

Network Contagion vs. Spatial Proximity: The Diffusion of EHR Incentive Programs in Physician Networks

Abstract

Prior literature on the network contagion theory suggests that health care providers are more likely to adopt the Medicare and Medicaid Electronic Health Record (EHR) incentive program when their direct relations have more prior adopters. Spatial proximity, however, exhibits an opposite finding that providers geographically surrounded with more prior adopters are less likely to adopt the EHR incentive program. The present study found that, when taking both network contagion and spatial proximity into account, providers connected with more prior adopters within 30 miles are more likely to adopt the EHR incentive program. The findings enrich our understanding of how network contagion influences the diffusion of EHR incentive programs and how spatial proximity moderates the effects of network contagion on the diffusion of the EHR incentive programs.

1. Introduction

Health information technology (HIT) are the electronic systems that health care professionals and patients use to store, share and analyze health information. HIT has been widely applied to support healthcare systems and improve cost-effectiveness, efficiency, quality and safety of healthcare delivery (Shekelle et al., 2006). The benefits of implementing HIT include automatizing labor-intensive work, minimizing human errors, speeding laboratory report deliveries, digitalizing patient records, and enhancing decision making and knowledge acquisition. Among those HIT, the electronic health records (EHRs) system is deemed as the most significant step in computerizing healthcare information systems. However, the adoption of the EHRs system had been less than 45 percent until 2009. The most common barriers for healthcare providers or hospitals in adopting EHRs included misaligned incentives, limited purchasing power among providers, viability of EHR products and companies, and lack of demonstrated value of EHRs in practice (Middleton et al., 2005).

In 2011, the Medicare and Medicaid EHR Incentive Programs (now known as the Promoting Interoperability Programs) were established to facilitate the adoption and meaningful use of certified EHR technology in

ambulatory practices and hospitals. The final goal of the program is to improve safety and quality of healthcare delivery. The current program evaluation mostly relies on conventional survey methods to investigate obstacles that the participants have encountered (Adler-Milstein et al., 2014; 2015). The survey evaluations assume that the respondents make their decisions on the EHR incentive program adoption *independently* by assessing its cost-benefit without taking the behavior of other providers into account.

The policy recommendations made based on the findings of such evaluation studies do not reflect the prior research on medical diffusions, which informed us, for instance, that provider networks are likely to influence the diffusion of new drugs through either direct (network contagion) or indirect provider relationships (structural equivalence) (Burt, 1987; Marsden & Podolny, 1994; Strang & Tuma, 1993; Van den Bulte & Lilien, 2001). It should be expected that the similar process would be observed in the diffusion of the EHR incentive programs.

In a provider network, structural equivalence (i.e., similar network positions) is useful normally when network size is small and well-connected, but it serves little utility when network size is large and fragmented. In addition, spatial proximity or spatial interaction between providers would affect the adoption/diffusion process. Spatial proximity creates a space where mimicking of behaviors and localized knowledge spillovers are possible and more likely through informal communications between providers (Autant-Bernard, Mairesse, & Massard, 2007). Hence, the purpose of this study is to understand how providers' network contagion and spatial proximity collectively determine the adoption of the EHR incentive programs.

There are three stages that providers need to go through to be eligible for the reimbursement under the EHR incentive programs. The first stage expects the participants to establish the EHR infrastructure for the electronic extraction of clinical data. The second stage expects the participants to ensure the meaningful use of EHRs. The final stage expects the participants to produce better clinical outcomes and quality of care. The programs specify eligible participants to Medicare and Medicaid providers and hospitals. When the participants complete the three stages, federal

reimbursements are given. The program participation data used in this study were downloaded from the Centers for Medicare and Medicaid Services, Department of Health and Human Services. The present study focused on 17,756 providers who were eligible to participate in the EHR incentive program between 2011 and 2015 in two hospital referral regions (HRR), Arlington (VA) areas (HRR code: 426) and Washington (DC) areas (HRR code: 113). The provider patient-sharing networks (network size = 17,756) were constructed to examine how the program participation spreads in the provider networks. Survival analysis was used to estimate the program diffusion process.

2. Literature review

Social contagion theory is one of the underlying theory to elucidate how the spread of new ideas or practices is contingent on the way in which social proximity brings adopters and non-adopters together. Social proximity of innovations is expressed in two pathways to manage uncertainty of costs and benefits: cohesion and structural equivalence (Burt, 1987; Marsden & Friedkin, 1993). The cohesion approach argues that direct contacts and more frequent communication between adopters and non-adopters is a socialization process where adopters and non-adopters establish normative understanding of the cost-benefit of adopting an innovation. When non-adopters are confronted with a need to make a decision in a vague situation, non-adopters would seek advice from whom they have established trust to discuss the innovation matter (Friedkin, 2004). The contagion phenomena have been continuously found in the topics of spread of options, attitudes, or behavior in communication networks (Christakis & Fowler, 2013). Following this theory, our first hypothesis is:

Hypothesis 1: Network contagion is positively associated with the adoption of the EHR incentive program.

The structural equivalence model holds a contradictory perspective stating that people would compete for “survival” and mimic or learn from each other when they occupy similar positions in the social structure but are not necessarily have a direct contact. For example, two primary care physicians compete to serve as a new drug advisor in the healthcare market, or two graduate students, trained by the same academic advisor, compete for publications to earn their degrees. The structural equivalence model depicts that innovations of non-adopters can be observed when non-adopters maintain similar social positions as adopters (Burt, 1987). The concept of structural equivalence is extended to different measures of structural proximity.

For example, Angst et al. (2010) investigated how prior adopters, social proximity and spatial proximity influence the adoption of EHRs. Social proximity was operationalized as hospitals in a same health system, and spatial proximity was calculated based on the Euclidian distance between two hospitals’ zip codes.

Spatial proximity as a predictor of the diffusion of adoption has demonstrated robust evidence. The arguments of spatial proximity follow a series of propositions. Companies consider location choices as a means of achieving economic benefits, such as the reduction of logistic or production costs, possibilities of recruiting skillful or low-cost employees, or opportunities of R&D collaboration with universities. Because of chasing similar economic incentives, companies with homogeneous features are likely to cluster in a same area, e.g. industrial parks (ref). However, the mechanism of information diffusions among companies is not merely based on homogeneous characteristics. Both competition and interaction play different roles in facilitating the diffusion of innovations. From the competition viewpoint, clustered companies with similar features are likely to form a competitive environment. Spatial proximity creates more opportunities for managers to observe and notice the incidence of innovation adoption from their rival companies. The diffusion of innovations is motivated by competition, and the diffusion process is based on mimicking behavior. From the interaction perspective, spatial proximity creates more opportunities for employees to initiate informal interactions and information exchange with other employees from rival companies. The information may be conveyed back to those employees’ companies and form a decision on innovations (Berry & Baybeck, 2005; Berry & Berry, 1990; Breschi & Lissoni, 2001). In addition, because of high transfer costs of tacit knowledge, spatial proximity offers the opportunity to reduce the costs and facilitate complex forms of knowledge exchange and creation. Within a small boundary of area, the frequent face-to-face interaction is a feasible means to distribute information and clarify whether the information is valuable (Katz, 1994; Ponds, Van Oort, & Frenken, 2007; Hoekman, Frenken, & Van Oort, 2009). Thus, in the process of knowledge transfer, spatial proximity serves as a resolution of overcoming institutional differences between organizations (Ponds, Van Oort, & Frenken, 2007). Geographically bounded and localized individual links and face-to-face interactions significantly contribute to knowledge transfer (Salter & Martin, 2001). Hence, we hypothesize that providers working with other adopters in a same area are more likely to adopt the EHR incentive program:

Hypothesis 2: Spatial proximity is positively associated with the adoption of the EHR incentive program

Moreover, a direct provider network connection coupling with spatial closeness increases the propensity for the program infection. Spatial proximity might serve as a mediator for the spread of the EHR incentive program from one provider to another provider with a direct connection:

Hypothesis 3: Spatial proximity is likely to accelerate the effect of network contagion on the adoption of the EHR incentive program.

3. Methods

3.1. Data sources and management

To understand the effects of network contagion and spatial proximity on adoption of the EHR incentive programs, this study used data from five sources:

1. *EHR Products Used for Meaningful Use Attestation Public Use File*: The dataset contains meaningful use attestations? from the Medicare EHR Incentive Program. (I think this needs to be elaborated)(<https://dashboard.healthit.gov/datasdashboards/documentation/ehr-products-mu-attestation-data-documentation.php>)

2. *Physician Shared Patient Patterns Data*: The dataset contains referrals from one provider to another within a certain time frame in the Medicare program. National Provider Identifier is used to establish referral networks. In their study, Barnett et al. (2011) examined the relationship between provider self-report networks and Medicare claim-based networks in the Boston Hospital Referral Region. The results concluded that two providers shared more Medicare patients are more likely to increase the recognition of referral relationships and advice relationships. Thus, using referral networks to construct provider networks is appropriate.

(<https://questions.cms.gov/faq.php?faqId=7977>)

3. *National Plan and Provider Enumeration System Data*: The dataset is comprised of detailed profiles of healthcare and linked with NPI.

(http://download.cms.gov/nppes/NPI_Files.html)

4. *Hospital Referral Regions*: The dataset “represents regional health care markets for tertiary medical care that generally requires the services of a major referral center. The regions were defined by determining where patients were referred for major cardiovascular surgical procedures and for neurosurgery.”

(<http://www.dartmouthatlas.org/tools/downloads.aspx>)

5. *TIGER/Line Shapefile, 2015, 2010 nation, U.S., 2010 Census 5-Digit ZIP Code Tabulation Area (ZCTA5) National*: The 2010 shpefile is used to create a map covering Arlington and Washington hospital referral regions.

(<https://catalog.data.gov/dataset/tiger-line-shapefile-2015-2010-nation-u-s-2010-census-5-digit-zip-code-tabulation-area-zcta5-na>)

The present study extracted? eligible NPIs (define the first time) registered in Arlington, VA (HRR code: 426) and Washington, DC (HRR code: 113) hospital referral regions from the National Plan and Provider Enumeration System (Dartmouth Atlas of Health Care, 2014). The boundary definitions of hospital referral regions are adjusted every year and the most up-to-date version was published in 2014. Thus, we used the hospital referral regions data from 2011 to 2014 and included all zip codes that appeared in any time periods in Arlington and Washington HRRs (Table 1). As the National Plan and Provider Enumeration System contains the NPIs’ addresses, zip codes from the system and hospital referral regions were used as the crosswalk variable to link provider addresses to zip codes in Arlington and Washington HRRs (Figure 1). The total number of zip codes was 761 representing the total of 4,986 provider locations. Those locations were geocoded to latitude and longitude coordinates using Census’s web service (<https://geocoding.geo.census.gov/>). Of those 4,986 locations, 600 addresses could not be found on the Census web. For those unfound locations, this study used Google Map to manually transform those addresses to latitude and longitude coordinates. The final data used in the analysis contained 17,756 providers and 3,418 locations.

Table 1: Arlington and Washington hospital referral regions

HRR Year	2011	2012	2013	2014	Final Area
Zip Codes	699	705	747	747	761



Figure 1: Map for hospital referral regions

To establish provider networks, the eligible NPIs were used to select claim referral data from the Physician Shared Patient Patterns data between 2011 and 2015. The network properties extracted from the data are summarized in Table 2. The original data shows that the number of edges downloaded from Physician Shared Patient Patterns. It should be noted that the number of referrals increased between 2011 and 2012 but decreased between 2012 and 2015. The network size is the total number of providers in the analysis. The total number of degrees is the number of all referrals made from a provider to other providers. The average degree represents the total number of degrees divided by the network size. The minimum degree reflects the number of providers who did not make Medicare claims in that year. The maximum degree represents the maximum number of claims that the providers made. The density represents all actual connections divided by all theoretically possible connections in the network. The density score ranges from 0 to 1. A density score that is close to 1 indicating the network is denser. A density score is close to 0 indicating the network is looser. The provider networks studied here has low values of the density scores (0.003-0.006). This is expected because a larger network normally has a low density value compared to a smaller network where network members have a higher probability to reach and know each other.

Table 2: Properties of provider networks

	2011	2012	2013	2014	2015
Network size	17,756	17,756	17,756	17,756	17,756
Total number of degrees	9,48,787	981,447	973,305	1,012,412	458,768
Average degree	53	55	55	57	26
Min degree	0	0	0	0	0
Max degree	1,413	1,445	1,394	1,388	866
Density	0.0060	0.0062	0.0062	0.0064	0.0029

The eligible NPIs were used to select providers who participated in the stage one of the EHR incentive programs from the *EHR Products Used for Meaningful Use Attestation Public Use File*.

3.2. Measurements

Program Adoption is a binary variable measuring whether a provider adopted the stage one of the EHR incentive program. One indicates that the provider adopted the program while 0 indicates otherwise.

Location Size is a binary variable measuring whether a location is large or small. One represents that the provider's location has more than 10 providers while 0 represents that the provider's location is equal or less than 10 providers. For most providers, a same location

listed by their NPI registration is likely to represent a same affiliation.

Network Contagion measures the probability of a provider being influenced by other connected providers for the decision to adopt the EHR incentive program. The variable is calculated by the summation of prior adopter/non-adopter multiplied by weighted connections. The weighted values are proportional to the provider's direct connections. (probably the equation here)

Spatial Proximity is the number of prior adopters within 30 miles of the provider's location. The decision for the 30 miles is arbitrary. The maximum distance for a standard patients to visit primary care providers or specialists vary by state, and whether the provider is located in urban or rural area (Table 3). Nonetheless, the number of primary care providers is larger than that of specialists, and most providers are located in urban areas, it may be reasonable to set the maximum distance based on the primary care providers in urban areas. Thus, the present study set the maximum distance as 15 miles for the Arlington HRR, reflecting that patients in the HRR are able to visit providers within 15 miles. In other words, if a patient lives in a place between two providers, an optimal maximum distance between two providers is 30 miles, allowing the patient to visit them within 15 miles. How about DC HRR?

Table 3: Maximum Distance or Time an Enrollee Should Have to Travel to See a Provider (HHS, 2014)

	Primary Care Providers	Specialists
District of Columbia	Within 30 minutes' travel time via public transportation or within 5 miles	No standard
Maryland	Urban: Within 30 minutes or 10 miles Rural: Within 30 minutes or 30 miles	No standard
Virginia	Urban: Within 30 minutes or 15 miles Rural: Within 60 minutes or 30 miles	Urban: Within 30 miles Rural: Within 60 miles

3.3. Model specialization

Because the program adoption variable is a time-event data with right censoring, the hazard modeling is used as the main statistical method to analyze the data. The analysis also includes time-varying variables (i.e. network contagion and spatial proximity variables). Thus, the random-effects parametric survival model with the Weibull survival distribution (time duration distribution) was chosen to test the hypotheses. The providers in the same location are likely to have erroneously small standard errors due to data correlations. Thus, the clustered standard errors are used

to correct the estimation, which yields 3,418 clusters (locations) (Arellano, 2003; Cleves, Gould, & Marchenko, 2016; Stock & Watson, 2008).

4. Analysis and results

4.1. Descriptive statistics

Table 4 shows that 63% of providers are in the locations where there are more than 10 providers, while 37% of providers are located in the locations with less than 10 providers. The EHR adoption rate was 4% in 2011, increased to 12% in 2012 and then decreased to 4% in 2014 and to 2% in 2015. The total adoption rate was 28.68% and the number of adoption was 5,092. The cumulative adoption rate is shown in Figure 4. Figure 5 shows the comparison between provider locations and program adoption locations.

Table 4: Descriptive Statistics

Variable	N	Mean/%	S.D.	Min	Max
Location Size (% of large)	17,756	63%	0.48	0	1
Adoption rate in 2011 (%)	17,756	4%	0.20	0	1
Adoption rate in 2012 (%)	17,756	12%	0.33	0	1
Adoption rate in 2013 (%)	17,756	6%	0.24	0	1
Adoption rate in 2014 (%)	17,756	4%	0.20	0	1
Adoption rate in 2015 (%)	17,756	2%	0.14	0	1
Network Contagion in 2011	17,756	0.05	0.12	0	1
Network Contagion in 2012	17,756	0.19	0.25	0	1
Network Contagion in 2013	17,756	0.27	0.31	0	1
Network Contagion in 2014	17,756	0.31	0.33	0	1
Network Contagion in 2015	17,756	0.27	0.34	0	1
Spatial Proximity in 2011	17,756	519.93	204.09	15	654
Spatial Proximity in 2012	17,756	1955.39	727.56	45	2482
Spatial Proximity in 2013	17,756	2677.47	1001.76	54	3364
Spatial Proximity in 2014	17,756	3161.33	1187.93	67	3999
Spatial Proximity in 2015	17,756	3406.26	1281.29	69	4317

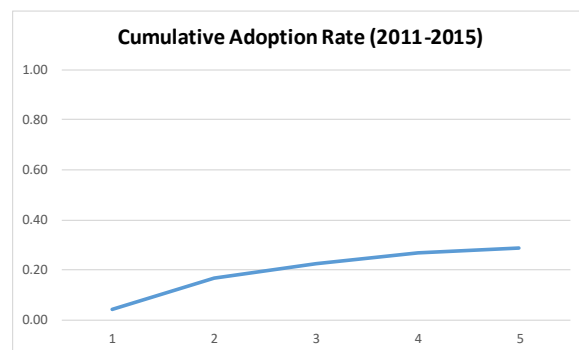


Figure 4: Cumulative Program Adoption Rate from 2011 to 2015

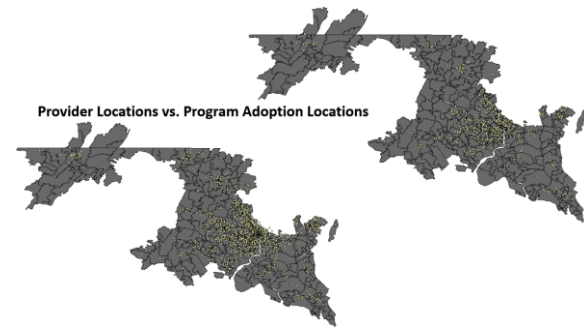


Figure 4 is very hard to see...

4.2. Hazard model analysis

Table 5 summarizes the results of the hazard models analyses with different predictors for the adoption of the EHR incentive program. The first model shows that location size does not have a significant effect on the adoption. In the second model predicts that the adoption rate would increase 177% with a unit increase in the network contagion measure. The adoption rate would decrease 0.05% with a unit increase in spatial proximity. The fourth model includes all three predictors. The results indicate that all predictors are statistically significant. Location size and network contagion are positively associated with adoption of the EHR incentive program, but spatial proximity is negatively associated. The fact that the location size is statistically insignificant in the first model while it has statistically significant positive effect in the third model indicates that location size is likely to have interaction effects with other predictors.

In the fifth model, we explored whether location size accelerates the effects of network contagion and spatial proximity on the adoption of the EHR incentive program (Hypothesis 3). The interaction effect of location size and spatial proximity was not statistically significant, while the other two interaction effects were statistically significant. Thus, the interaction effect of location size and spatial proximity was subsequently dropped from the fifth model. In the sixth model, both interaction terms were statistically significant, indicating that a large location size coupling with a high value of network contagion tends to lead to EHR adoption compared to a small location size with a higher value of network contagion. Likewise, a higher value of network contagion coupling with a higher value of spatial proximity tends to promote the adoption EHR incentive program compared to a lower value of

network contagion coupling with a lower value of spatial proximity.

Finally, there are several parametric distributions, which can be used to specify the hazard model. To ensure that the Weibull distribution is appropriate, we tested the goodness of fit of Gamma, Loglogistic and Lognormal distributions for the last model (Table 6). The table shows that the Weibull distribution has the best goodness of fits in terms of AIC and BIC.

Table 5: Random effects Weibull regression

	1 Hazard Ratio (SE)	2 Hazard Ratio (SE)	3 Hazard Ratio (SE)
LocationSize	1.1236 (0.0831)		
NetworkContagion $t-l$		2.7679*** (0.1728)	
SpatialContagion $t-l$			0.9995*** (0.0000)
Constant	0.0054*** (0.0003)	0.0044*** (0.0003)	0.0145*** (0.0013)
Log pseudolikelihood	-19812	-19502***	-18698***
Observations	71,024	71,024	71,024
Groups	17,756	17,756	17,756

*p < 0.05; **p < 0.01; ***p < 0.001; SE adjusted for 3,418 clusters (locations)

Table 5: Random effects Weibull regression (cont.)

	4 Hazard Ratio (SE)	5 Hazard Ratio (SE)	6 Hazard Ratio (SE)
LocationSize	1.3531** (0.1332)	1.8633*** (0.3248)	1.5670*** (0.1794)
NetworkContagion $t-l$	2.3715*** (0.2004)	1.5275** (0.2069)	1.5548** (0.2046)
SpatialContagion $t-l$	0.9995*** (0.0000)	0.9995*** (0.0000)	0.9994*** (0.0000)
LocationSize x NetworkContagion $t-l$		0.7074* (0.0971)	0.6850** (0.0952)
LocationSize x SpatialContagion $t-l$		0.9999 (0.0000)	
NetworkContagion $t-l$ x SpatialContagion $t-l$		1.0003*** (0.0001)	1.0003*** (0.0001)
Constant	0.0096*** (0.0008)	0.0098*** (0.0009)	0.0109*** (0.0009)

Log pseudolikelihood	-18413***	-18341***	-18353***
Observations	71,024	71,024	71,024
Groups	17,756	17,756	17,756

*p < 0.05; **p < 0.01; ***p < 0.001; SE adjusted for 3,418 clusters (locations)

Table 6: Cross-Validation Tests

	Weibull Distribution	Gamma Distribution	Loglogistic Distribution	Lognormal Distribution
AIC	36712.45	44762.89	44956.41	43886.89
BIC	36778.21	44828.65	45022.17	43952.65

5. Discussion

The present study is the first research that used provider referral networks in panel data to examine the factors influencing the diffusion of the EHR incentive program in Arlington, VA and Washington, DC Hospital Referral Regions (Bae et al., 2015). The results support first and third hypotheses but did not support second hypothesis. The findings indicate that providers exposed to more prior adopters in referral relations are more likely to adopt the EHR incentive program. Nevertheless, spatial proximity is negatively associated with the adoption of the EHR incentive program, indicating that providers geographically surrounded with more prior adopters within 30 miles are less likely to adopt the EHR incentive program. When specializing spatial proximity as a moderator, providers exposed to more prior adopters within 30 miles are more likely to adopt the EHR incentive program. Another intriguing finding is that location size matters, but only when network contagion is considered. A large location size coupling with a higher network contagion tends to increase the likelihood of the adoption of the EHR incentive program.

The analytical approach and the findings of the present study have several implications. First, the analytical framework used in the present study can be applied to understand other diffusion phenomena including that of other health policy programs, new drugs or therapies diffusion. Prior research explored the association between properties of provider referral networks and patient characteristics (Landon et al., 2012), while other researchers examined how provider referral networks are associated with health care patterns (Barnett et al., 2012). For policymakers, the network analysis approach can be used as a guidance to identify key providers that may facilitate the policy implementation process (Valente, 2012; Valente et al., 2015). Such a study, however, would require collecting more data on provider characteristics, e.g., whether the provider is a specialist or a primary care provider.

Second, the spatial proximity theory is not supported in our findings. One possible explanation is

the inappropriate measure of the variable. In this study, spatial proximity is defined as the number of prior adopters within 30 miles of the provider's location. Although 30 miles may be appropriate for providers in the urban area in Virginia, it may be too large for providers in the urban areas in Maryland or District of Columbia. Further investigation on the optimal distance is warranted as well as a sensitivity analysis with different values for the maximum distance.

Third, the location size in our study plays a significant role in facilitating the network contagion process. Providers with a large location size can be viewed as working in large hospitals, i.e., large hospitals are expected to have a higher capacity of implementing EHR systems or handling the administrative process of the program participation. When those providers in a large hospital system are exposed to more prior adopters via referral networks, the peer pressure will influence their decisions on the program adoption. In contrast, providers in a small location tend to have a less capacity to implement EHR or to handle the administrative process. Even though peer pressure can influence those providers' decisions to adopt the program, lack of organizational resources may hamper the program

adoption. Furthermore, the matter of a location size depends on? the unit of analysis. In practice, the EHR incentive program may be? adopted by hospitals and then spreads to providers. However, this study assumed that providers are the decision makers of the program. Future investigation may aggregate the data to estimate whether the network contagion and spatial proximity still contribute to the adoption of the EHR incentive program at the hospital level.

6. References

List and number all bibliographical references in 9-point Times, single-spaced, at the end of your paper. When referenced in the text, enclose the citation number in square brackets, for example [1]. Where appropriate, include the name(s) of editors of referenced books.

References should be organized according to the order in which they are referred to in the paper.

- [1] A.B. Smith, C.D. Jones, and E.F. Roberts, "Article Title", Journal, Publisher, Location, Date, pp. 1-10.
- [2] Jones, C.D., A.B. Smith, and E.F. Roberts, Book Title, Publisher, Location, Date.