pandemic is triggering quick modifications to food processing practices to protect against the spread of the virus and future diseases. Technology and the use of real-time data can reduce disruptions in the food supply chain by minimizing delays and extending shelf lives (Galanakis, 2020). The use of information technology for food distribution has expanded and improved and is likely to grow in the future, particularly with the expansion of delivery services that may remain a major segment of the food supply chain. Concern for future pandemics may lead to increased automation in harvesting, processing and delivery, thus leading to a shorter and more diversified supply chain, and an expanded plant-based meat industry. Innovation and technological improvements driven by disasters may increase the sustainability of food production, generating benefits for the environment (Rowan and Galanakis, 2020).

Both COVID-19 and drought have raised awareness of the importance of research and innovation. The pandemic accelerated research for vaccines, testing, and cures for the virus, and drought led to investments in drought-tolerant crop varieties and increased water efficiency. COVID is a zoonotic disease, and such diseases are likely to occur as humans continue to encroach on wildlife habitats. Protecting existing wildlife areas and imposing restrictions on the consumption of bush meat may reduce the risk of future pandemics. Further, increased investments in agricultural and veterinarian research, taking advantage of novel ecological and molecular technologies, combined with improved water use will be most important in increasing agricultural productivity and preventing livestock disease (e.g. the recent African swine fever that eliminated 30% of the Chinese swine population and increased the demand for alternative meats).

5. Some common challenges and future directions

There are several common challenges in addressing droughts and pandemics. Both disasters feature great uncertainty in the timing of onset, duration, and degree of severity. When experienced together, these uncertainties and disruptions are compounded, which may lead to severe economic stress and food insecurity. We outline four takeaways and policy responses to better manage coupled human and natural disasters in the future.

First, the pandemic and droughts have important lessons for climate change policy and agricultural sustainability. Minimal initial investment in mitigation strategies requires subsequent costly adaptations, resulting in significant loss of life and economic welfare. Differences in anti-contagion policies in various nations under similar pandemic conditions suggest that an earlier response saved lives and resources (Hsiang et al., 2020). Given the likely increase in the severity and frequency of drought, we can mitigate the costs of future droughts by mitigating climate change. Similarly, investing in mitigation strategies for future global health crises can reduce the costs of the next pandemic.

Second, the recovery from droughts and pandemics requires financial and economic relief efforts to allow affected parties to reestablish themselves. Such relief programs are subject to resource constraints, and their design needs to flexibly adapt to specific regional situations and to control for excessive exposure to future disasters (Hazell et al., 2001). The World Food Organization and other relief agencies can provide emergency food aid, but they require financial resources and access to food supplies. Solving regional hunger problems may be subject to concerns about transmitting infection during pandemics. Robust emergency aid programs are crucial for mitigating economic and public health consequences.

Third, both droughts and pandemics change food supplies and disrupt supply chains, the impacts of which can be buffered through world trade. Closing borders to trade makes it more difficult for any one country to buffer shocks from a pandemic or drought. The strength of the food supply during this pandemic shows that global supply chains continue to function in spite of isolation policies. Reardon et al. (2020) argue that private intermediaries control more than 90% of food processing and transport in India, and the situation is similar elsewhere. The private traders and intermediaries have the resources and know-how to adapt to most changes, and their willingness to do so has important implications for the fallout of these disasters. Global trade enhances our collective resilience to natural or human disasters, but the public sector must monitor industry performance, including possible price gouging and market power abuse, and identify niches to augment private activities.

Finally, modern agriculture is a testimony to the power of science. The introduction of fertilizer, modern breeding, soil management and irrigation has enabled expansion of the human population and a longer life expectancy, with a smaller share of the population working in agriculture (Huffman and Evenson, 2008). However, droughts and pandemics reveal human vulnerability and the limits of our knowledge. While these phenomena demonstrate the limits of science, they also suggest the need for further scientific research and the importance of adhering to scientific advice. Scientists have developed the capacity to better predict droughts and they can initiate early warnings to potential pandemics. While science does not have all the answers, governments that rely on scientific advice are likely to better manage human and natural disasters. To better respond to crises like these, science needs to assist in designing risk governance strategies, namely institutions, rules and capabilities that balance central and regional responsibilities to achieve socially improved outcomes (Van Asselt et al., 2011). Hopefully, these crises will lead to further reliance on science in addressing phenomena such as climate change.

Declaration of competing interest

We acknowledge that our manuscript is original, and it is not submitted for review in another journal. We have provided references for the data set used in our study.

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