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Racial and Ethnic Disparities in Breastfeeding Practices and the Impact of Interventions in a Low-Income Population in Los Angeles County

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Racial and Ethnic Disparities in Breastfeeding Practices and the Impact of Interventions in a Low-Income Population in Los Angeles County

A dissertation submitted in partial satisfaction of the

requirements for the degree Doctor of Philosophy in

Community Health Sciences

by

Linghui Jiang

2021

ABSTRACT OF THE DISSERTATION

Racial and Ethnic Disparities in Breastfeeding Practices and the Impact of Interventions in a Low-Income Population in Los Angeles County

by

Linghui Jiang

Doctor of Philosophy in Community Health Sciences

University of California, Los Angeles, 2021

Professor May C. Wang, Chair

Breastfeeding is one of the most effective 'interventions' for reducing infant mortality. Despite ongoing efforts to promote breastfeeding, current breastfeeding rates in the U.S. are still low, and socioeconomic and racial/ethnic disparities in breastfeeding practices have persisted. Improving breastfeeding practices among socially disadvantaged groups remains challenging.

The goal of this dissertation is to improve breastfeeding rates and reduce racial/ethnic disparities in breastfeeding practices in the United States. Specifically, this dissertation aims to: (1) assess the influences of breastfeeding support from family, hospitals and workplaces on breastfeeding duration; (2) determine the extent to which racial/ethnic disparities in breastfeeding duration could be explained by breastfeeding support; and (3) estimate the population impact of multifaceted breastfeeding promotion interventions.

Using data on approximately 4,000 mothers enrolled in the Special Supplemental Nutrition Program for Women, Infants and Children (WIC), from the triennial Los Angeles County WIC Survey (2014, 2017), this dissertation found that breastfeeding support from family, hospitals and workplaces was significantly associated with longer breastfeeding duration, and that Black mothers and English-speaking Latina mothers have significantly lower breastfeeding rates than White mothers, with the difference widening over increasing duration. Results from causal mediation analysis (specifically, g-computation) showed that lack of access to breastfeeding support from family, hospitals and workplaces accounted for approximately two-thirds of the difference in breastfeeding duration between White and Black mothers, and one-third of the difference between White and English-speaking Latina mothers. This dissertation also illustrated the use of agent-based modeling (ABM) for estimating the population impact of five selected breastfeeding promotion interventions (improving knowledge, implementing Baby-Friendly Hospital Initiative practices, providing breastfeeding counseling, strengthening family support, and fostering supportive workplace environments) implemented singly or in combination with each other. The ABM demonstrated that while improving knowledge and increasing the availability of Baby-Friendly Hospital Initiative practices improve breastfeeding initiation rates, breastfeeding counseling, family support and a supportive workplace environment are more effective in improving breastfeeding duration. Increasing the coverage of multiple interventions simultaneously had a synergistic effect on breastfeeding duration, with their effects being greater than the additive effects of increasing the coverage of these interventions singly.

This dissertation of Linghui Jiang is approved.

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LIST OF ACRONYMS

AAP	American Academy of Pediatrics
ABM	Agent-based modeling
BFHI	Baby-Friendly Hospital Initiative
CDC	Centers for Disease Control and Prevention
CI	Confidence interval
LAC	Los Angeles County
FPL	Federal poverty level
OR	Odds ratio
RCT	Randomized control trial
SES	Socioeconomic status
SNAP	Supplemental Nutrition Assistance program
TRA	Theory of Reasoned Action
TPB	Theory of Planned Behavior
UNICEF	United Nations Children's Fund
WHO	World Health Organization
WIC	Special Supplemental Nutrition Program for Women, Infants and Children

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credited. A copy of the published paper and supplementing information was attached as an appendix for Chapter 7.

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Chapter 1: Introduction

Breastfeeding is beneficial for both infants and their mothers [1-3]. Breastfeeding provides children with protection against infections, improves cognitive development, and is associated with reduced risk of obesity development and diabetes later in life [1, 2]. Some examples of potential benefits for mothers include reducing risk of breast and ovarian cancer, diabetes, and improving birth spacing [1, 2]. It is estimated that 823,000 deaths of children under 2 years old could have been prevented every year with universal breastfeeding [4]. The American Academy of Pediatrics (AAP), and international organizations concerned with child health such as the United Nations Children's Fund (UNICEF) and the World Health Organization (WHO), recommend that infants be breastfed exclusively through the first six months of life, followed by continued breastfeeding and complementary foods until at least 1-2 years of age [1, 2]. The 2020-2025 Dietary Guidelines for Americans, for the first time since its 1985 edition, has included these same recommendations on breastfeeding as healthy dietary patterns for infants [5].

The current duration and exclusivity of breastfeeding in developed countries including the United States are far behind the aforementioned recommendations. According to the National Immunization Survey Report, among all American infants born in 2017, only 58% were breastfed and 26% were exclusively breastfed through 6 months [6]. Furthermore, there are sociodemographic and racial/ethnic disparities in breastfeeding practices, with the lowest socioeconomic status (SES) women having the lowest breastfeeding rates [6]. There is at least a 15 percentage-point difference in rates of breastfeeding initiation and breastfeeding for 6 months between White and Black mothers [7]. In general, Black women and American Indian/Alaska Native (AI/AN) women had lower breastfeeding rates at birth, 6 months and 12 months

postpartum than their White counterparts, while other minorities group such as Asian and Hispanic women had comparable or even higher breastfeeding rates than non-Hispanic Whites [6].

Efforts to increase the prevalence of breastfeeding require identification of factors associated with the decision to breastfeed, and facilitators of and barriers to the practice of breastfeeding. The decision to initiate and maintain breastfeeding is influenced by individual-level factors such as personal sociodemographic characteristics, health conditions, and sociocultural beliefs and norms regarding breastfeeding as well as structural-level factors such as hospital practices, workplace policies and employment policies (e.g. paid parental leave that supports breastfeeding) [8-10]. To achieve optimal duration of breastfeeding, women have to overcome many barriers. Studies have suggested that support from family, health care systems, and workplace may help to promote breastfeeding [9-11]. However, few studies have examined differential access to breastfeeding support among socially disadvantaged women and the role of breastfeeding support in breastfeeding outcomes [12-16].

Although breastfeeding rates have improved during the past few decades, racial/ethnic disparities in breastfeeding practices have persisted in the United States [17-19]. While racial/ethnic disparities in breastfeeding are often intertwined with socioeconomic disparities in breastfeeding, studies suggest that access to breastfeeding support from family, health care systems, and workplace may play a critical role in narrowing sociodemographic and racial/ethnic disparities in breastfeeding practices [20, 21]. However, the causal pathways by which socioeconomic and racial/ethnic factors influence breastfeeding practices have not been elucidated.

A large number of breastfeeding promotion interventions have been conducted in developed countries, and there is growing evidence on the efficacy and effectiveness of various interventions [22-29]. The U.S. Centers for Disease Control and Prevention (CDC) categorized six types of interventions as effective: maternal care practices, breastfeeding support in the workplace, peer support, educating mothers, professional support, media and social marketing [30]. However, health professionals and other decision makers face challenges in selecting the most appropriate interventions for promoting breastfeeding as there is a dearth of information on the potential population impact of various interventions implemented singly or in combination with each other in community settings. Practical and ethical constraints render the application of experiments to evaluate potential interventions almost impossible. As a result, there is increasing interest in the use of systems science approaches such as agent-based modeling for predicting the potential population impact of different intervention strategies under varying policy scenarios [31-33].

The purpose of this dissertation is to investigate breastfeeding practices among low-income families enrolled in the Special Supplemental Nutrition Program for Women, Infants and Children (WIC) in Los Angeles County (LAC). LAC is one of the most socioeconomically and ethnically diverse regions in the U.S. and is home to the largest local agency WIC program in the country, PHFE-WIC (https://www.phfewic.org/). WIC is a federal nutrition assistance program mandated to provide nutrition education, supplemental foods, and health care referrals to low-income pregnant and postpartum women, and children ages 0-5 years [34]. Using data from the 2014 and 2017 Los Angeles County WIC Survey (https://lawicdata.org/), this dissertation aims to: (1) assess the influences of breastfeeding support from family, hospitals and workplaces on breastfeeding duration; (2) determine the extent to which racial/ethnic disparities in

breastfeeding duration could be explained by breastfeeding support; and (3) estimate the population impact of multifaceted breastfeeding promotion interventions on breastfeeding practices.

This dissertation consists of eight chapters. In chapter 2, I give an overview of the importance and trends of breastfeeding practices, the factors influencing breastfeeding behavior, and major interventions implemented to improve breastfeeding rates in the United States. Research gaps in the existing literature are discussed. In chapter 3, I present the conceptual framework for investigating the factors that influence breastfeeding practices, causal mechanisms underlying racial/ethnic disparities, and the population impact of various breastfeeding promotion interventions. The theories behind the conceptual framework include the Theory of Reasoned Action (TRA), Theory of Planned Behavior (TPB), socioecological model and fundamental cause theory. Chapter 4 provides a detailed description of the datasets used for this dissertation. In chapter 5, 6 and 7, the three specific aims of this dissertation are addressed by three separate but related individual studies. **Table 1.1** summarizes the study aims, data source and analytical methods for each of the three studies. In the last chapter, I conclude by discussing the contribution of this dissertation to the literature on breastfeeding behavior and interventions, and provide recommendations on future research directions.

Table 1.1 Overview of three individual studies

#	Study aims	Data sources	Exposure/ Interventions	Outcomes	Analytical methods
1	Assess the influences of breastfeeding support from family, hospitals and workplaces on breastfeeding duration	2014 and 2017 Los Angeles County WIC Survey Baby-Friendly USA	Family support Baby-Friendly designation of hospital Baby-Friendly hospital practices Workplace support	Breastfeeding duration	Multiple logistic regression
2	Determine the extent to which the differential access to breastfeeding support explains the racial/ethnic disparities in breastfeeding duration	2014 and 2017 Los Angeles County WIC Survey	Race/ethnicity	Breastfeeding duration	Causal mediation analysis (parametric G-computation)
3	Estimate the population impact of multifaceted breastfeeding promotion interventions on breastfeeding practices	2014 WIC survey Empirical evidence from the literature	Improving knowledge through education Implementing Baby-Friendly Hospital Initiative practices Providing breastfeeding counseling Strengthening family support Fostering supportive workplace environments	Breastfeeding initiation and duration	Agent-based modeling

Chapter 2: Background and Significance

In this chapter, I will review the existing literature on breastfeeding promotion and discuss the importance and trends of breastfeeding practices in the United States, the factors influencing breastfeeding behaviors, and major interventions implemented to improve breastfeeding rates in the United States. Research gaps in the existing literature will be summarized at the end. Consistent with the widely accepted definitions of the World Health Organization [1] and the Interagency Group for Action on Breastfeeding [35], the following definitions for breastfeeding practices are used in this chapter and throughout this dissertation:

- *Any breastfeeding* is defined as feeding the infant any amount of breast milk (including expressed milk and milk from a wet nurse), regardless of whether the infant is given other food or liquid.
- *Exclusive breastfeeding* is defined as feeding the infant only breast milk and no other food or liquid (including milk from a wet nurse), not even water; oral rehydration solution, and drops and syrups (vitamins, minerals and medicines) are allowed.

Importance of breastfeeding and trends in the United States

The benefits of breastfeeding are well established in the literature. Breastfeeding has many short-term and long-term health benefits for both infants and mothers [1-3]. Breast milk provides optimal nutrients to meet infants' nutritional and developmental needs, and reduces the risk for obesity and diabetes later in their life [3, 36-38]. The immunological substances in mothers' breast milk provide protection for children against common infections, such as acute otitis media, atopic dermatitis, gastrointestinal infections, and lower respiratory tract diseases [3,

39, 40]. Potential health benefits for nursing women include reduced risk for breast cancer and ovarian cancer, and improved birth spacing [41-43]. Breastfeeding is one of the most effective public health practices for reducing child mortality [4]. It is estimated that 823,000 deaths of children under 2 years old and more than 22,000 breast cancer deaths of women could have been prevented every year with universal breastfeeding [4, 44].

In addition, breastfeeding provides social and economic benefits to families and the whole society. Breastfeeding facilitates bonding between mother and infant, alleviates financial burden from formula purchase for families, reduces health care costs associated with adverse health outcomes, and decrease parental absenteeism from work due to child illness [2]. A recent and widely-cited study by Bartick and Reinhold [45] estimated the excess cost of 10 pediatric diseases (such as necrotizing enterocolitis, otitis media, and gastroenteritis) and child deaths attributable to the suboptimal breastfeeding rates in 2005 and concluded that the United States would save $13 billion annually if 90% of American families were to breastfeed their infants exclusively for 6 months.

Recognizing the evidence on the benefits of breastfeeding, the World Health Organization (WHO) and the United Nations Children's Fund (UNICEF) released a global health recommendation in 2002 that infants should be exclusively breastfed for the first six months of life, and thereafter should receive nutritionally adequate and safe complementary foods while breastfeeding continues for up to two years of age or beyond [46, 47]. Starting 1997, the American Academy of Pediatrics (AAP) has provided its infant feeding recommendations in various versions of the policy statement, *Breastfeeding and the Use of Human Milk*. The AAP recommended exclusive breastfeeding for the six months for infants, then continuing

breastfeeding with proper complementary foods for at least one year or longer if mutually desired by mother and child [2, 48, 49].

The current rates and duration of breastfeeding in the United States fall short of these global and national health recommendations [4]. The 20th century witnessed dramatic changes in breastfeeding rates in the United States. Breastfeeding was universal at the beginning of the 1900s, then, decreased significantly during the following decades reaching its nadir in the early 1970s when only 22% women initiated breastfeeding [50-52]. The downward trend in breastfeeding rates is often attributed to large-scale social changes that have taken place over the past few decades. For example, increasing female participation in the work force, increasing use of anesthesia and centralized nurseries for birthing, and aggressive marketing of infant formula industry have presented barriers to the adoption of breastfeeding [50, 53].

Since the mid-1990s, breastfeeding rates have been climbing slowly in parallel with major efforts to promote breastfeeding [50, 54]. In 1981, the WHO adopted the *International Code of Marketing of Breast-milk Substitutes* to regulate the marketing of infant formula and other breast-milk substitutes [55]. In 1990, the WHO and UNICEF released the *Innocenti Declaration on the Protection, Promotion and Support of Breastfeeding* [56]. Shortly after that, the Baby-Friendly Hospital Initiative (BFHI) was launched in 1991 to promote breastfeeding in maternity care facilities [57]. In the United States, the federal regulation, *Family and Medical Leave Act*, was passed in 1993 to provide eligible employees with up to 12 weeks of unpaid family leave [58]. The key indicators of breastfeeding were included in the 1990 Health Objectives for the nation and in the Healthy People goals for the following four decades. Progress towards these objectives has been regularly monitored [59, 60]. In 2011, the *Surgeon*

General's Call to Action to Support Breastfeeding laid out the action steps to create a supportive environment to make breastfeeding possible for every mother who desired to breastfeed [9]. The Special Supplemental Nutrition Program for Women, Infants and Children (WIC) also launched several policies and interventions to promote and support breastfeeding among low-income mothers, including training staff to provide breastfeeding education and counseling, developing and distributing information and educational materials, offering a greater quantity and variety of foods for breastfeeding mother-infant dyads, providing breastfeeding aids such as breast pumps and breast shells, and establishing the Loving Support Award program to recognize local WIC agencies that implemented exemplary breastfeeding interventions [61].

During the 21st century, the breastfeeding rates in the United States have been continuously improving. The national average of most key breastfeeding indicators in 2017 has met the Healthy People 2020 targets except the rate of any breastfeeding at 6 months (**Table 2.1**). However, the current rate and duration of breastfeeding are still far from optimal in the United States compared to the recommendations. Among all American infants born in 2017, although 84.1% were ever breastfed, only 25.6% were exclusively breastfed through 6 months and only 35.3% were breastfed for at least one year [6]. Meanwhile, there are significant racial/ethnic and socioeconomic disparities in breastfeeding practices. Specifically, fewer Non-Hispanic Black infants were breastfed than infants of other racial/ethnic groups; mothers from the families with income below the Federal Poverty Level (100% FPL) are much less likely to breastfeed their children compared to other higher income groups; mothers with college education are more likely to breastfeed their children than those with less than high school education [62]. A more detailed review of literatures on the racial/ethnic disparities in breastfeeding as well as its interaction with socioeconomic disparities will be discussed later in this chapter.

Table 2.1 Healthy People 2020 goals on breastfeeding and breastfeeding rates by race/ethnicity and socioeconomic status among infants born in 2017

Socio-demographics	Any Breastfeeding			Exclusive Breastfeeding	
	Ever breastfed (%)	Breastfed at 6 months (%)	Breastfed at 12 months (%)	Exclusive breastfeeding through 3 months (%)	Exclusive breastfeeding through 6 months (%)
Health People 2020 goal	81.9	60.6	34.1	46.2	25.5
US National	84.1	58.3	35.3	46.9	25.6
Race/ethnicity					
Hispanic	84.1	55.4	33.9	41.5	21.5
Non-Hispanic White	86.7	61.9	38.2	52.4	28.7
Non-Hispanic Black	73.7	47.8	26.1	38.7	21.2
Non-Hispanic Asian	90.0	73.5	50.0	47.7	26.8
Non-Hispanic Hawaii/Pacific Islanders	85.2	NA	NA	NA	NA
Non-Hispanic American Indian/Alaska Native	80.7	NA	NA	NA	NA
2 or more races	83.7	56.5	31.0	43.9	26.6
Maternal Education					
Less than high school	73.6	49.0	28.9	30.8	17.1
High school graduate	75.6	44.1	25.7	41.7	21.5
Some college or technical school	84.7	53.6	31.1	45.4	23.3
College graduate	93.3	74.0	46.6	57.2	32.8
Poverty Income Ratio					
Less than 100	76.6	46.9	27.0	39.1	20.0
100-199	80.3	52.1	31.9	42.7	23.8
200-399	86.4	61.8	39.0	49.9	28.6
400-599	91.8	67.0	41.0	54.7	29.3
600 or greater	93.1	75.7	45.1	56.3	30.6

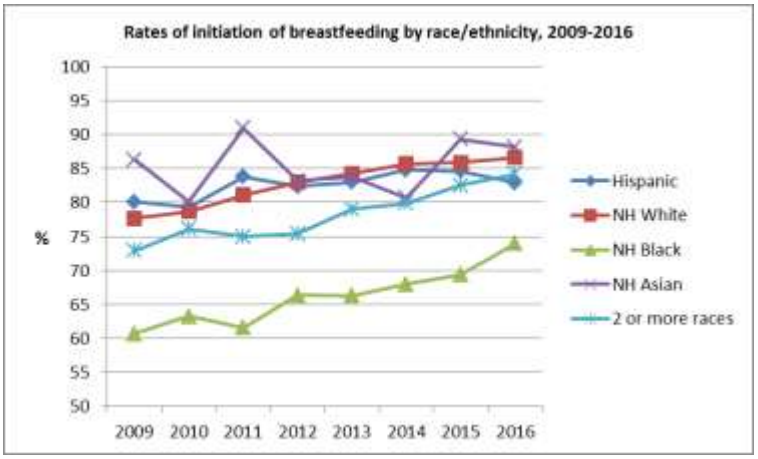
Note: (1) Data source for breastfeeding rates: National immunization survey, Center for Disease Control and Prevention, Department of Health and Human Services. https://www.cdc.gov/breastfeeding/data/nis_data/rates-any-exclusive-bf-socio-dem-2017.html (2) The Healthy People 2020 targets on breastfeeding: https://www.healthypeople.gov/2020/topics-objectives/topic/maternal-infant-and-child-health/objectives

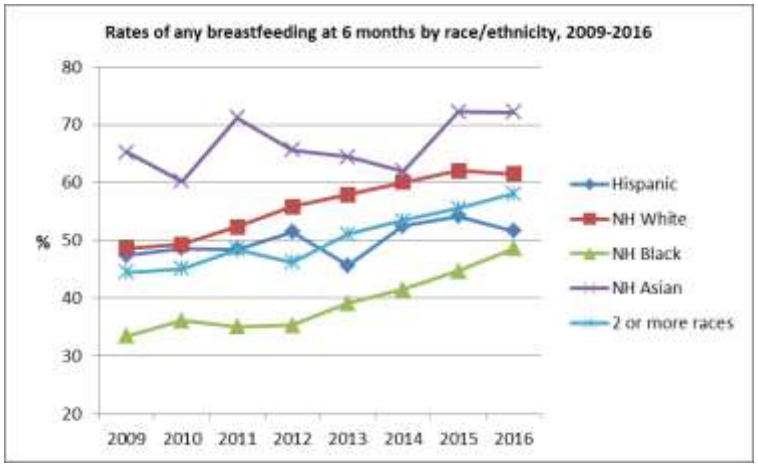
Racial and ethnic disparities in breastfeeding practices

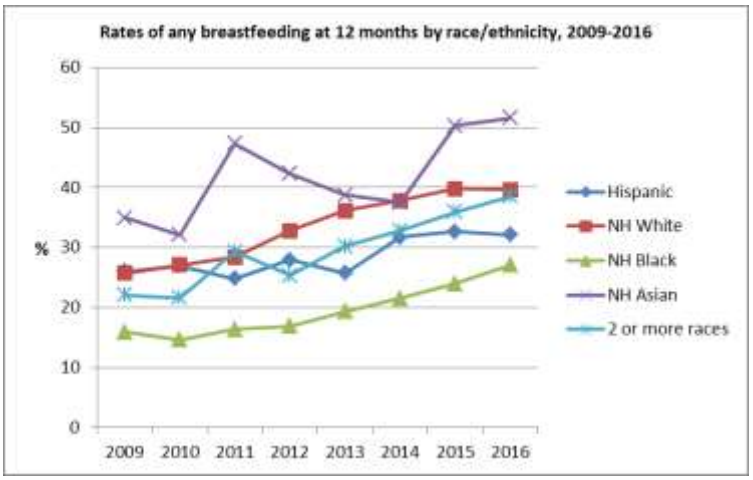
As discussed above, significant racial and ethnic disparities in breastfeeding rates and duration exist in the United States (**Table 2.1**). In general, Black women and American Indian/Alaska Native women have lower breastfeeding rates than White women, while Asian and Hispanic women have similar or even higher breastfeeding rates than White women [62]. In 2017, the breastfeeding initiation rates for Black mothers and American Indian/Alaska Native mothers (73.7% and 80.7% respectively) remain below the Healthy People 2020 goal (81.9%), while the rates for Hispanic, White and Asian mothers (84%, 87% and 90% respectively) have met the goal [6, 60].

Despite the improved breastfeeding rates for all racial or ethnic groups over the past few decades in the United States, the racial/ethnic disparities in breastfeeding have persisted [17, 19, 63]. From 2000 to 2008, the White-Black gap in breastfeeding initiation and breastfeeding for 6 months narrowed from 24.4 to 16.3 percentage points and from 21.3 to 16.5 percentage points respectively [7]. From 2009 to 2016, the White-Black gap in breastfeeding initiation and breastfeeding for 6 months continued to narrow but still remained at least 12 percentage points in 2016 (Figure 2.1). For each of these years, Black mothers had significantly lower breastfeeding initiation prevalence and duration compared to White and Hispanic mothers [7, 64].

Figure 2.1 Rates of breastfeeding at birth, 6 and 12 months by race/ethnicity, 2009-2016







Note: Data source: National immunization survey, Center for Disease Control and Prevention, Department of Health and Human Services. https://www.cdc.gov/breastfeeding/data/nis_data/results.html

Although the persistent racial/ethnic disparities in breastfeeding are well documented, the causes of the disparities remain unclear. In the United States, racial/ethnic disparities in health are often intertwined with socioeconomic disparities in health due to significant racial/ethnic disparities in socioeconomic status, usually measured by education, income and occupation. For example, the higher educational attainment and household income level of White mothers compared to mothers in other racial/ethnic groups are often considered major contributors to their higher breastfeeding rates [65]. Most existing studies examined breastfeeding disparities by adjusting demographic characteristics and socioeconomic status such as maternal age, education attainment and income [13, 15, 16, 65]. However, several studies have found that even after controlling for these sociodemographic characteristics, race/ethnicity remains a strong predictor of breastfeeding outcomes [18, 66, 67], suggesting that other factors such as breastfeeding support, culture and norms may also contribute to racial/ethnic disparities in breastfeeding.

Only one study has attempted to investigate the causes of the racial/ethnic disparities using mediation analysis [68]. In this study, McKinney and colleagues found that sociodemographic factors (college education and marital status) and maternity care practices (hospital use of infant formula) together fully explained the White-Black disparities in breastfeeding duration while family breastfeeding history and living with the infant's father together partially explained the longer breastfeeding duration of Spanish-speaking Hispanic mothers relative to Black mothers. However, the authors did not depict the possible linkage between the multiple potential mediators, and the study failed to assess the relative importance of different mediators and estimate the mediated effect through different causal pathways.

Factors influencing breastfeeding practices

Breastfeeding behavior is influenced by a complex combination of multiple factors including sociodemographic characteristics, maternal and child health conditions, psychosocial factors, health care and services, family and social support, workplace support, social norms, and public policies [8-10]. Several systematic reviews have been done on the association of these factors with breastfeeding initiation and duration [12-16]. We will discuss the association between some factors and breastfeeding outcomes in detail with an emphasis on studies conducted in the context of United States.

Sociodemographic characteristics

Maternal and infant characteristics found to be associated with breastfeeding practices include maternal age [69-75], race/ethnicity [72, 75], nativity/immigration status [8, 76, 77], socioecnomic status [13, 78-80], marital status, and parity [70, 71, 81, 82]. Older maternal age is consistently found to be positively associated with initiation of breastfeeding and longer breastfeeding duration in both cross-sectional and cohort studies [69-75]. For example, the results of a study by Ryan and Zhou [75] using national surveys data showed that the younger the mothers were, the less likely that they would continue breastfeeding to 6 months.

In the United States, race/ethnicity has been shown to be associated with breastfeeding initiation and duration even after taking into account socioeconomic status [17, 67]. Studies consistently found that Black mothers had lower rates in both initiation and continuation of breastfeeding [18, 72, 75, 83] and that Hispanic ethnicity was associated with higher initiation and longer duration of breastfeeding [18, 72]. Researchers have also found an association between maternal immigrant status and breastfeeding outcomes [8, 76, 77]. An analysis of

national survey data for 33121 children conducted by Singh and Kogan [8] found that immigrant women in each racial/ethnic group (Hispanic, White, Black and other) had higher breastfeeding initiation and longer duration rates than native women.

Many studies also found that socioeconomic status, usually measured by education, income and occupation, is positively related to breastfeeding outcomes in the United States [13, 78-80]. Of these three indicators, higher maternal educational attainment is a consistent predictor for higher initiation and and longer duration while income and occupation are less consistently associated with breastfeeding outcomes [80]. For example, Heck and colleagues [80] examined the influence of socioeconomic status on breastfeeding initiation in a random sample of 10,519 California mothers and found that women with higher family incomes and education levels, and in professional or executive occupations were more likely than their counterparts to breastfeed. However, after adjusting for potential confounders, only maternal education remained positively associated with initiation of breastfeeding, while income and occupation were no longer significant.

The association between parity and breastfeeding outcomes is not consistent across studies [70, 71, 81, 82]. Studies by Barnes and Stein [70] and by Mclnnes and Love [71] found that primiparity was associated with intent to breastfeed. In a cross-sectional study among rural WIC participants, Gielen and Faden [82] also found that primiparous mothers were four times as likely to initiate breastfeeding as were multiparous mothers. However, in a study among women who intended to breastfeed, Hackman and Schaefer [81] found that multiparous mothers had a longer intended and actual breastfeeding duration than primiparous mothers.

Maternal and child health conditions

Maternal and child health conditions such as premature birth, Caesarean delivery, and maternal smoking also influence breastfeeding behaviors [14-16]. Infants who were born prematurely or by Caesarean delivery are less likely to be breastfed due to the separation of the mother and the infant, feeding difficulties or a significant delay in initiating breastfeeding [84-86]. Mothers who are smokers tend to breastfeed for a shorter duration [87].

Psychological factors

Psychological factors including women's stated intention to breastfeed, attitudes towards breastfeeding, perceived subjective norms and perceived behavioral control, have been well-studied and are established predictors for breastfeeding initiation and short-term duration [69, 73, 74, 88, 89]. These factors were all components of the Theory of Reasoned Action (TRA) [90, 91] and the Theory of Planned Behavior (TPB) [92, 93]. According to the TRA, women's intention to breastfeed is the most important predictor of actual breastfeeding behavior; this intention is the result of women's attitude towards breastfeeding as well as perceived subjective norms about breastfeeding. The TPB added to the model one additional construct, perceived behavioral control, which influences both behavioral intention and actual behavior.

Expectant mothers usually form their infant feeding intentions by the third trimester of pregnancy [94]. Studies on psychological factors that have applied the TRA/TPB have confirmed that the intention to breastfeed is a significant predictor of initiation and short-term duration of breastfeeding [69, 95-99]. However, intention to breastfeed is a much weaker predictor of breastfeeding duration [69, 95-99].

Social support

Family, communities and social networks have important influences on women's decisions to continue breastfeeding, including the attitudes and support of the woman's partner and other family members [100, 101], and the breastfeeding experiences and preferences of friends [102]. Baranowski and colleagues [103] found that there are significant racial/ethnic differences in who in a woman's network is most likely to influence breastfeeding decisions. For Black mothers, it is a close friend; for Latina mothers it is their own mother; and for White mothers, the most influential person is their partner.

A number of studies have examined the influential role of partners in women's breastfeeding behavior, and the influence could be positive or negative depending on their attitudes toward breastfeeding [71, 74, 100, 103-106]. Studies have found that partner's positive attitudes toward breastfeeding are significantly associated with women's intention to breastfeed and self-efficacy on breastfeeding [74, 104]. A study of WIC-participating mothers found that their partners' preferences for breastfeeding were associated with longer breastfeeding duration [106]. A cross-sectional study with socially disadvantaged women in Scotland by Mclnnes and Love [71] also found that living with a partner is associated with better breastfeeding outcomes, the possible reasons being the availability of a comfortable physical environment and privacy. A qualitative study by Bryant [105] suggested that living with a partner may support breastfeeding since partners can provide practical help with housework and child care.

Hospital practices

It has been widely documented that maternity care practices play a critical role in breastfeeding initiation by facilitating or hindering mothers to realize their intention to

breastfeeding [10, 107]. Baby-friendly hospital practices such as early skin-to-skin contact between baby and mother (i.e. placing the naked baby prone on the mother's bare chest immediately following birth), rooming in (allowing mothers and infants to remain together 24 hours a day), giving only breast milk and breastfeeding on demand significantly increase the likelihood of breastfeeding initiation [108-110]. For example, babies who received early skin-to-skin care in hospitals were significantly more likely to breastfeed successfully during their first feed than those in routine care in randomized controlled trials [111, 112], These practices were summarized and recommended as a comprehensive package in the *Ten steps to successful breastfeeding*, which is the foundation of the Baby-Friendly Hospital Initiative, a major WHO/UNICEF effort to promote breastfeeding through strengthening support from health care system [107, 113, 114]. The commercial hospital discharge packs with infant formula are commonly given to mothers in the United States which have been associated with shortened duration of exclusive breastfeeding among recipients [115].

Workplace policies and accommodations

In 2017, more than half of American mothers who had an infant worked outside the home [116]. In 2018, the Society for Human Resource Management reported that while an increasing number of companies provide workplace lactation support, only 48% of companies surveyed had lactation programs or made special accommodations for breastfeeding. Small businesses (fewer than 100 employees) are the least likely to have lactation programs [117]. A qualitative study using focus groups with African American mothers revealed that the majority of mothers perceived the workplace as not being supportive of breastfeeding (e.g. having to return to work early before establishing breastfeeding routines, no or very limited nursing breaks, no private

space for expressing breast milk) and were of the opinion that more workplace protections are needed to support breastfeeding among working mothers [118].

Public policies

For working mothers, the length of maternity leave is positively associated with breastfeeding duration while returning to work shortly after childbirth is associated with significantly increased probability of not breastfeeding or early cessation [119]. After Canada extended its mandate parental leave duration from 25 weeks to 50 weeks in December 2000, the duration of any breastfeeding and exclusive breastfeeding in the post-reform birth cohorts increased by one month and 0.5 month respectively [120]. It should be noted that the United States is the only industrialized country in the world that does not have a federal law that provides for paid maternity leave [121]. All other member countries of the Organization for Economic Co-operation and Development (OECD) offer paid maternity leave of at least three months [122]. The widespread marketing and promotion of infant formula by industry has also affected breastfeeding practices [55, 123].

Breastfeeding promotion interventions and evaluation

In response to the *Surgeon General's Call to Support Breastfeeding* [9] and to achieve the breastfeeding goals set in the Healthy People 2020 [60], a large number of breastfeeding promotion interventions have been implemented in the United States in recent years. The United States Centers for Disease Control and Prevention (CDC) compiled a comprehensive guide to help state decision makers to choose appropriate breastfeeding interventions [30]. In this guide,

six interventions were categorized as effective including maternal care practices, support for breastfeeding in the workplace, peer support, educating mothers, professional support, media and social marketing. Adapting the categorization of interventions in this guide and in another systematic review by Sinha and Chowdhury [26], I will discuss six types of interventions commonly applied in the United States to promote breastfeeding: prenatal educational programs, health care system and services, family support, community support, workplace support, and public policies.

Prenatal educational programs

Educational interventions for perinatal women have been widely implemented through health care systems and the WIC program [22, 124, 125]. These educational programs are usually delivered prenatally, during pregnancy, either through one-on-one sessions or group classes, and are frequently offered by primary care facilities or WIC local agencies. The content of the education sessions is usually structured around core topics such as the benefits of breastfeeding, nutrition needs of infants, and the physiology of breastfeeding. Some programs also provide skills training such as breastfeeding positioning, and latching techniques.

Prenatal education programs have been shown to be effective in increasing rates of breastfeeding initiation [126-128] but the impact of educational programs on long-term breastfeeding outcomes remains unclear in the previous evaluation studies. A retrospective cohort study by Rosen and Krueger [129] indicated that women who attended prenatal breastfeeding classes were more likely to breastfeed at 6 months than those in the control group. However, a meta-analysis by Guise and Palda [22] found that these education programs have no significant effects on long-term breastfeeding duration.

Health care system and services

The Baby-Friendly Hospital Initiative (BFHI) is a comprehensive package of breastfeeding promotion interventions in healthcare systems. In response to the *Innocenti Declaration on the Promotion, Protection and Support of Breastfeeding* [56], the World Health Organization and the United Nations Children's Fund launched the Baby-Friendly Hospital Initiative (BFHI) in 1991 to protect and promote breastfeeding [114]. The BFHI includes training materials and self monitoring tools for health facilities to use. In 1998, the *Ten Steps to Successful Breastfeeding* (Box 2.1) was included as an key criteria for Baby-Friendly hospitals. To become Baby-Friendly designated, health facilities must demonstrate a successful implementation of *the Ten Steps to Successful Breastfeeding* such as having a written policy, training staff and practicing room in [130]. As of 2017, more than 152 countries have implemented the initiative [57]. BFHI in the United States is recent but has been expanding quickly especially in California. In Los Angeles County, out of 60 birthing facilities, there were 4 baby-friendly hospitals in 2010; the number has increased to 33 in 2017. More than half of births (58%) in Los Angeles County are taking place in Baby-Friendly facilities [131].

Although BFHI was considered one of the most effective breastfeeding support interventions [30], evaluation of the effectiveness of BFHI in improving breastfeeding practices in the U.S. population remains challenging [132]. A critical concern is how to attribute the observed changes in breastfeeding practices to the BFHI and rule out effects of known and unknown confounding factors. As with many other public health policy changes or large-scale community interventions, it is difficult to conduct a randomized controlled trial (RCT) to evaluate the impact of BFHI due to practical and ethical barriers [33]. An exception is a cluster

randomized trial conducted in the Republic of Belarus by Kramer and colleagues [133]. Although the authors found that the BFHI interventions were effective in increasing duration and exclusivity of breastfeeding, two unique features of the Belarussian health care system – it being highly centralized and the prolonged postpartum hospital stay for childbirth – limit the generalizability of the findings to the U.S. population.

Evaluation of BFHI in the US has been conducted only through observational or quasi-experimental studies [132]. These observational studies suffer from weakness in the design such as not having a representative sample or failing to control for confounders [134-136]. A few quasi-experimental studies have reported higher breastfeeding rates at hospitals after they were designated 'Baby-Friendly' compared to before; however, the quality of these studies was also compromised due to the lack of a comparison group [137, 138]. Better designed studies are needed in the future to address these issues. Furthermore, no evaluation studies have been conducted to-date to assess the effects of the BFHI on breastfeeding practice in low-income populations who are usually the least likely to breastfeed. Future evaluation studies on BFHI need to improve the study design and pay attention to vulnerable populations.

Instead of implementing the whole BFHI package, some health facilities have chosen to make incremental changes such as implementing one or some steps of BFHI as well as adding some new practices that promote breastfeeding. The interventions often adopted by health facilities include training health care staff on breastfeeding and lactation management (step 2), early initiation of breastfeeding (step 4), practicing rooming-in (step 7) and not distributing infant formula at discharge [139]. Observational studies evaluating these practices have reported

that increased implementation of these Baby-Friendly practices is associated with higher initiation and longer duration of breastfeeding [134-136].

Box 2.1 Ten Steps to Successful Breastfeeding

1. Have a written breastfeeding policy that is routinely communicated to all health care staff
2. Train all health care staff in skills necessary to implement this policy
3. Inform all pregnant women about the benefits and management of breastfeeding
4. Help mothers initiate breastfeeding within an hour of birth
5. Show mothers how to breastfeed, and how to maintain lactation even if they should be separated from their infants
6. Give breastfeeding newborn no food or drink other than breastmilk unless medically indicated
7. Practice rooming in – that is, allow mothers and infants to remain together 24 hours per day
8. Encourage breastfeeding on demand
9. Give no artificial teats or pacifiers to breastfeeding infants
10. Foster the establishment of breastfeeding support groups and refer mothers to them on discharge from the hospital or clinic

Source: WHO and UNICEF [114]

Postpartum professional support and peer counseling

Postpartum lactation counseling is a type of intervention that usually delivered at home and family environment [140-142]. The counseling is often provided by professional lactation consultant or lay personnel (peer counsellors) through home visits or telephone. The main purpose of the counseling is to encourage continuation of breastfeeding, offer emotional support, and help with solving lactation problems. One example of peer counseling intervention is the group peer support offered by La Leche League International (LLLI) through a series of four monthly meetings either through phone call or home visits (https://www.llli.org). Other interventions include working with family members such as partner and grandparents to foster

supportive home environment and strengthen psycho-emotional support from family members [143].

Evaluation studies on home and family environment interventions suggest that the evidence for effectiveness of peer counseling in improving the continuation of breastfeeding in the postnatal period is relatively clear [25]. For example, Shaw and Kaczorowski [144] found that being in a peer counselor group is associated with higher likelihood of breastfeeding initiation and continuation until 6 weeks among WIC participants. Two randomized trials [140, 141] also showed that support from peer counsellors significantly improves breastfeeding initiation and duration, but both trials are not double-blinded and have a substantial attrition rate which may result in bias towards overestimating the effectiveness of these interventions. However, the effectiveness of postpartum counseling support by professionals (e.g. lactation consultants or registered nurses) remains unclear. The randomized trials conducted by Bunik and Shobe [145] and by Grossman and Harter [146] failed to show significant improvements in any breastfeeding rates either at 3 months or 6 months postpartum, whereas another randomized trial including both prenatal and postnatal counseling interventions showed a substantial increase in the breastfeeding rate at week 20 postpartum [147].

Workplace support

Workplace interventions to support breastfeeding include several types of employee benefits and services, including organizational policies to support breastfeeding women such as paid maternity leave, employer sponsored breastfeeding education programs, flexible working scheduling, on-site child care, physical facilities such as designated private space for breastfeeding or expressing milk and high-quality breast pumps, and access to refrigeration [148,

149]. Even just some of these low-cost interventions can reduce the barriers for working mothers to breastfeed [10].

For workplace interventions, a Cochrane database systematic review by Abdulwadud and Snow [150] concluded that no randomized controlled trials or quasi-experimental studies have evaluated the effectiveness of workplace interventions in promoting breastfeeding. Two observational studies only reported the breastfeeding practices of women with access to workplace support while no comparison was made pre- and post-intervention or with control groups [148, 149]. Using cross-sectional survey data, Dabritz and Hinton [151] compared breastfeeding practices among women having access to workplace support with those not having access, and found no significant association between workplace support factors and breastfeeding rates at 6 months.

Support in the community

Community support plays a crucial role in promoting breastfeeding practices [10]. The key elements of community interventions include fostering positive social norms in favor of breastfeeding through mass media and community mobilization approach as well as group counseling or education to improve general knowledge and skills about breastfeeding. One example is the U.S. Department of Agriculture (USDA) 'Loving Support Makes Breastfeeding Work' campaign to improve breastfeeding practices among WIC participants [152].

Evaluations of community support interventions such as social marketing programs have been conducted mostly using cross-sectional study designs and focus only on the knowledge and attitude rather than behavioral changes. One example is the evaluation of the USDA 'Loving Support Makes Breastfeeding Work' campaign by Mitra and Khoury [153] which showed that

the campaign has a positive impact on health professionals based on their self-reported changes in their comfort level in promoting breastfeeding and managing breastfeeding problems. Further studies are needed to assess the impact of the intervention on women's breastfeeding practices.

Public policies

Public policy interventions include policy changes in national or state level maternity leave regulations, the *International Code of Marketing of Breastmilk Substitutes*, and national maternal and child health programs such as the Special Supplemental Nutrition Program for Women, Infants and Children (WIC). Administered by the Food and Nutrition Service of the U.S. Department of Agriculture (USDA), WIC provides nutritional supplementation, nutrition education, and health care and social service referral for pregnant women, infants, and children up to age five at nutritional risk. WIC plays a vital role in providing breastfeeding support among low-income women [154-156]. Required by WIC program regulations, WIC state and local agencies increased emphasis on breastfeeding promotion, including integrating breastfeeding support and management in staff training, providing counseling and education material and services throughout the perinatal period, allowing longer participation of postpartum women in the program (up to one year for nursing mothers), offering a greater quantity and variety of foods for breastfeeding mother and infant dyads, and providing breastfeeding aids such as breast pumps [157-159].

Table 2.2 presents study designs, findings and limitations of some selected evaluations studies on breastfeeding support interventions in the US population. To summarize, formal evaluation of breastfeeding promotion interventions is not widely used in the United States and the evidence on the effectiveness of many interventions is not clear in the literature [30]. In

addition, very few evaluation studies have attempted to assess the impact of a combination of multiple interventions, which is often the situation in the reality.

A summary of gaps in the literature and how this dissertation will fill the gap

Gap 1: Lack of understanding on the influences of supportive environment on breastfeeding duration

Despite a large body of literature examining factors influencing breastfeeding practices in the United States, there is a dearth of research on social and environmental-level influences on breastfeeding. Further, while many studies have addressed factors influencing initiation of breastfeeding, few studies have investigated factors associated with breastfeeding duration. It is well known that a high proportion of mothers do not breastfeed for as long as they intend to after they initiate breastfeeding especially among socially disadvantaged women such as WIC-participating mothers. Rothman [160] suggested that how long a mother breastfeeds her child is influenced by her actual breastfeeding experience. Although studies have suggested that lactation problems/difficulties and the lack of a supportive environment may be important determinants of women's actual breastfeeding experience [161-163], few studies have investigated the influences of breastfeeding support on breastfeeding duration.

This dissertation study will investigate access to breastfeeding support from family, hospitals and workplaces among WIC-participating mothers, and assess the influences of breastfeeding support on breastfeeding duration.

Gap 2: Causal pathways of racial and ethnic disparities in breastfeeding practices is unclear

Persistent racial and ethnic disparities in breastfeeding practices have been well documented in the literature but the causal pathways through which the maternal race/ethnicity impact breastfeeding outcomes remain unclear. Racial/ethnic disparities are often intertwined with socioeconomic disparities in breastfeeding since race/ethnicity and socioeconomic status are highly correlated, and breastfeeding rates are lower among women of lower socioeconomic status. However, several studies found that even after controlling for socioeconomic status, race/ethnicity is still a predictor of breastfeeding outcome, which suggests that racial/ethnic disparities are also mediated through other pathways. Few studies have attempted to explore the contribution of other potential mediators to racial/ethnic differences in breastfeeding.

Access to breastfeeding support may explain some proportion of the observed racial/ethnic differences in breastfeeding rates as studies suggest that there are racial/ethnic differences in breastfeeding support, and access to breastfeeding support is associated with breastfeeding outcomes. This dissertation study will assess the extent to which racial/ethnic differences in breastfeeding duration can be explained by access to breastfeeding support.

Gap 3: Lack of studies on estimating the population impact of multifaceted breastfeeding interventions in communities

There is growing evidence on the efficacy and effectiveness of various breastfeeding promotion interventions such as maternal care practices, breastfeeding support in the workplace, peer support, educating mothers, professional support, media and social marketing [22-29]. However, local decision makers and health professionals face challenges in selecting the most appropriate interventions due to the complex factors influencing breastfeeding behavior, the

various levels of effectiveness of interventions, and the difficulties in estimating the potential population impact of multifaceted interventions in real-world settings [164, 165]. Despite the increasing interest in the potential utility of systems science approaches such as agent-based modeling in predicting the potential population impact in alternative intervention and policy scenarios [31-33], no studies have applied the approach to estimate the population impact of breastfeeding promotion interventions in a given population and community [166].

This dissertation study will introduce the agent-based modeling approach and illustrate its utility in facilitating decision making with regard to the selection of appropriate interventions for promoting breastfeeding. An agent-based model on breastfeeding interventions will be used to estimate the population impact of multifaceted breastfeeding promotion interventions.

Table 2.2 A summary of selected evaluation studies on breastfeeding promotion interventions in the U.S. population

Study	Study design	Intervention	Findings	Limitations
Kramer et al., 2001 [133]	Cluster randomized control trial	BFHI	The BFHI interventions are effective in increasing duration and exclusivity of breastfeeding	Limited generalizability to the US population due to the Belarussian health care system being highly centralized and the prolonged hospital stay for childbirth
Hawkins et al., 2015 [167]	Quasi-experimental with comparison group	BFHI	No overall differences in breastfeeding initiation between BFHI and non-BFHI; Increased breastfeeding initiation and duration only among mothers with lower education	Non-BFHI (comparison group) implemented some breastfeeding support interventions (contamination)
Philipp et al., 2001 [137]	Quasi-experimental without comparison group	BFHI	The breastfeeding initiation rate and exclusive breastfeeding rate increased after the hospital in Boston implemented BFHI	Before-after comparison in a single hospital without comparison group
Perrine et al., 2012 [135]	Longitudinal survey	Baby-Friendly practices	Not being given supplemental feedings is associated with achieving exclusive breastfeeding intention	Sample not representative
Rosenberg et al., 2008 [136]	Cross-sectional survey of institutions	Baby-Friendly practices	Increased implementation of the Ten Steps is associated with increased breastfeeding	Bias with self-reported information from one single person on institutional breastfeeding practices; fail to control for some known institutional and individual level confounders due to data availability
DiGirolamo et al., 2008 [134]	Longitudinal survey	Baby-Friendly practices	Increased "Baby-Friendly" hospital practices are associated with higher chances of breastfeeding beyond 6 weeks.	Sample not representative; fail to control for some known individual level confounders
Rosen et al., 2008 [129]	Retrospective cohort study	Antenatal education	Women who attended prenatal breastfeeding classes had significantly increased breastfeeding at 6 months than control group	Loss of follow-up resulting in unequal group size; no measures on exclusivity; conducted in a military population limiting its generalizability

Study	Study design	Intervention	Findings	Limitations
Chapman et al., 2004 [141]	Randomized controlled trial Low-income Latina population	Peer counseling	Compared to the control group, the probability of not initiating breastfeeding (RR=0.39), stopping breastfeeding at 1 month (RR=0.72) and at 3 months (RR= 0.78) is significantly lower in the intervention group.	Not double blind
Anderson et al., 2005 [140]	Randomized controlled trial Low-income Latino population	Peer counseling through home visits	The likelihood of exclusive breastfeeding at hospital discharge and through the first 3 months was significantly higher in the intervention group than that of control group.	Not double blind; high attrition rate (16.7%)
Mitra et al., 2003 [153]	Cross-sectional study	Social marketing	The social marketing program "the loving support" has a positive impact on nurses and physicians in terms of their comfort level in promoting breastfeeding and managing breastfeeding problems.	Did not measure the breastfeeding perceptions and practices among women; self-reported changes after the campaign
Ortiz et al., 2004 [149]	Retrospective review of lactation records	Workplace support	Of those who returned to work after giving birth, 78.9% attempted pumping milk at work. They expressed milk in the workplace for a mean of 6.3 months.	Review of the self-reported lactation data; no comparison group
Cohen and Mrtek, 1994 [148]	Cross-sectional survey	Workplace support	The average duration of breastfeeding among participants of a workplace support program was 8.1 months, equivalent to the statistical norms for women not employed outside the home.	No comparison group; no before-after comparison; self-selection of participants
Dabritz et al., 2009 [151]	Cross-sectional survey	Workplace support	None of the workplace factors significantly associated with breastfeeding rate at 6 month.	Self-reported data of breastfeeding practice and workplace support; maternal education may confound the relationship

Chapter 3: Theoretical Framework

It is well established that breastfeeding behavior is influenced by multiple demographic, biomedical and psychosocial factors [8, 9]. However, it remains a challenge to explain how these factors work together to influence breastfeeding initiation and continuation. In this chapter, I will present the conceptual framework for investigating the factors that influence breastfeeding practices, causal mechanisms underlying racial/ethnic disparities, and the population impact of various breastfeeding promotion interventions. This conceptual framework is supported by the Theory of Reasoned Action (TRA), the Theory of Planned Behavior (TPB), socioecological model and fundamental cause theory.

Theory of Reasoned Action (TRA) and Theory of Planned Behavior (TPB)

One theory that has been applied in studies of breastfeeding [95, 96, 98, 168, 169] is the Theory of Reasoned Action [90, 91] and the associated Theory of Planned Behavior [92, 93]. Fishbein and Ajzen [91] proposed the TRA in 1975 to predict an individual's intention to perform a specific behavior over which people have the ability to exert self-control. The theory posits that behavioral intention is the most important determinant of behavior. The intention captures the motivating factors which reflect 'how hard people are willing to try' or 'how much of an effort they are planning to exert' (p.181) to perform a specific behavior [93]. Behavioral intentions are a result of a person's own attitudes towards the behavior and subjective norms related to the behavior, i.e. his/her belief about whether engaging in the behavior will be approved by his/her significant others. The TPB differs from the TRA in that it includes one additional construct, perceived behavioral control, as another determinant of behavioral intention.

Perceived behavioral control is influenced by specific situational factors and reflects the perceived ease or difficulty to perform the behavior [92, 93].

According to the TRA, the key determinant of a woman's breastfeeding behavior is her intention to breastfeed. The intention to breastfeed in turn is influenced by both her attitudes toward breastfeeding and her perceived subjective norms, i.e. her beliefs about whether people in her social network approve breastfeeding or formula feeding [8, 79, 170]. The TPB suggests that in addition to attitudes and subjective norms, perceived behavioral control over breastfeeding is also positively associated with breastfeeding intention and initiation [97, 98, 168].

Although the TRA and TPB have identified the intention to breastfeed as a key predictor of breastfeeding initiation [93, 96, 97, 169], they are not adequate for also explaining breastfeeding maintenance. Breastfeeding practice is a dynamic process in which factors influencing initiation are different from those influencing the continuation of breastfeeding. As Rothman [160] has suggested, the decision to initiate a behavior depends on favorable expectations about potential outcomes while the decision to maintain that behavior is mostly influenced by perceived satisfaction with the actual experience. After a woman initiates breastfeeding, her experience of lactation-related problems and barriers, as well as the amount of support she receives from her environment plays a critical role in her decisions to continue breastfeeding. In addition, TRA and TPB focus primarily on the individual psychological process through which behavioral control is exerted by the person [171] and environmental influences are largely ignored since they are considered to influence breastfeeding practices only indirectly through the individual psychological process.

Socioecological model

The socioecological model emphasizes that health behaviors are shaped by multiple levels of influence: intrapersonal, interpersonal, organizational, community and public policy [172]. Therefore the implication is that comprehensive interventions targeting both individual and environmental levels are more effective in changing behavior than single-level interventions.

Unlike the TRA and TPB, the social ecological model explicitly takes into account both individual and environmental factors influencing a specific health behavior [173-176]. Applying this framework to the examination of breastfeeding behavior, I summarize factors influencing breastfeeding behavior and potential interventions at each level in **Table 3.1**.

Table 3.1 Factors influencing breastfeeding behavior and intervention strategies from a social ecological perspective

Level	Barriers to breastfeeding	Intervention strategies
Intrapersonal	• Lack of Knowledge • Unfavorable attitude toward breastfeeding • Birth outcomes (e.g. preterm birth) • Lactation problems • Lack of lactation skills	• Educating mothers • Professional support (counseling or other behavioral interventions)
Interpersonal	• Lack of family support (e.g. partner) • Peer influence	• Fostering family/partner support • Peer support programs
Organizational	• Maternity care practices • Early return to work • Workplace environment and policies	• Baby-Friendly Hospital Initiative • Baby-Friendly practices • Workplace support (e.g. nursing breaks, private space for expressing milk)
Community	• Unfavorable social norms	• Social marketing • Community support groups
Public policy	• Absence of federal laws on mandate paid maternity leave • Insufficient enforcement of the *International Code of Marketing of Breastmilk Substitutes* (e.g. free hospital discharge packs with formula sample)	• State-level legislation to offer minimum paid maternity leave policy • Monitoring implementation of the Code in market and health care systems

The social ecological model is useful for bringing attention to the environmental influences of organizations, communities and public policies (which are usually not within the control of individuals) on behavior as well as the interactions between these influences at different levels. By combining the TRA and TPB with the ecological model of health behavior, and taking into account of the dynamics of breastfeeding behavior over time, I propose a theoretical framework for this study to examine factors influencing breastfeeding behavior over time and to evaluate the effectiveness of potential interventions (**Figure 3.1**).

In this framework, the behavioral constructs (indicated by black font) include breastfeeding intention, initiation and maintenance. While the decision to initiate breastfeeding is based on expectations of future health and other benefits from breastfeeding, the decision to maintain breastfeeding depends on the satisfaction of the actual breastfeeding experience [160]. Constructs indicated by brown font in the model are factors influencing breastfeeding intention and behaviors at the intrapersonal, interpersonal, organizational and community levels. For example, breastfeeding intentions are influenced by demographic characteristics, breastfeeding related knowledge/attitude, and perceived behavioral control (intrapersonal-level factors); initiation of breastfeeding is also influenced by maternity care practices (organizational-level factor). After breastfeeding is initiated, the continuation of breastfeeding is influenced by the mother's experience of barriers to breastfeeding such as lactation problems and return to work, as well as the support she receives from health professions, family/partner and workplace to overcome these barriers (interpersonal- and organizational-level factors). At the community level, social norms have influences on breastfeeding intention, initiation and maintenance. Although public policy-level factors such as paid maternity leave policies are also important for breastfeeding, they are beyond the scope of this study and are not included in the proposed

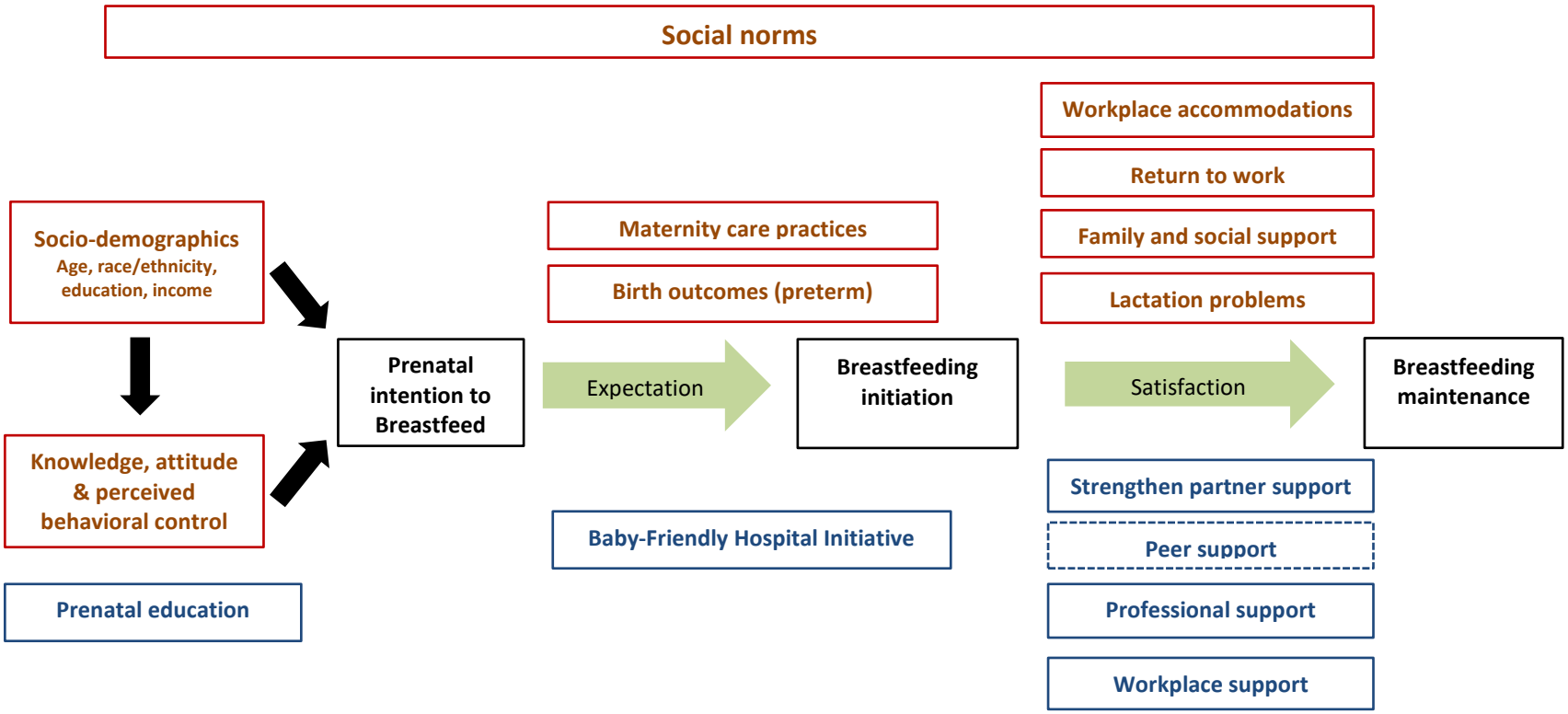
framework. The intrapersonal-, interpersonal- and organizational-level interventions which are delivered throughout the perinatal period include:

- Educational programs (antepartum period and intrapersonal level): Interventions by breastfeeding experts to educate pregnant women about the benefits of breastfeeding, foster positive attitudes towards breastfeeding and prepare them with basic skills.
- Maternity care practices (intrapartum period and organizational level): Examples are medical practices that take place during the intrapartum hospital stay, e.g. Baby-Friendly Hospital practices.
- Professional support (postpartum period and interpersonal level): Counseling or behavioral interventions provided by health professionals (e.g. physician, nurses, and lactation consultants) to mothers after they return home from their hospital stay, to improve breastfeeding outcomes.
- Partner support (postpartum period and interpersonal level): Strengthening psycho-emotional and other types of support from women's partners to facilitate their breastfeeding efforts.
- Workplace support (postpartum period and organizational level): Foster supportive workplace environment including provision of facilities, services and employee benefits in workplace that enable working mothers to breastfeed their infants, such as a designated private space for breastfeeding or expressing milk, flexible work schedules, extended maternity leave, and on-site child care.

The abovementioned theoretical framework, which includes both individual and environmental determinants of breastfeeding behavior and reflects the changes in importance of

these factors over time, will be used to guide the investigation of factors that influence breastfeeding behavior (Chapter 5) and the estimation of the population impact of multiple interventions (Chapter 7).

Figure 3.1 Theoretical framework on factors and interventions influencing breastfeeding behavior



Note: The constructs in black font represent behavioral outcomes of interest; the constructs in brown font are factors influencing breastfeeding practices at the intrapersonal, interpersonal, organizational, and community level; and the constructs in blue font specify key breastfeeding promotion interventions (intervention in the dotted line box not examined in this study).

Fundamental cause theory

In the seminal paper on "Social Conditions as Fundamental Causes of Disease", Link and Phelan [177] proposed fundamental cause theory to support causal mechanisms that explain enduring health disparities, particularly socioeconomic disparities in health conditions. The theory posits that social conditions embody flexible health-enhancing resources such as money, knowledge, power, prestige, freedom, and beneficial social connections and are therefore fundamental causes of diseases. There are four essential features of a fundamental cause: (a) it influences multiple disease outcomes; (b) it affects these disease outcomes through multiple risk factors; (c) it involves access to resources; and (d) the association between a fundamental cause and health is reproduced over time via the replacement of intervening mechanisms [177]. Some examples of social conditions that meet these criteria and are considered fundamental causes of health include socioeconomic status (SES) and social support.

The persistent racial disparities in health in the United States have motivated Phelan and Link [178], and other scholars [179-181] to investigate the potential causes and they have concluded that race (racism) is a fundamental cause of health disparities as race and ethnicity are strongly associated with flexible resources in the United States. They suggested that the enduring association between race and health in the United States results mainly from two causal pathways: (a) race (racism) is a fundamental cause of racial differences in SES, and SES is a fundamental cause of health inequalities; (b) race is associated with flexible resources other than SES such as non-occupational prestige and power, freedom, and beneficial social connections, and these resources are associated with health outcomes independent of SES.

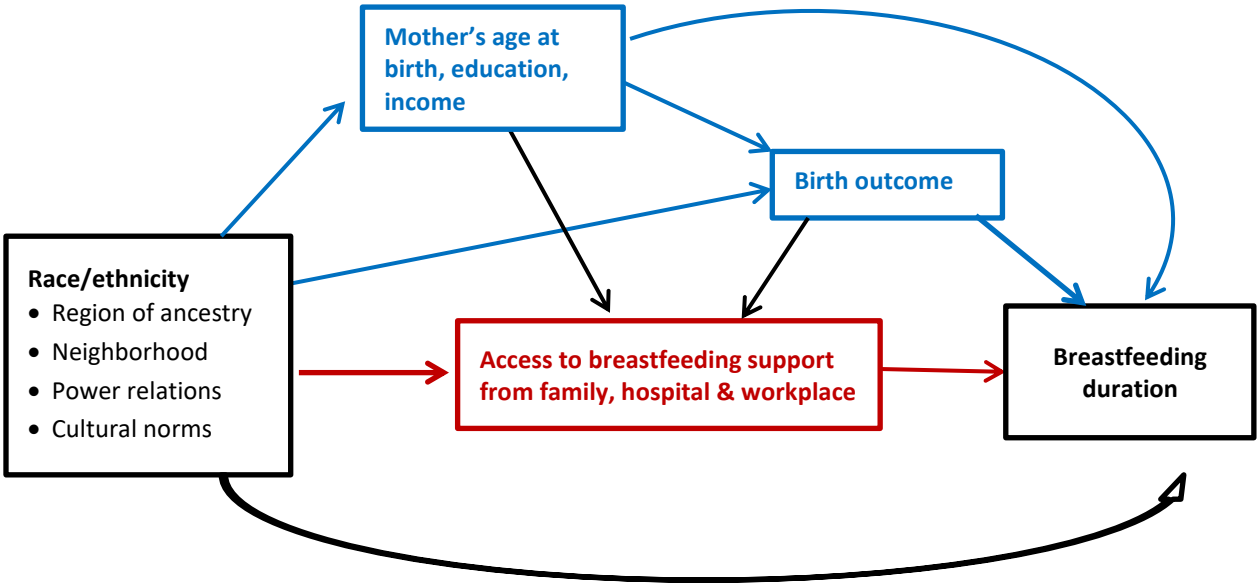
Persistent racial/ethnic disparities in breastfeeding rates in the United States and other societies have been well documented. The causes of racial/ethnic disparities in breastfeeding, however, remain unclear. Applying the fundamental cause theory, we propose that a substantial proportion of racial/ethnic differences in breastfeeding occur through two causal pathways (**Figure 3.1**):

- *Race/ethnicity → SES & maternal age at birth → breastfeeding duration*: Race/ethnicity is associated with SES and maternal age at birth as well as birth outcomes (e.g. preterm birth) which in turn influence breastfeeding duration;

- *Race/ethnicity → breastfeeding support → breastfeeding duration*: Race/ethnicity is associated with mother's access to social support and health care which in turn influence breastfeeding duration.

It should be noted that the two causal pathways are not independent of each other. Instead, they are inter-dependent as a woman's access to breastfeeding support (the mediator in the second pathway) is also influenced by her SES, age at childbirth and birth outcome (the mediator in the first pathway). As a result, the racial/ethnic differences mediated through the two pathways cannot be naturally separated from one another. In this conceptual model, I consider race/ethnicity a social construct that encompasses region of ancestry, neighborhood, institutional power relationships, family patterns, cultural norms, and the social history of specific groups [181-184]. Thus it is an aggregate of many manipulatable elements rather than an "immutable characteristic".

Figure 3.2 Conceptual model showing causal pathways explaining racial/ethnic disparities in breastfeeding duration



Note: The diagram illustrates two causal pathways through which race/ethnicity influences breastfeeding duration: (1) race/ethnicity→SES and maternal age at birth →breastfeeding duration (pathway in blue color) and (2) race/ethnicity→breastfeeding support→breastfeeding duration (pathway in red color). SES=socioeconomic status.

This conceptual model, which depicts the potential causal mechanisms underlying the racial/ethnic disparities in breastfeeding outcomes in the U.S., will be used to guide the study on the contributions of access to breastfeeding support from family, hospitals and workplaces to racial/ethnic disparities in breastfeeding duration (Chapter 6).

Chapter 4: Data sources

This dissertation used data from the Los Angeles County WIC Survey and Baby-Friendly USA, Inc. (BFUSA), the accrediting body and national authority for the Baby-Friendly Hospital Initiative in the United States.

Los Angeles County WIC survey data

Since 2005, a phone survey of a random sample of approximately 5,000 WIC-participating families residing in Los Angeles County has been conducted every 3 years by PHFE WIC, the largest local agency WIC program in the nation, with support from First 5 LA[1]. The survey gathers information about the health status of WIC-participating women and children, breastfeeding, child feeding and parenting practices, and home and community environment. Currently, data are available from 5 surveys conducted in 2005, 2008, 2011, 2014 and 2017. A detailed description of this survey and the sample questionnaires are available on the website: https://lawicdata.org/survey/.

Eligible participants for the survey are WIC participants living within Los Angeles County, including children ages five or younger who receive WIC benefits, as well as pregnant mothers receiving WIC benefits. A random sample is drawn from all eligible WIC participants in Los Angeles County for each survey. Data are collected by phone interview with selected pregnant women and parents or primary caregiver of the selected children using a structured questionnaire. The questionnaire contains a list of core questions with a few questions added or

[1] First 5 LA is an independent public agency which was created by voters in 1998 to invest L.A. County's allocation of funds from California's Proposition 10 tax revenues to support the safe and healthy development of children under the age of 5. For detail information, please refer to: https://www.first5la.org/about-us/.

changed every three years to address new issues. The phone interviews are conducted by trained interviewers in English or Spanish through a computer-assisted telephone interviewing system. Up to sixteen call attempts are made to reach and interview each eligible participant. For families with more than one child receiving WIC benefits, only one child (with the most recent birthday) from each family is included in the survey. If participants cannot speak English or Spanish, or are mothers under the age of 18, they are excluded from the survey.

The survey is designed to produce a representative sample of the Los Angeles County WIC recipient population countywide. Additional interviews are conducted with WIC participants in the less populated Antelope Valley area and with WIC participants within First5 LA's fourteen Best Start communities located throughout Los Angeles County to allow for separate analyses for these areas to be conducted.

For this dissertation, I used data from countywide WIC surveys conducted in 2014 and 2017 excluding the special augment samples. Since 2014, the survey has added new questions about birthing hospital and some hospital practices related to breastfeeding, which allow for examination of the influences of hospital practices on breastfeeding practices. The response rate was 50% for the 2014 survey [185] and 52% for the 2017 survey. Among these who were reached by phone, the cooperation rates were 88% and 82% for 2014 and 2017, respectively. The distribution of race/ethnicity, age of child recipient and number of pregnant women recipient among the respondents matches that of the countywide sample (combination of respondents and non-respondents); compared to the countywide sample, there are higher proportion of Spanish-speaking participants among the respondents. Data from 4,990 and 4,243 completed interviews

with parents of WIC-participating children ages 0-5 years in 2014 and 2017 respectively were used for this dissertation.

Table 4.1 Response rates of WIC surveys in 2014 and 2017

	2014 survey	2017 survey
Response rate	50%	53%
Cooperation rate among those reached by phone	88%	82%
# completed interviews with parents of children ages 0-5	4,990	4,232

Baby-Friendly hospital designation

We created a dataset of birthing hospitals in Los Angeles County with their Baby-Friendly designation status. The data elements in this dataset are the name of the birthing hospital/center, and its Baby-Friendly designation status. The list of 57 birthing hospitals and centers was obtained from the WIC survey questionnaire.

The Baby-Friendly designation status for each hospital was extracted from the website of Baby-Friendly USA (https://www.babyfriendlyusa.org/for-parents/baby-friendly-facilities-by-state/). This website has been commonly used by researchers to categorize the Baby-Friendly status of hospitals [186-188]. Baby-Friendly USA is the national accrediting body for the Baby-Friendly Hospital Initiative (BFHI) in the United States and is responsible for coordinating and conducting evaluation activities to confer the Baby-Friendly designation for hospitals in the United States. On the organization's website, Baby-Friendly USA maintains a list of hospitals which are currently designated as Baby-Friendly for each state in the country. For each hospital on the list, the initial designation date (year and month) is noted. According to the guideline, the designation is valid for only five years and designated facilities need to submit an application for

re-designation before their designation expires. If the facility is re-designated, the date of the most recent re-designation is also noted on the website. Otherwise, the facility is removed from the list after its designation has expired.

For each birthing hospital in LAC, we checked the Baby-Friendly USA website to determine its Baby-Friendly designation on October 31, 2020, and the date of initial designation. These data were also cross-checked with a list of California's Baby-Friendly hospitals on the website of the California Breastfeeding Coalition (http://californiabreastfeeding.org/focus-areas/hospitals/). If the facility was not on the current list on October 31, 2020, we used the Wayback Machine (https://web.archive.org/) to check the historical records of the website of the California Breastfeeding Coalition (http://californiabreastfeeding.org/focus-areas/hospitals/) in previous years, going as far back as August of 2016. If the facility was on any of the historical lists of the Baby-Friendly facilities, we obtained the date of initial designation and the date of expiration (five years after the last designation date). Other facilities which were not on the current list or on any historical list were recorded as not Baby-Friendly. A description of variables included in the dataset is presented in **Table 4.2**.

Table 4.2 Variables included in the Baby-Friendly designation data

Variable	Variable label	Variable type and values
Hospital name	Name of the hospital	Nominal
Baby-Friendly designation	The facility has ever been designated as Baby-Friendly, either on the current list or on any historical list of Baby-Friendly hospital	Binary 0=non Baby-Friendly 1=Baby-Friendly
Initial date of designation	The date when the hospital was first accredited as Baby-Friendly	Date (year and month)
Date of expiration	The date when the Baby-Friendly designation expired	Date (year and month)

Chapter 5: Interpersonal and Institutional Factors Associated with Breastfeeding Maintenance among WIC-participating Mothers in Los Angeles County

Background

Breastfeeding confers life-saving health benefits for both mothers and their children [3] and is one of the most effective public interventions to reduce child mortality [4]. Breastfed children have reduced risk of gastroenteritis and respiratory infections, otitis media, and sudden infant death syndrome, and less likely to develop obesity and diabetes later in life [3, 4, 189]. Potential benefits for mothers include reduced risk of breast and ovarian cancer, diabetes and improved birth spacing [3, 4, 189]. The American Academy of Pediatrics (AAP) and the World Health Organization (WHO) recommend that infants should be breastfed exclusively for the first six months of life, after which they should continue to breastfeed, while supplementary foods are being introduced, until 12 months or older [2, 46]. To meet these recommendations, it is critical for breastfeeding policies and interventions to not only increase the percentage of mothers who initiate breastfeeding but to also support maintenance of breastfeeding.

Despite the improvement in breastfeeding rates during the past few decades, only a small fraction of American infants are breastfed in compliance to medical recommendations. According to the National Immunization Survey Report, among all American infants born in 2017, 84.1% were breastfed at birth, but only 58.3 % and 35.3% were breastfed through 6 months and 12 months respectively, and only 25.6% were exclusively breastfed for 6 months [6]. Breastfeeding rates for infants of socially disadvantaged populations such as WIC-participating women are even lower: 77.0% at birth, 45.4% at 6 months and 24.8% at 12 months. The rate of exclusive breastfeeding at 6 months averages about 19.0%. None of these indicators for this

population is on track to meet the Healthy People 2020 targets for breastfeeding [6]. In order to improve breastfeeding rates among socially disadvantaged women and reduce related health disparities, it is critical to identify what modifiable factors are associated with breastfeeding maintenance in this population.

Breastfeeding behavior is influenced by a complex set of factors related to individual characteristics as well as having access to a supportive environment for breastfeeding [8-10]. The existing literature heavily focuses on individual level factors such as sociodemographic characteristics, maternal and child health conditions, and psychological factors [190]. Numerous studies have examined the influence of sociodemographic characteristics such as maternal age, marital status, education attainment, income, race/ethnicity and immigrant status, on breastfeeding practices [12-16]. Specifically, mothers who are younger [69-74], African American [72], unmarried [69], less educated and low-income [13, 78, 79], and born in the United States [8] are less likely to breastfeed longer. Maternal and child health conditions such as premature birth, Caesarean delivery, and maternal smoking also influence breastfeeding behaviors [14-16]. Infants who were born prematurely or by Caesarean delivery are less likely to be breastfed due to the separation of the mother and the infant, feeding difficulties or a significant delay in initiating breastfeeding [84-86]. Mothers who are smokers tend to breastfeed for a shorter duration [87]. Psychological factors, including attitudes towards breastfeeding, perceived subjective norms and perceived behavioral control, have been well-studied and are established predictors of breastfeeding initiation and duration [69, 73, 74, 88, 89].

Less attention has been paid to factors beyond the individual level such as social support from family and friends, hospital practices, workplace support, social norms, and public policies.

A few experimental [133] and quasi-experimental studies [137, 138] have found that maternal care practices, particularly those recommended by the Baby-Friendly Hospital Initiative (BFHI) – a global movement launched by the World Health Organization and the United Nations Children's Fund in 1991 to advocate for a package of 10 breastfeeding promotion practices – have been associated with increased breastfeeding duration and intensity (exclusive or partial). Some studies suggest that some of these practices, such as having the baby room-in with mother, or giving free formula samples to new mothers, may also influence at least, breastfeeding initiation, if not maintenance [10, 107-110]. Finally, a few observational studies have suggested that early return to work is associated with shorter breastfeeding duration [87, 191, 192].

Breastfeeding is a dynamic process and the behavior unfolds over time, from forming intentions to breastfeed to initiating breastfeeding, then continuing breastfeeding. However, much less is known about the mechanisms by which the myriad of factors discussed above influence breastfeeding behaviors maintenance over time. The sharp drop of breastfeeding rates in the first few months, particularly in low-income populations in the United States suggests that it is challenging for mothers to overcome barriers to maintaining breastfeeding for the recommended duration of 6 months [6, 193]. To date, the most widely applied behavioral theory for explaining breastfeeding behavior is the Theory of Reasoned Action [90, 91] – or its expanded version, the Theory of Planned Behavior [92, 93] – which posits that behavioral intention is a key predictor of actual behavior, and behavioral intentions are affected by attitudes toward behavior, subjective norms and perceived behavioral control. Although the intention to breastfeed has been shown in many studies to be strongly associated with the initiation of breastfeeding, it is not a consistent predictor of breastfeeding duration [69, 95-99], indicating that the Theory of Planned Behavior is not sufficient or appropriate for understanding the factors that

influence maintenance of breastfeeding [89, 160]. The Theory of Planned Behavior is also limited in that it does not consider the influences of social and physical environments in breastfeeding behavior.

In comparison, the social ecological model explicitly takes into account both individual and environmental factors influencing a specific health behavior [173-176]. A supportive environment is particularly important for breastfeeding maintenance [190, 194]. While expectations about breastfeeding may motivate women to initiate breastfeeding, whether she continues to breastfeed (and for how long) is likely to be influenced by her satisfaction with the actual experience of breastfeeding [160]. Women who continue to breastfeed after the initial 1-2 weeks often have to overcome difficulties and barriers such as discomfort and pain, insufficient milk supply, and having to return to work early [195]. Whether their environments (family, birthing hospitals and workplaces) are supportive of breastfeeding may significantly contribute to their breastfeeding experiences and influence how long and how intensive they breastfeed [9-11]. Relatively few studies have examined the impact of these environment factors on breastfeeding maintenance, especially for socially disadvantaged groups. To my knowledge, no studies have examined the multiple and interactive contributions of support for breastfeeding from family, birthing hospital and workplace to breastfeeding behavior. Investigating the roles of these environments for women with varying family environments, access to delivery facilities and work-place environments has implications for the design of effective breastfeeding promotion interventions.

The primary purpose of this study is to examine the influences of breastfeeding support from family (interpersonal level factor) and birthing hospital and workplaces (institutional level

factors) on breastfeeding maintenance among low-income women enrolled in the WIC program in the Los Angeles County, California. Specifically, this study is to: (1) describe breastfeeding rates in this population, and (2) examine the effects of support that women receive from family, birthing hospitals and workplaces on breastfeeding maintenance. The following hypotheses will be tested:

- *Hypothesis 1: Breastfeeding rates among WIC-participating mothers differ by maternal age, race/ethnicity, education level and household income.*
- *Hypothesis 2: Receiving support from family, birthing hospitals and workplace for breastfeeding is associated with longer breastfeeding duration.*

Methods

Study design and sample

Data for this study were obtained from two sources: the triennial Los Angeles county WIC Survey and Baby-Friendly USA. Los Angeles County WIC Survey is a cross-sectional survey, which has been conducted once every three years since 2005. Respondents are a random sample of approximately 5000 WIC-participating pregnant women and parents of WIC-participating children. Data are collected by phone interview. While most questions remain the same across surveys to allow for comparisons across time, a few questions may be replaced by new questions of current interest or relevance. We used data from the 2014 and the 2017 surveys which collected information that allowed for the assessment of family, workplace and health professional support for breastfeeding. Hospital Baby-Friendly designation status of birthing

hospitals in Los Angeles County was obtained from the website of Baby-Friendly USA. Chapter 4 provides a detailed description of the two data sources.

The analytic sample for this study was restricted to 3,812 WIC-participating children ages 12-35 months whose data were reported by the biological mother from five racial/ethnic groups. Children older than 35 months were excluded to avoid possible maternal recall bias of breastfeeding practices [196]. Children younger than 12 months were also excluded to allow for the examination of breastfeeding practices up to 12 months postpartum. Survey respondents whose race /ethnicity was "other" or missing were also excluded (n=53). Another 58 observations (approximately 1.5%) were excluded due to missing data on breastfeeding outcome variables. This sample comprised 3,687 WIC-participating children ages 12-35 months was used for descriptive analysis of breastfeeding trends and disparities.

To assess the influences of support from family, birthing hospitals and workplaces on breastfeeding maintenance, we further restricted the sample to 3,355 WIC-participating children ages 12-35 months who were born in a hospital in Los Angeles County and had been breastfed. A total of 598 observations (approximately 8%) were excluded due to missing data on variables of relevance to the study. The final analytic sample comprised 2,768 WIC-participating children with complete data.

Measures

Outcome variables

Outcomes of interest are breastfeeding initiation, any breastfeeding at 1, 3, 6, 9 and 12 months, and exclusive breastfeeding at 1, 3 and 6 months. Outcomes for assessing the influences

of interpersonal and institutional factors on breastfeeding duration are any breastfeeding at 6 and 12 months, and exclusive breastfeeding at 3 and 6 months, measured as binary variables (Yes/No). Breastfeeding was initiated if a mother has ever breastfed her infant, either at hospital or after return home. Any breastfeeding was defined as having been fed any amount of breast milk either through nursing or bottle. Exclusive breastfeeding was defined as having been fed only breast milk either through nursing or bottle and no other food, not even water. The survey questions used to operationalize these variables are provided in **Table 5.1.**

Table 5.1 Questions used to assess breastfeeding outcomes

Variable	Survey questions
Breastfeeding initiation	• Have you ever breast-fed NAME?
Any breastfeeding at 1, 3, 6, 9 and 12 months	• Are you currently breast-feeding NAME? • (If no): How old was NAME when you completely stopped breast-feeding (him/her)?
Exclusive breastfeeding at 1, 3 and 6 months	• How old was NAME the first time (he/she) was given anything besides breast milk? This includes formula, baby food, juice, cow's milk, sugar water or anything else you fed your baby.

Source: The 2014 and 2017 WIC survey instruments https://lawicdata.org/survey/

Independent variables of interest

The interpersonal and institutional factors examined are family support, hospital practices and workplace support. Family support was measured by a proxy indicator of whether the partner lives in the same household as the mother (Yes/No). Hospital practices were assessed by Baby-Friendly designation of birthing hospital at the time of childbirth (Yes/No) and four individual baby-friendly practices received by mothers (Yes/No): (1) initiating breastfeeding within one hour after delivery, (2) not distributing supplementary formula in hospital, (3) not distributing free formula packages to take home, and (4) providing mothers with telephone

numbers to call for help with breastfeeding after discharge. A numeric variable was created to sum the total number of baby-friendly practices that mothers received (ranging from 0 to 4). Workplace support was coded into three categories depending on when they returned to work after childbirth and whether their workplaces provided accommodations for breastfeeding: 1=returned to work within three months and the workplace did not have breastfeeding accommodations, 2=returned to work within three months and the workplace provided breastfeeding accommodations, and 3=did not return to work within three months. The survey questions used to operationalize these variables are provided in **Table 5.2**.

Table 5.2 Questions used to assess breastfeeding support from family, hospitals and workplace

Variable	Survey questions
Living with partner	• Does NAME's other parent or legal guardian live in this household?
Baby-Friendly designation status of the hospital at the time of childbirth	• Was NAME born in a hospital? • (If yes): Was the hospital in Los Angeles County? • (If yes): What was the name of the hospital where NAME was born?
Initiating breastfeeding within one hour	• Did you breastfeed NAME in the first hour after birth?
Given no supplementary feeding in hospital	• Was NAME fed only breast milk at the hospital?
Given no free formula package to take home	• Did the hospital staff give you formula to take home?
Given a telephone number to call for help with breastfeeding	• Did the hospital give you a telephone number to call for help with breastfeeding?
Workplace arrangement	• Since the birth of NAME did you return to work or begin a new job? • (If yes): How old was NAME when you first returned to work or began work? • When you went back to work, did your workplace have accommodations for you to breast-feed? This includes giving you a break time and a place to pump milk or breast-feed your baby.

Source: The 2014 and 2017 WIC survey instruments https://lawicdata.org/survey/

A birthing hospital with the Baby-Friendly designation is accredited by Baby-Friendly USA, the national accrediting body for the Baby-Friendly Hospital Initiative in the United States, This designation is given after the hospital has successfully implemented the *Ten Steps to Successful Breastfeeding* [114] and the *International Code of Marketing of Breast-milk Substitutes* [55] and met the evaluation standards [197]. The designation expires in 5 years if a re-designation request is not submitted and approved. A list of birthing hospitals with Baby-Friendly designation, the designation date and expiration date (if the designation expired) was extracted from the website of Baby-Friendly USA (https://www.babyfriendlyusa.org/for-parents/baby-friendly-facilities-by-state/) and used to assign the Baby-Friendly designation status for each birthing hospital in Los Angeles County.

Covariate variables

To test the second hypothesis regarding the influences of interpersonal and institutional factors on breastfeeding duration, several individual level confounding factors which are potentially associated with both the outcome (breastfeeding duration) and independent variables (family support, hospital practices and workplace support) were included in the analysis as covariates. These factors include sociodemographic characteristics of mothers and infants: mother's age at childbirth (<20 years old, 20-29 years old, ≥30 years old), education level (less than high school, high school graduate, some college or associated degree, college graduate or above), race/ethnicity and preferred language (English-speaking Latina, Spanish-speaking Latina, Non-Hispanic White, Non-Hispanic Black, and Non-Hispanic Asian), household income level measured by a proxy indicator whether the household receive SNAP in the last twelve months (Yes/No), infant gender (Male/Female), and infant gestational age (full-term/preterm), and

mother's prenatal intention to breastfeed (Yes/No). Relevant survey questions are provided in **Table 5.3**.

Table 5.3 Questions used to measure covariates

Variable	Survey questions
Mother's age at childbirth	• What is your age? • The child's age has been calculated in the dataset, so the mother's age at childbirth is derived from the current age at the interview subtracting her child's age
Mother race/ethnicity	• Are you of Latino or Hispanic origin? • Are you White, Black or African-American, Asian, Pacific Islander, American Indian or an Alaskan native, a member of another race or a combination of these? • Language of interview: English or Spanish
Mother education level	• What is the highest level of school you have completed or the highest degree you have received? • (If High school): What was the highest grade you completed?
Household receiving SNAP	• In the last twelve months, have you or has anyone in your household used an EBT card for food stamps to buy food?
Child gender	• NAME is a (boy) (girl). Is that correct?
Child gestational age	• Was NAME born early as a pre-term baby? (If necessary:) A pre-term baby is one born at 36 weeks or earlier in pregnancy. • How many weeks pregnant were you when NAME was born?
Intention to breastfeed	• While you were pregnant with NAME, which of the following describe what you thought you would do with regard to breast-feeding NAME? (1) You knew you would breast-feed NAME (2) You thought you might breastfeed NAME (3) You knew you would not breast-feed NAME (4) You did not know what to do about breastfeeding NAME

Source: The 2014 and 2017 WIC survey instruments https://lawicdata.org/survey/

Statistical analysis

Analyses were performed using the SAS version 9.4 software (SAS Institute, Cary, NC). All the variables are categorical and they were summarized by computing frequency distributions. To describe the trend and disparities in breastfeeding practices among WIC-participating mothers, we calculated the prevalence of breastfeeding at various ages (any breastfeeding at 1, 3, 6, 9, and 12 months, and exclusive breastfeeding at 1, 3 and 6 months) and compared them by year and mother's sociodemographic characteristics (age, race/ethnicity, education and income) using chi-square tests.

To assess the influences of interpersonal and institutional factors on breastfeeding duration, multiple logistic regression models were fitted to assess their associations with each of the four outcome variables (any breastfeeding at 6 and 12 months, and exclusive breastfeeding at 3 and 6 months); adjusted odds ratios (OR) and 95% confidence interval (CI) were estimated. Adjusted analyses controlled for the individual sociodemographic factors (i.e. mother's age, race/ethnicity, education level and household income) and prenatal intention to breastfeed. A p-value < 0.05 was chosen for statistical significance.

Results

All women surveyed: distribution of sociodemographic characteristics

The characteristics of the 3,687 surveyed WIC-participating mothers in this study are presented in **Table 5.4**. Approximately 9% were younger than 20 years old when giving birth to their children. About 86% were Latina, with the remaining being White, Black or Asian. Nearly

two thirds of them received a high school or higher education and about half of their families received benefits from the Supplemental Nutrition Assistance Program (SNAP). Fifty-two percent of the infants were male and about 9% of the births were preterm.

Breastfeeding trends

For the surveyed children born during 2011-2016, the vast majority of their mothers (93.5-95.2% in various years) initiated breastfeeding. The breastfeeding rates, either any breastfeeding or exclusive breastfeeding, did not improve during this period except for exclusive breastfeeding at 1 month (**Figure 5.1** and **Appendix S5-1**). Despite the high breastfeeding initiation rates, only 30.3% of infants born in 2016 were breastfed up to 12 months and only 7.9% of them were exclusively breastfed up to 6 months.

Figure 5.1 Rates of any and exclusive breastfeeding among WIC-participating mothers in the Los Angeles County, 2011-2016

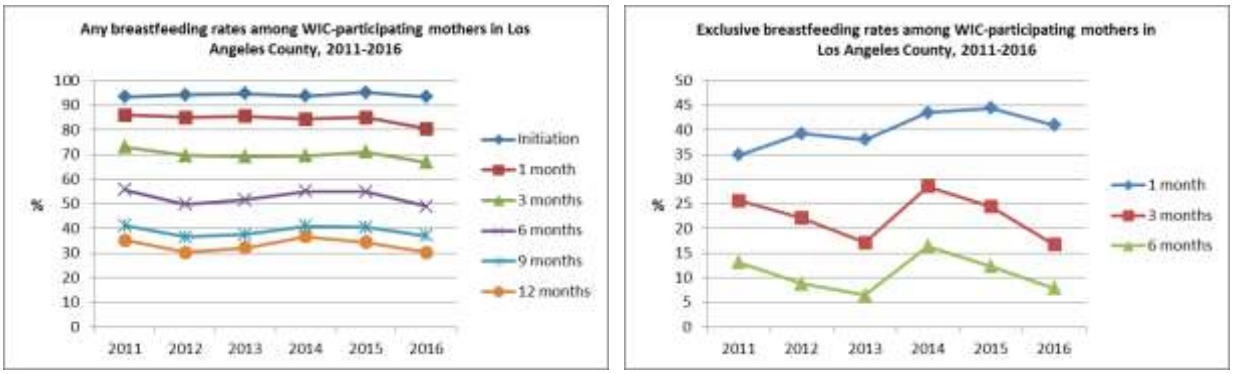


Table 5.4 Sociodemographic characteristics among WIC-participating mothers of children aged 12-35 months in Los Angeles County (n=3,687)

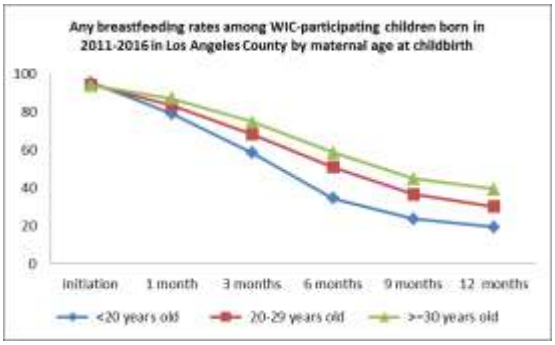
Variables	N	Percentage
Mother's age at childbirth		
< 20 years	330	9.0
20-29 years	1845	50.0
≥ 30 years	1512	41.0
Mother's race/ethnicity		
Spanish-speaking Latina	1579	42.8
English-speaking Latina	1608	43.6
NH-White	150	4.1
NH-Black	272	7.4
NH-Asian	78	2.1
Mother's educational attainment		
Less than high school	1265	34.3
High school graduate	1074	29.1
Some college	997	27.0
College grad or above	351	9.5
Household income		
SNAP recipient	1801	48.8
Non-SNAP recipient	1886	51.2
Infant gender		
Male	1916	52.0
Female	1771	48.0
Infant gestational age		
Full-term	3349	90.8
Preterm	329	8.9
Missing	9	0.2
Birth year of the surveyed child		
2011	475	12.9
2012	907	24.6
2013	432	11.7
2014	439	11.9
2015	956	25.9
2016	478	13.0

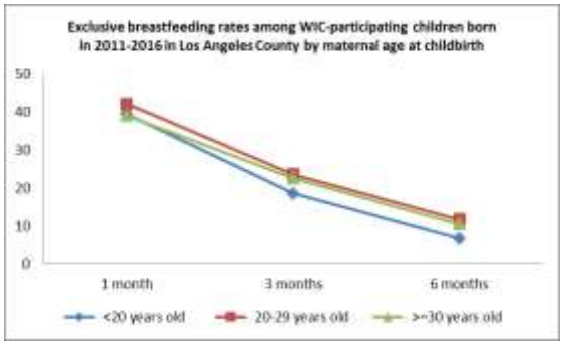
Note: WIC = Special Supplemental Nutrition Program for Women, Infants and Children.
SNAP = Supplemental Nutrition Assistance Program.

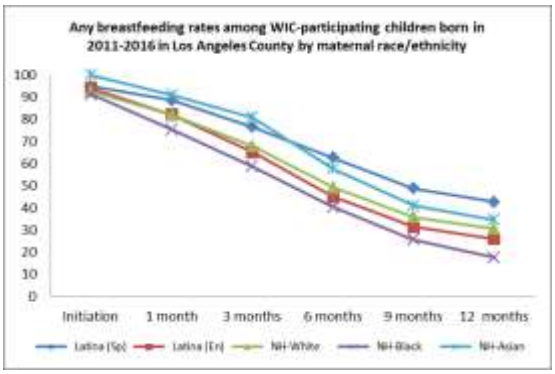
Breastfeeding rates by sociodemographic characteristics

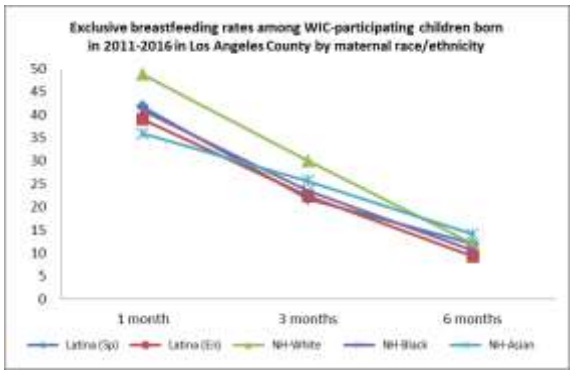
Differences in breastfeeding rates, particularly for any breastfeeding, were observed by maternal age, race/ethnicity, educational level and household income **(Figure 5.2** and **Appendix S5-2)**. Mothers aged 30 years or older had higher rates of any breastfeeding than mothers aged 20-29 years, and mothers aged below 20 years had the lowest rates of any breastfeeding. Spanish-speaking Latina mothers had the highest rates of any breastfeeding, followed by Asian, White, English-speaking Latina, and Black mothers. The differences in any breastfeeding rates at 6 and 12 months between Spanish-speaking Latina and Black mothers were 22.3 and 25.1 percentage points respectively. Mothers with college education or above showed higher rates of any breastfeeding than mothers with lower education levels. Mothers from SNAP-recipient household had slightly lower rates of any breastfeeding but the difference between SNAP-participating and non-SNAP-participating mothers diminished at 12 months. The differences in exclusive breastfeeding rates were mostly not statistically significant and differences observed narrowed by six months.

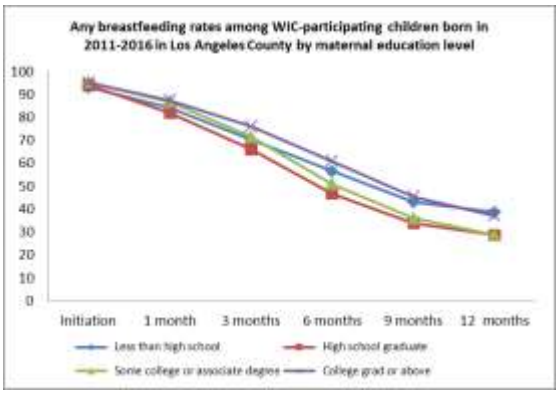
Figure 5.2 Rates of any and exclusive breastfeeding among WIC-participating mothers in the Los Angeles County by maternal age, race/ethnicity, education level, household income

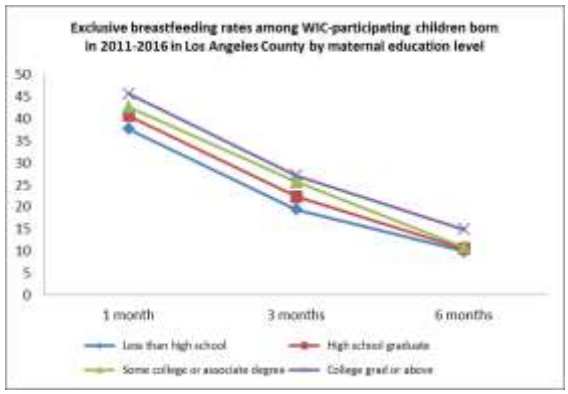


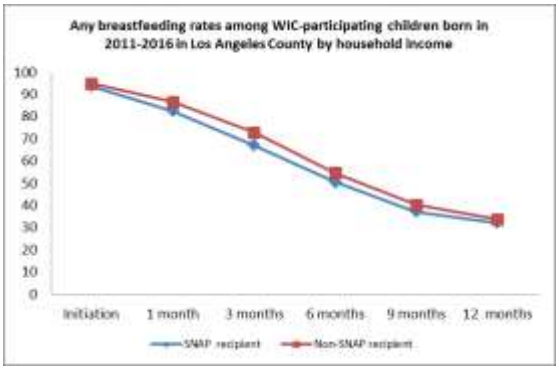


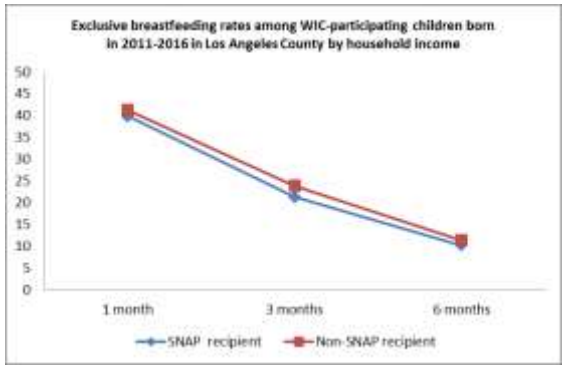












Women who initiated breastfeeding: distribution of individual, interpersonal and institutional factors

The distribution of individual, interpersonal and institutional factors related to breastfeeding among the 2,746 surveyed WIC-participating mothers who initiated breastfeeding are presented in **Table 5.5**. Approximately 9% of the surveyed women were younger than 20 years old when giving birth. About 87% of them were Latina, with the others being White, Black or Asian. About 67% received a high school or higher education and 52.0% received SNAP benefits. About 52% of the infants were male, and 8.6% were born preterm. During pregnancy, approximately 92% of these mothers intended to breastfeed their children.

Over two thirds of mothers lived with their partner. About 29% of infants were born in a designated Baby-Friendly hospital. About 77% of mothers were able to breastfeed their newborn in the first hour after birth and about 52% of newborns were fed only breast milk during their hospital stay. Nearly half of mothers received free formula packages from hospital staff to take home. About 85% of women reported being provided with a telephone number to call for assistance with breastfeeding. The majority of surveyed women did not return to work within three months after childbirth; 10.6% of women returned to work within 3 months but their workplace did not provide breastfeeding accommodations; and 14.6% returned to work within 3 months and their workplace provided breastfeeding accommodations such as a lactation room, refrigerator and break time.

Table 5.5 Distribution of individual, interpersonal and institutional factors among WIC-participating mothers (n=2,746)

Factor	N	Percentage
Mother's age at childbirth		
< 20 years	254	9.2
20-29 years	1371	49.9
≥ 30 years	1121	40.8
Mother's race/ethnicity		
Spanish-speaking Latina	1157	42.1
English-speaking Latina	1240	45.2
NH-White	98	3.6
NH-Black	191	7.0
NH-Asian	60	2.2
Mother's educational attainment		
Less than high school	918	33.4
High school graduate	809	29.5
Some college	756	27.5
College grad or above	263	9.6
Household income		
SNAP recipient	1428	52.0
Non-SNAP recipient	1318	48.0
Infant gender		
Male	1419	51.7
Female	1327	48.3
Infant gestational age		
Full-term	2510	91.4
Preterm	236	8.6
Prenatal intention to breastfeed child		
Yes	2524	91.9
No	222	8.1
Partner live in the household		
Yes	1905	69.4
No	841	30.6
Infant was born in a Baby-Friendly hospital in LA county		
Yes	808	29.4
No	1938	70.6
Infant was fed only breast milk at hospital		
Yes	1436	52.3
No	1310	47.7
Breastfeed child in the first hour after birth		
Yes	2116	77.1
No	630	22.9

Hospital staff did NOT give formula to take home		
Yes	1384	50.4
No	1362	49.6
Mother was given a phone number to call for help with breastfeeding		
Yes	2342	85.3
No	404	14.7
Time of returning to work and workplace breastfeeding accommodations		
Return to work by 3 month and no workplace accommodations	292	10.6
Return to work by 3 month and have workplace accommodations	401	14.6
Did not return to work by 3 months	2053	74.8

Note: WIC = Special Supplemental Nutrition Program for Women, Infants and Children.
SNAP = Supplemental Nutrition Assistance Program.

Influences of interpersonal and institutional factors on breastfeeding maintenance

Table 5.6 presents adjusted odd ratios and 95% confidence interval for the interpersonal and institutional factors associated with breastfeeding duration. Living with partner is associated with both any and exclusive breastfeeding, although the association for exclusive breastfeeding at 6 months is not statistically significant. Compared to mothers who did not live with partner, mothers who lived with their partner had a higher odds of breastfeeding at 6 months (OR: 1.46, 95% CI: 1.22, 1.75) and 12 months (OR: 1.42, 95% CI: 1.17, 1.73). The odds of their exclusively breastfeeding at 3 months was also higher (OR: 1.30, 95% CI: 1.05, 1.60).

Workplace support was statistically significant associated with all four breastfeeding duration outcomes. For example, compared to mothers whose workplaces did not provide breastfeeding accommodations and returned to work within 3 months after childbirth, mothers who returned to work within 3 months and received accommodations for breastfeeding at work had higher odds of breastfeeding at 12 months (OR: 1.96, 95% CI: 1.35, 2.86) and exclusive breastfeeding at 6 months (OR: 2.93, 95% CI: 1.52, 5.65). Mothers who did not return to work

within 3 months also had higher odds of breastfeeding at 12 months (OR: 2.59, 95% CI: 1.87, 3.58) and exclusive breastfeeding at 6 months (OR: 3.34, 95% CI: 1.84, 6.07).

In terms of hospital related factors, giving birth in a Baby-Friendly designated hospital was not associated with breastfeeding duration. However, each of the four Baby-Friendly hospital practices was observed to be independently associated with any breastfeeding or exclusive breastfeeding duration or both ($p<0.05$). Early initiation of breastfeeding in the first hour after birth increased the odds of exclusive breastfeeding at 3 months (OR: 1.58, 95% CI: 1.25, 2.00) and 6 months (OR: 1.42, 95% CI: 1.04, 1.95). Feeding infant with only breast milk while in the hospital was associated with increased odds of any breastfeeding at 6 months (OR: 2.73, 95% CI: 2.32, 3.22) and 12 months (OR: 2.34, 95% CI: 1.97, 2.77), and exclusive breastfeeding at 3 months (OR: 20.92, 95% CI: 15.22, 28.75) and 6 months (OR: 15.67, 95% CI: 9.97, 24.65). Compared to mothers who were given free formula to take home, mothers not being given free formula packages had higher odds of breastfeeding at 6 months (OR: 2.01, 95% CI: 1.71, 2.36) and 12 months (OR: 1.68, 95% CI: 1.43, 1.98), and higher odds of exclusive breastfeeding at 3 months (OR: 2.29, 95% CI: 1.90, 2.75) and 6 months (OR: 2.23, 95% CI: 1.74, 2.87). Being provided with a telephone number to call for help with breastfeeding was associated with a higher odds of breastfeeding at 6 months (OR: 1.29, 95% CI: 1.02, 1.61). The total number of studied Baby-Friendly practices received by mothers was positively associated with the odds of continuing to breastfeed at 6 and 12 months and exclusive breastfeeding at 3 and 6 months. In particular, each additional Baby-Friendly practice was associated with a 39% increase in the odds of breastfeeding at 12 months (OR: 1.39, 95% CI: 1.29, 1.51) and 119% increase in the odds of exclusive breastfeeding at 6 months (OR: 2.19, 95% CI: 1.90, 2.52).

Table 5.6 Adjusted Odds Ratios for interpersonal and institutional factors related to breastfeeding maintenance among WIC-participating mothers in Los Angeles County (n=2,746)

Factors	Any breastfeeding at 6 months		Any breastfeeding at 12 months		Exclusive breastfeeding at 3 months		Exclusive breastfeeding at 6 months	
	OR	**95% CI**	**OR**	**95% CI**	**OR**	**95% CI**	**OR**	**95% CI**
Family support								
Live with a partner	**1.46**	**(1.22, 1.75)**	**1.42**	**(1.17, 1.73)**	**1.30**	**(1.05, 1.60)**	1.22	(0.92, 1.62)
Hospital practices								
Child was born in a Baby-Friendly hospital	0.89	(0.75, 1.06)	0.95	(0.79, 1.13)	1.02	(0.84, 1.23)	0.99	(0.76, 1.28)
Child was fed only breastmilk in hospital	**2.73**	**(2.32, 3.22)**	**2.34**	**(1.97, 2.77)**	**20.92**	**(15.22, 28.75)**	**15.67**	**(9.97, 24.65)**
Initiate breastfeeding within one hour of birth	**1.22**	**(1.01, 1.48)**	1.13	(0.93, 1.39)	**1.58**	**(1.25, 2.00)**	**1.42**	**(1.04, 1.95)**
Given NO free formula to take home	**2.01**	**(1.71, 2.36)**	**1.68**	**(1.43, 1.98)**	**2.29**	**(1.90, 2.75)**	**2.23**	**(1.74, 2.87)**
Given telephone number to call for help with breastfeeding	**1.29**	**(1.02, 1.61)**	1.09	(0.87, 1.38)	1.25	(0.96, 1.63)	**1.47**	**(1.01, 2.13)**
Number of baby-friendly practices received by mother (0-4)	**1.54**	**(1.43, 1.67)**	**1.39**	**(1.29, 1.51)**	**2.38**	**(2.15, 2.65)**	**2.19**	**(1.90, 2.52)**
Workplace support								
Return to work within 3 mons & workplace provides bf accommodations	**2.13**	**(1.55, 2.93)**	**1.96**	**(1.35, 2.86)**	**1.85**	**(1.26, 2.73)**	**2.93**	**(1.52, 5.65)**
Did not return to work within 3 mons	**2.08**	**(1.60, 2.71)**	**2.59**	**(1.87, 3.58)**	**1.83**	**(1.31, 2.56)**	**3.34**	**(1.84, 6.07)**

Note: (1) OR, adjusted odds ratio. CI, Confidence Interval. WIC, the Special Supplemental Nutrition Program for Women, Infants and Children. Statistically significant odds ratios are in bold. (2) The adjusted analyses were controlled for mother's age at childbirth, mother's race/ethnicity, mother's education level, household income, child's gender, child's gestational age (full-term or preterm birth) and mother's prenatal intention to breastfeed. (3) Omitted reference category for workplace arrangement is that mother returned to work within 3 months and workplace did not provide accommodations for breastfeeding.

Discussion

This study examined the trend, disparities and influencing factors of breastfeeding practices among WIC-participating mothers in Los Angeles County. The breastfeeding rates of WIC-participating mothers have been significantly lower than those of the general population nationally [198]. Our study found that in Los Angeles County in 2016, a relatively high proportion of WIC-participating mothers (over 93%) actually initiated breastfeeding. However, at 3 months, only 67% of infants were breastfed and 17% exclusively. In comparison, corresponding rates for all infants in the county were 71% and 43% respectively [199]. When examining trends, we noted that breastfeeding rates generally did not improve during the years 2011-2016; the exception was the exclusive breastfeeding rate at one month, which increased from 35% in 2011 to 41% in 2016. One possible reason is the declining proportion of Spanish-speaking Latina mothers (who have higher breastfeeding rates than other racial/ethnic groups) enrolled in the WIC program nation-wide [200] and in our study sample (47% in 2011 to 37% in 2016.

While WIC-participating mothers are often considered a homogenous group for policy and intervention program development [201, 202], our study revealed that breastfeeding rates among WIC-participating mothers varied by age, race/ethnicity and socioeconomic status. WIC-participating mothers who are at older age at childbirth, better educated, and have higher household income are more likely to continue breastfeeding for longer periods. In addition, it is important to note the significant difference in breastfeeding rates between Spanish-speaking and English-speaking Latina mothers. While Spanish-speaking Latina mothers have the highest breastfeeding continuation rates among the five racial/ethnic groups, English-speaking Latina mothers have among the lowest rates. These individual sociodemographic factors could be useful

in identifying subgroups of women who terminate breastfeeding earlier than recommended so that interventions can be tailored for them.

This study also identified several modifiable interpersonal and institutional level factors that may influence breastfeeding duration among WIC-participating mothers. First, the living with a partner was found to be positively associated with breastfeeding duration among WIC-participating mothers. This is consistent with the findings from a cross-sectional study with socially disadvantaged women in Scotland by Mclnnes and Love [71]. A number of studies have documented the influential role of male partners in women's breastfeeding behavior, and the influence could be positive or negative depending on their attitudes towards breastfeeding [71, 74, 100, 103-105]. A qualitative study by Bryant [105] suggested that living with a partner may support breastfeeding since partners can provide practical help with housework and child care. Mclnnes and Love [71] discussed other reasons including physical environment and privacy. When mothers live with their partner instead of extended families, it is more likely that they have a private place for breastfeeding.

At the institutional level, early return to work is commonly cited as a key reason for stopping breastfeeding in the general population [87] and among WIC-participating mothers [192]. Our study revealed that if women have to return to work, the availability of workplace accommodation for breastfeeding such as break times and private lactation rooms significantly increased their chances of meeting recommendations for continuing breastfeeding and exclusive breastfeeding.

Finally, our study examined the influences of another set of institutional factors, hospital practices, on long-term breastfeeding outcomes. Previous studies suggested that maternity care

practices may play a role in breastfeeding initiation by facilitating or hindering a mother's intent to breastfeeding [108-111]. Our study found that the four Baby-Friendly hospital practices we examined – feeding the infant only breast milk in the hospital, initiating breastfeeding within one hour after delivery, not receiving free formula packages, and providing mothers with a phone number to call for help with breastfeeding – have a positive impact on breastfeeding outcomes at 6 months and 12 months, way beyond the hospital stay period. However, we did not find an association between infant being born at a Baby-Friendly hospital and long-term breastfeeding outcomes. Although a cluster randomized trial conducted in the Republic of Belarus by Kramer, Chalmers [133] has found that BFHI interventions were effective in increasing duration and exclusivity of breastfeeding, two unique features of the Belarussian health care system – it being highly centralized and the prolonged postpartum hospital stay for childbirth – limit the generalizability of the findings to the U.S. population. A few quasi-experimental studies conducted in the United States have suggested that BFHI interventions may increase breastfeeding initiation and short-term breastfeeding rates but their influence on long-term breastfeeding outcomes were not examined [137, 138]. Our additional analysis found that infants being born at a Baby-Friendly hospital were more likely to be exclusively breastfed while in the hospital (data not shown) but not after they returned home. Our findings suggest that support from family and workplace for breastfeeding mothers may be important for increasing the likelihood that mothers meet recommendations for breastfeeding. It is also possible that hospitals not designated as 'baby-friendly' implement Baby-Friendly hospital practices, which results in an underestimation of the real impact of BFHI interventions. In fact, we noted that mothers delivering at Baby-Friendly hospitals received an average of 2.9 Baby-Friendly hospital

practices (out of the four Bay-Friendly hospital practices studied) while mothers delivering at non Baby-Friendly hospital also received an average of 2.6 practices.

It has been well documented in the literature that socially disadvantaged women such as WIC-participating mothers face more barriers to initiating or continuing breastfeeding [118, 193, 203]. Despite the increase in breastfeeding initiation rates, the duration of breastfeeding has remained low in low-income populations. There is a dearth of research on the factors that influence women's decision to breastfeed for only a short period of time. Rothman [160] suggested that satisfaction with the breastfeeding experience may be an important factor. However, little is known about what determines satisfaction with the breastfeeding experience. Our study found that support for breastfeeding women from family, Baby-Friendly hospital practices, and workplace policies that support breastfeeding women are associated with longer duration of breastfeeding. Women who continue to breastfeed after the initial week often have to overcome real and perceived barriers such as discomfort and pain, deprivation of sleep, not having sufficient milk, and needing to return to work outside the home [195]. Receiving support from the environment that they regularly interact with (e.g. family, health care system and workplace) may provide the self-efficacy needed for breastfeeding their babies for the recommended duration.

This study has several limitations. First, it was conducted with WIC-participating mothers and the findings may not be generalizable to the general population. Second, to a large extent, breastfeeding outcomes were determined from women's recall. We restricted our analytical sample to children younger than 36 months to avoid possible maternal recall bias since studies have shown that maternal recalls on breastfeeding practices are reliable and valid up to 3 years after childbirth [196]. Third, previous breastfeeding experience may affect the

maintenance of current breastfeeding [71, 72, 78, 96], and we were not able to account for this as parity data were not available. Finally, the study used data from cross-sectional surveys and hence cannot provide evidence of temporal relationships. We examined each of the investigated factors separately and did not explore the interaction between these factors. Future studies using more rigorous study designs to evaluate the independent and combined effects of Baby-Friendly hospital practices and workplace support on women with and without family support will have implications for the design and implementation of impactful programs and policies to promote breastfeeding.

Chapter 6: Racial and ethnic disparities in breastfeeding practices in a low-income population: Does breastfeeding support matter?

Background

Over the past few decades, while breastfeeding rates have improved for all racial and ethnic groups in the United States, racial/ethnic disparities in breastfeeding practices have persisted [17-19]. In general, Black women and American Indian/Alaska Native women have lower breastfeeding rates at birth, 6 months and 12 months postpartum than White women, while Asian and Hispanic women have similar or even higher breastfeeding rates than White women [62]. In 2017, the breastfeeding initiation rates for Black mothers and American Indian/Alaska Native mothers (74% and 81% respectively) remain below the Healthy People 2020 goal (82%), while the rates of Hispanic, White and Asian mothers (84%, 87% and 90% respectively) have met the goal [6, 60]. Since 2000, rates of breastfeeding initiation and breastfeeding for 6 months have differed by at least 15 percentage points between White and Black mothers [7, 64]. This racial/ethnic disparity in breastfeeding initiation and duration has contributed significantly to disparities in infant morbidity and mortality [204]. Forste, Weiss, and Lippincott [65] have suggested that breastfeeding is as important as low birth weight in explaining the racial difference in infant mortality in the United States.

Factors that may explain the persistent racial/ethnic disparities in breastfeeding include demographic characteristics and socioeconomic status [68, 80], birth outcomes [205, 206], breastfeeding support from family and friends [21], hospital practices [20], workplace policies [207, 208], and culture and norms [8, 66, 77]. Most existing studies have focused on maternal sociodemographic characteristics including maternal age, education attainment and income [13,

15, 16, 65]. For example, the higher educational attainment and household income level of White mothers compared to mothers in other racial/ethnic groups are often considered a major contributor to their higher breastfeeding rates [65]. However, several studies have found that even after controlling for maternal sociodemographic characteristics, race/ethnicity remains a strong predictor of breastfeeding outcomes [18, 66, 67], suggesting that other factors such as breastfeeding support, culture and norms may also contribute to racial/ethnic disparities in breastfeeding.

Breastfeeding support from family and friends, health professionals, and workplaces is critical for women to continue breastfeeding for the recommended duration [9]. Compared to individual sociodemographic characteristics, these breastfeeding support factors are relatively modifiable. Studies reveal that access to breastfeeding support varies by race/ethnicity [209]. For example, compared to White mothers, African American mothers are less likely to report receiving breastfeeding advice from their families and social networks [21], and more likely to return to work earlier than 12 weeks and to work in environments that do not support breastfeeding [207, 208]. Maternal care facilities (typically in hospitals) in neighborhoods with higher percentages of African Americans are also less likely to implement 'Baby-Friendly' hospital practices that support breastfeeding [20].

Although a large number of studies have documented racial/ethnic differences in breastfeeding rates and identified factors influencing breastfeeding practices, only one study has attempted to examine the potential causal mechanisms that may explain racial/ethnic differences in breastfeeding practices [68]. In this study, McKinney and colleagues applied the classic mediation analysis methods developed by Baron & Kenny [210] to test whether a set of potential mediators explain the observed racial/ethnic disparities in breastfeeding intention, initiation and

duration among Hispanic, White and Black mothers. The authors concluded that sociodemographic factors (college education and marital status) and maternity care practices (hospital use of infant formula) together fully explained the White-Black disparities in breastfeeding duration while family breastfeeding history and living with the infant's father together partially explained the longer breastfeeding duration of Spanish-speaking Hispanic mothers relative to Black mothers. This study on causal mechanisms of racial/ethnic disparities in breastfeeding, however, suffers both theoretical and methodological limitations. First, the causal pathways for the effect of race/ethnicity on breastfeeding duration as well as the theories supporting these pathways were not clearly stated in the study. Each of the potential mediators (such as maternal age, education, income, preterm birth, smoking, belief that "breast is best", family history of breastfeeding, in-hospital formula introduction, and WIC participation) was treated as independent of others and the linkage between mediators was ignored. Second, the authors only assessed the joint effect of all mediators rather than the effect mediated by each individual mediator. Such information – on the joint effect of all possible mediators – provides little utility for policy and program design since it is either too costly to intervene on all mediators or some mediators may not be modifiable. Therefore, it is critical to estimate the mediation effects of individual factors, particularly those modifiable factors, so as to provide more useful guidance for intervention design. Furthermore, the traditional mediation analysis methods applied in this study assumed that there is no interaction between the exposure (race/ethnicity) and mediators [211]. This assumption is violated if a potential mediator (e.g. hospital use of infant formula) affects breastfeeding practices differently across racial/ethnic groups. Such hetergenous effects of maternity care service [212] among racial/ethnic groups have been documented in the literature.

The primary aim of this study is to advance knowledge about the factors that contribute to racial/ethnic disparities by estimating the extent to which racial/ethnic differences in breastfeeding duration could be explained by access to breastfeeding support from family, hospitals and workplaces. We consider race/ethnicity a socially constructed category that encompasses region of ancestry, neighborhood, institutional power relationships, family patterns, cultural norms, and the social history of specific groups [181-184]. Thus it is an aggregate of many manipulatable elements rather than an 'immutable characteristic'. Five racial/ethnic groups were examined in this study, i.e. Spanish-speaking Latina, English-speaking Latina, Non-Hispanic White, Non-Hispanic Black and Non-Hispanic Asian.

Applying the theory that race/ethnicity is a fundamental cause of health inequalities [178-181], we propose that a substantial proportion of racial/ethnic differences in breastfeeding duration may occur through two causal pathways (**Figure 6.1**):

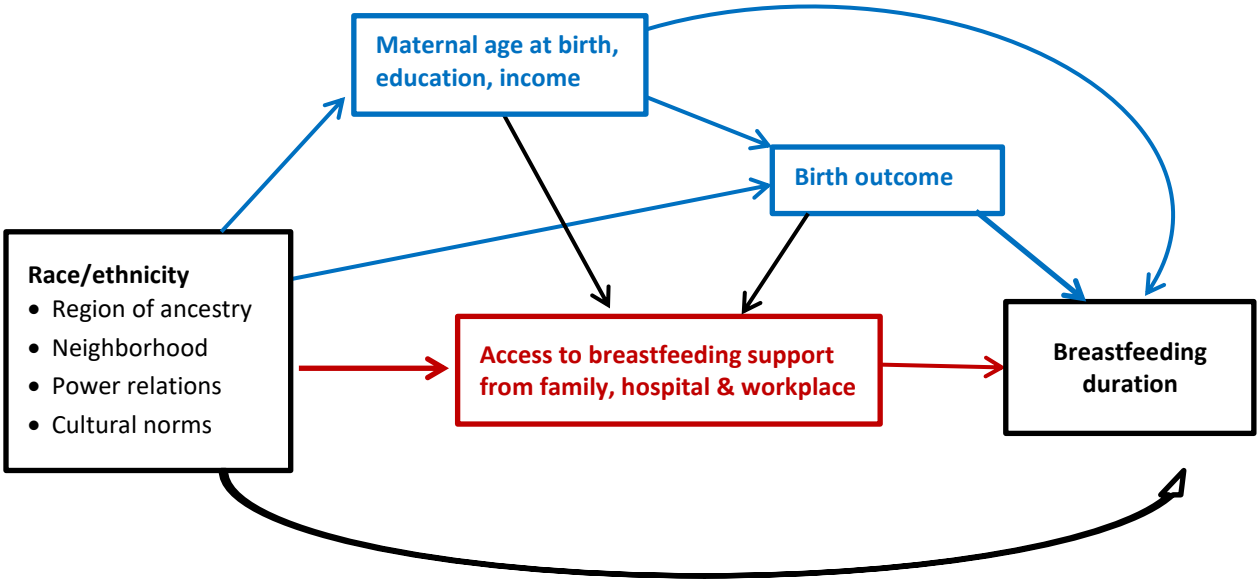
- *Race/ethnicity → SES & maternal age at birth → breastfeeding duration*: Race/ethnicity is associated with SES and maternal age at birth as well as birth outcomes (e.g. preterm birth) which in turn influence their breastfeeding duration;

- *Race/ethnicity → breastfeeding support → breastfeeding duration*: Race/ethnicity is associated with mother's access to social support and health care which in turn influence their breastfeeding duration.

The two causal pathways are not independent of each other as women's access to breastfeeding support (the mediator in the second pathway) is also influenced by their SES, age at childbirth and birth outcomes (the mediator in the first pathway). Therefore, the SES, maternal age at birth and birth outcomes (thereafter referred to as sociodemographic characteristics) are

also confounders for the relationship between breastfeeding support (mediator) and breastfeeding duration (outcome).

Figure 6.1 Conceptual model on causal pathways for racial/ethnic disparities in breastfeeding duration



Note: The diagram illustrates two causal pathways through which race/ethnicity influences breastfeeding duration: (1) race/ethnicity→SES and fertility pattern →breastfeeding duration (pathway in blue color) and (2) race/ethnicity→breastfeeding support→breastfeeding duration (pathway in red color). SES=socioeconomic status.

To estimate the racial/ethnic differences mediated by breastfeeding support, we applied a recent causal mediation analysis approach, *parametric g-computation*, which allows us to (i) estimate the contribution of breastfeeding support independent of other factors such as sociodemographic characteristics and birth outcomes and (ii) consider interaction between race/ethnicity and breastfeeding support. The specific study hypotheses are:

- ***Hypothesis 1****: The lower prevalence of BF at 6 months among Black women and English-speaking Latina women is partially explained by their lower levels of breastfeeding support than those of White women.*
- ***Hypothesis 2****: The higher prevalence of BF at 6 months among Spanish-speaking Latina women and Asian women is partially explained by their higher levels of breastfeeding support than those of White women.*

Methods

Study design and sample

This study uses cross-sectional survey data from the Los Angeles County WIC Survey (LAC-WIC), which was first conducted in 2005. LAC-WIC is conducted once every three years and selects a random sample of approximately 5,000 WIC-participating families residing in Los Angeles County. Data are collected by phone interview with a structured questionnaire. While most questions remain the same across surveys to allow for comparisons across time, a few questions may be replaced by new questions of current interest or relevance. In 2014 and 2017, LAC-WIC collected information that allowed for the assessment of family, workplace and health care system support for breastfeeding. This study uses data from these two survey years. A detailed description of this data set is available in Chapter 4 of this dissertation.

The analytic sample for this study was restricted to 4,404 children aged 6-35 months whose data were reported by the biological mother, and whose mothers were from the racial/ethnic groups of interest and had initiated breastfeeding. Children older than 35 months were excluded to avoid possible maternal recall bias of breastfeeding practices [196]. Children

younger than 6 months were also excluded to allow for the examination of breastfeeding practices up to 6 months postpartum. A total of 172 observations (approximately 4%) with missing data on breastfeeding outcomes (61 observations), sociodemographic characteristics (38 observations) and/or access to breastfeeding support (73 observations) were excluded. The final analytic sample comprised 4,232 children.

Measures

Outcome variables

The primary outcome of interest for testing the stated hypotheses is 'any breastfeeding' at 6 months. Since our analysis in Chapter 5 suggested that there were no significant racial/ethnic differences in exclusive breastfeeding rates, we did not intent to include 'exclusive breastfeeding' at 6 months as an outcome of interest for this study. For descriptive purposes, we estimated the prevalence of any breastfeeding at 1, 3, and 6 months, and exclusive breastfeeding at 1, 3, and 6 months. The questions used to operationalize these binary variables are provided in **Table 6.1**.

Table 6.1 Questions used to assess breastfeeding outcomes

Variable	Survey questions
Any breastfeeding at 1, 3 and 6 months	• Are you currently breast-feeding NAME? • (If no): How old was NAME when you completely stopped breast-feeding (him/her)?
Exclusive breastfeeding at 1, 3 and 6 months	• How old was NAME the first time (he/she) was given anything besides breast milk? This includes formula, baby food, juice, cow's milk, sugar water or anything else you fed your baby.

Independent variable – maternal race/ethnicity

Race/ethnicity was a categorical variable, defined by four racial/ethnic groups based on mothers' self-reports of Hispanic origin and race category: Latina, Non-Hispanic White, Non-Hispanic Black, and Non-Hispanic Asian. Latina mothers were further categorized as English- or Spanish-speaking based on the language they chose to be interviewed in. Preferred speaking language has been shown to be associated with breastfeeding practices [8].

Mediator of interest –access to breastfeeding support

The potential mediator of interest is access to breastfeeding support, which is operationalized by three variables: 1) living with partner (Yes/No); 2) Number of practices received by mothers out of 4 Baby-Friendly hospital practices (Low=0-2 practices/High=3-4 practices); 3) workplace arrangement (1=return to work within three months and the workplace did not have breastfeeding accommodations, 2=return to work within three months and the workplace has breastfeeding accommodations, and 3=did not return to work within 3 months). The questions used to measure these variables are given in **Table 6.2**.

Table 6.2 Questions used to assess breastfeeding support from family, hospital and workplace

Variable	Survey questions
Living with partner	• Does NAME's other parent or legal guardian live in this household?
Number of Baby-Friendly hospital practices received	(1) Initiating breastfeeding within one hour: • Did you breastfeed NAME in the first hour after birth? (2) Given no supplementary feeding in hospital: • Was NAME fed only breast milk at the hospital? (3) Given no free formula package to take home: • Did the hospital staff give you formula to take home? (4) Given a telephone number to call for help with breastfeeding: • Did the hospital give you a telephone number to call for help with breastfeeding?
Workplace	• Since the birth of NAME did you return to work or begin a new job? • (If yes): How old was NAME when you first returned to work or began

arrangement	work? • When you went back to work, did your workplace have accommodations for you to breast-feed? This includes giving you a break time and a place to pump milk or breast-feed your baby.

Mediator-outcome confounders-- Sociodemographic characteristics

Sociodemographic variables of relevance are mother's age (years), education (less than high school, high school graduate, or some college or above), household income level indicated by whether the household receive SNAP in the last twelve months (Yes/No) and whether the child was born at preterm (Yes/No). The questions used to measure these variables are given in **Table 6.3**.

Table 6.3 Questions used to measure covariates

Variable	**Survey questions**
Mother age	• What is your age? • The child's age has been calculated in the dataset, so the mother's age at childbirth is derived from the current age at the interview subtracting her child's age
Mother education level	• What is the highest level of school you have completed or the highest degree you have received? • (If High school): What was the highest grade you completed?
Household receiving SNAP	• In the last twelve months, have you or has anyone in your household used an EBT card for food stamps to buy food?
Preterm birth	• Was NAME born early as a pre-term baby? (If necessary:) A pre-term baby is one born at 36 weeks or earlier in pregnancy. • How many weeks pregnant were you when NAME was born?

Statistical analysis

All statistical analyses were conducted using SAS version 9.4 (SAS Institute, Cary, NC). Univariate analysis was conducted to provide descriptive statistics (frequency distributions for categorical variables; means and standard deviations for continuous variables) of the survey participants' race/ethnicity, breastfeeding outcomes, access to breastfeeding support and other sociodemographic characteristics. Bivariate analysis (Chi-square test for categorical variables; ANOVA for continuous variables) was conducted to compare the distribution of sociodemographic characteristics, access to breastfeeding support and breastfeeding outcomes across racial/ethnic groups. If overall test results are statistically significant at α=0.05 level, post hoc pairwise tests (the Tukey's methods) were conducted with a familywise error rate (α) of 0.05. The SAS macros PAIRWISE_CHISQ and CHISQ_MC proposed by Jin and Wang [213] were applied for post hoc pairwise comparison of frequencies.

Causal mediation analysis was conducted to determine whether differential access to breastfeeding support partially explain the racial/ethnic differences in rates of any breastfeeding at 6 months and if yes, how much of the difference can be attributed to differential access to breastfeeding support. Specifically, we used *parametric G-computation* to estimate racial/ethnic differences mediated by access to breastfeeding support from family, health professionals and workplace.

Causal graph and G-computation algorithm

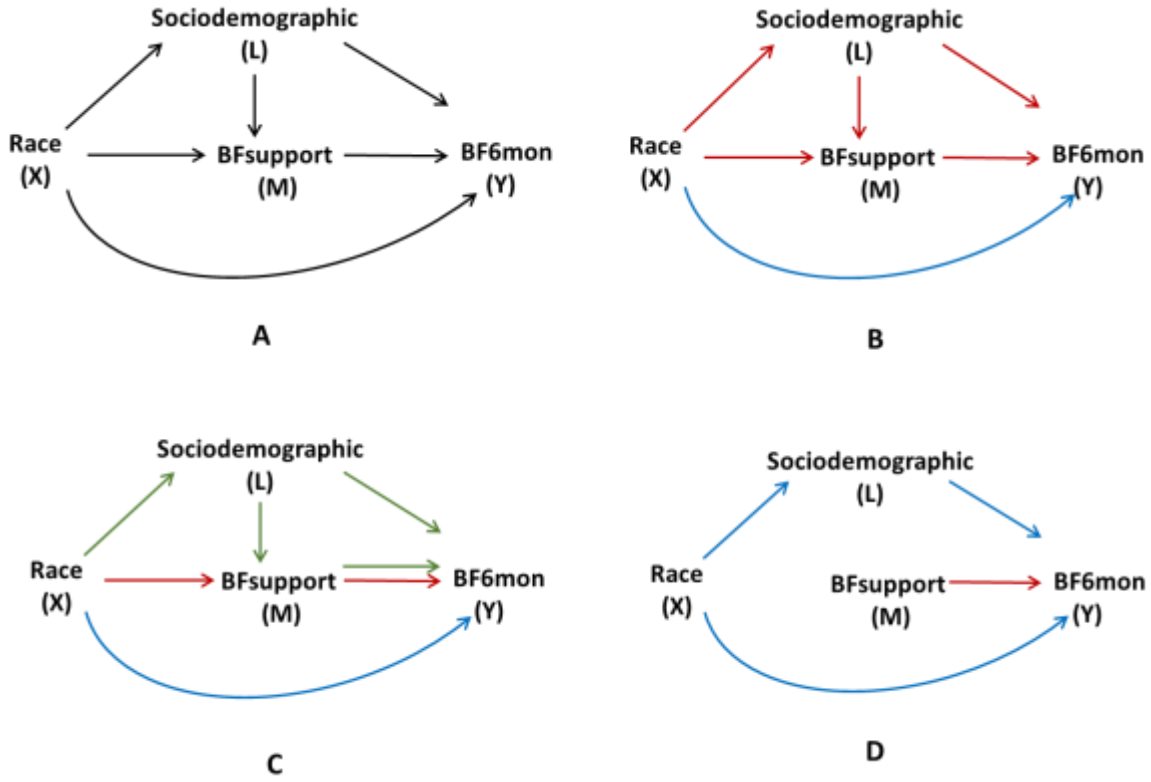
We developed a directed acyclic graph (DAG) to illustrate our assumptions about the causal pathways from race/ethnicity to breastfeeding duration. The relationships between

exposure (race/ethnicity), mediator (breastfeeding support), outcome (breastfeeding duration), and confounder (sociodemographic characteristics) are shown in the causal graph (**Figure 6.2**).

Due to the potential interaction between the exposure (race/ethnicity) and mediator (breastfeeding support), the conventional regression-based difference approach popularized by Baron and Kenny [210], which estimates the mediated effect by comparing the coefficients of the exposure variable in the model with and without the mediator variables, is not appropriate in this study [211]. Instead, the g-computation methods, based on the counterfactual framework [214-216], allows for the quantification of effects mediated by a specific variable or a set of variables in a multiple-mediator context and in the presence of exposure-mediator interactions. It is particularly useful in this study where confounding variables (sociodemographic characteristics) are affected by prior exposures (race/ethnicity).

We used the G-computation algorithm to decompose the effect of race/ethnicity on breastfeeding duration (i.e. the racial/ethnic differences in breastfeeding duration). First introduced by Robins [217], G-computation is a generalization of the standardization methods for time-varying exposures and confounders. Compared to standard regression methods, G-computation, like other G-methods, estimates contrasts of average potential outcomes under a less restrictive set of identification conditions. The prerequisite of this method is the correct specification of models for mediator, outcome and confounders.

Figure 6.2 Simplified directed acyclic graph (DAG) of the assumptions about the causal pathways between race/ethnicity and breastfeeding duration



Note: X: exposure variable, Y: outcome variable, M: mediators, L: exposure-induced mediator-outcome confounder, Race: maternal race/ethnicity, Sociodemographic: maternal age at childbirth, education, income, and birth outcome (full term or preterm), BFsupport: access to breastfeeding support from family, health professional and workplace, BF6mon: any breastfeeding at 6 months. DAG A: the assumptions about the causal pathways between race/ethnicity and breastfeeding at 6 months; B: Joint effect approach, the mediation effect of sociodemographic characteristics and breastfeeding support (red lines) and direct effect (blue line); C: Path-specific effect approach, the mediation effect of sociodemographic characteristics (Race→Sociodemographic→BF6mon and Race→Sociodemographic→BFsupport→BF6mon, green lines), the mediation effect breastfeeding support but not involving sociodemographic characteristics (Race→BFsupport→BF6mon, red lines), and direct effect (blue line); D: Interventional effect approach: the effect of intervening on breastfeeding support by setting breastfeeding support at a value from a reference distribution (red line) and effect not through breastfeeding support (blue lines).

Effect decomposition and estimation

The total effect (TE) measures the overall effect of race/ethnicity on breastfeeding outcome, i.e. the overall racial/ethnic differences in the rates of any breastfeeding at 6 months. It was estimated by the following expression:

$$E_{TE} = E[Y_{X=1} - Y_{X=0}]$$

Based on the causal diagram (**Figure 6.2**), the total effect can be decomposed into various components in three ways using the analytical approaches proposed by VanderWeele, Vansteelandt [218]. Let *Y*, *X*, *L* and *M* denote random variables that takes the value *y*, *x*, *l* and *m* respectively. *Y* is the outcome, *X* is the exposure, *M* is the mediator of interest, and *L* is a mediator that is an exposure-induced confounder of the relationship between *M* and *Y*. For any variable *B*, $B_{A=a}$ is the potential outcome of *B* had *A* been set to *a*. For example, $Y_{x=0}$, $M_{x=0}$, $L_{x=0}$ is the potential outcome of *Y*, *M* or *L* had *X* been set to 0. We will use these notations in the effect estimation equations in the following three approaches.

Approach 1: Joint mediator approach

In this analytical approach, we considered L (sociodemographic characteristics) and M (access to breastfeeding support) jointly, treating them as one set of mediators of interest. The overall racial/ethnic difference then can be decomposed into two components: (i) one indirect effect through L and M, i.e. the amount of racial/ethnic difference attributed to the joint mediator set L and M; and (ii) one direct effect through pathways other than through the joint mediator set L and M, i.e. the amount of racial/ethnic difference not attributed to L or M.

The pure indirect effect (PIE) measures the racial/ethnic difference in any breastfeeding at 6 months attributable to the joint mediator set L and M, not accounting for the possible interaction between race/ethnicity and the joint mediator. PIE was estimated by the following expression:

$$E_{PIE} = E[Y_{X=0,\, L_{X=1}, M_{X=1, L_{X=1}}} - Y_{X=0,\, L_{X=0}, M_{X=0, L_{X=0}}}]$$

The total indirect effect (TIE) measures the racial/ethnic difference in any breastfeeding at 6 months attributed to the joint mediator set L and M, but accounting for the possible interaction between race/ethnicity and the joint mediator. PIE was estimated by the following expression:

$$E_{TIE} = E[Y_{X=1,\, L_{X=1}, M_{X=1, L_{X=1}}} - Y_{X=1,\, L_{X=0}, M_{X=0, L_{X=0}}}]$$

The pure direct effect (PDE) measures the racial/ethnic difference in any breastfeeding at 6 months attributed to pathways other than through the joint mediator set L and M. PDE was estimated by the following expression:

$$E_{PDE} = E[Y_{X=1,\, L_{X=0}, M_{X=0, L_{X=0}}} - Y_{X=0,\, L_{X=0}, M_{X=0, L_{X=0}}}]$$

The total direct effect (TDE) measures the racial/ethnic difference in any breastfeeding at 6 months attributed to pathways other than through the joint mediator set L and M, allowing the joint mediator set to simultaneously boost up or tune down such effect at the same time. TDE was estimated by the following expression:

$$E_{TDE} = E[Y_{X=1,\, L_{X=1}, M_{X=1, L_{X=1}}} - Y_{X=0,\, L_{X=1}, M_{X=1, L_{X=1}}}]$$

The relations between the total effect and these indirect/direct effect quantities are in the following equation:

$$E_{TE} = E_{TIE} + E_{PDE} = E_{PIE} + E_{TDE}$$

Approach 2: Path-specific approach

In this analytical approach, we considered only access to breastfeeding support (M) as the principal mediator of interest, treating sociodemographic status (L) as a confounder of the mediator-outcome relation. The overall racial/ethnic difference then can be decomposed into a sum of effects through three pathways: (i) the effect through pathways involving neither sociodemographic status nor access to breastfeeding support (i.e. X□Y); (ii) the effect through additional pathways not involving sociodemographic status (i.e. X□M□Y); and (iii) the effect through pathways involving only sociodemographic status (i.e. the combination of X□L□Y and path X□L□M□Y, summarized as X□LY). These effects are estimated by the following equations:

$$E_{X\to Y} = E[Y_{X=1,\, L_{X=0}, M_{X=0, L_{X=0}}} - Y_{X=0,\, L_{X=0}, M_{X=0, L_{X=0}}}]$$

$$E_{X\to M\to Y} = E[Y_{X=1,\, L_{X=0}, M_{X=1, L_{X=0}}} - Y_{X=1,\, L_{X=0}, M_{X=0, L_{X=0}}}]$$

$$E_{X\to LY} = E[Y_{X=1,\, L_{X=1}, M_{X=0, L_{X=1}}} - Y_{X=1,\, L_{X=0}, M_{X=0, L_{X=0}}}]$$

The relations between the total effect and these path-specific effect quantities are in the following equation:

$$E_{TE} = E_{X\to Y} + E_{X\to M\to Y} + E_{X\to LY}$$

Approach 3: Intervention effect

In this analytical approach, we consider access to breastfeeding support (M) as our principal mediator of interest and estimated the effect by fixing the mediator for each person to a level that is randomly chosen from the distribution of the mediator of a specific racial/ethnic group. The overall effect of race/ethnicity on breastfeeding maintenance decomposes into the sum of two components: (i) one interventional effect (IE) through access to breastfeeding support, i.e. the effect on the outcome of randomly assigning a woman from a specific racial/ethnic group a value of the mediator from the distribution of mediator of that racial/ethnic group versus the reference group (Non-Hispanic White women in this study); and (ii) one direct effect (DE) comparing a specific racial/ethnic group versus the reference group with the mediator in both cases randomly drawn from the distribution of the reference group.

$$E_{IE} = E[Y_{X=1,\, L_{X=1}, M_{X=1}} - Y_{X=1,\, L_{X=1}, M_{X=0}}]$$

$$E_{DE} = E[Y_{X=1,\, L_{X=1}, M_{X=0}} - Y_{X=0,\, L_{X=0}, M_{X=0}}]$$

The relations between the total effect and these indirect/direct effect quantities are in the following equation:

$$E_{TE} = E_{IE} + E_{DE}$$

Following a recent methods demonstration paper by Wang and Arah [219], the parametric g-computation method applied in this study was implemented in several steps: (i) obtaining empirical parameters including the marginal expectation of the exposure (X) and mediator (M), and the regression coefficients for the confounder (L), mediator (M) and outcome

(Y) model; (ii) creating 1000 copies of the original data sample and simulating the potential confounders, mediators and outcomes based on the causal diagram and the parameters obtained in step 1; (iii) fitting final marginal structural models to obtain point estimates of each effect quantity; and (iv) repeating step 2-3 on 200 bootstrapped samples to obtain standard errors and 95% confidence interval (CI) for each effect quantity. A detailed description of variables, protocols and equations used in the simulation step is provided in the appendices (**Appendix S6-1** and **Appendix S6-2**).

Results

4.3.1 Racial/ethnic differences in breastfeeding practices

The vast majority of WIC participating mothers initiated breastfeeding. However, the proportion of these mothers who continued to breastfeed their children beyond the first month dropped quickly from 89.7% at 1 month to 73.4% at 3 months and 54.8% at 6 months postpartum. Only 42.5%, 21.6% and 9.6% of mothers breastfed their children exclusively at 1, 3, and 6 months postpartum respectively.

There are racial/ethnic differences in the rates of any breastfeeding (**Table 6.4**). Spanish-speaking Latina mothers reported the highest breastfeeding rates at 3 and 6 months (80.0% and 65.0% respectively), and Black mothers reported the lowest any breastfeeding rates (64.2% and 41.1% respectively). The racial/ethnic difference in any breastfeeding rates between Spanish-speaking Latinas and Blacks increases over time with the difference reaching 24 percentage points at 6 months postpartum (**Figure 6.4**). As for exclusive breastfeeding rates, White mothers have higher rates at 1 month (52.2%) and 3 months (27.7%), than other racial/ethnic groups but

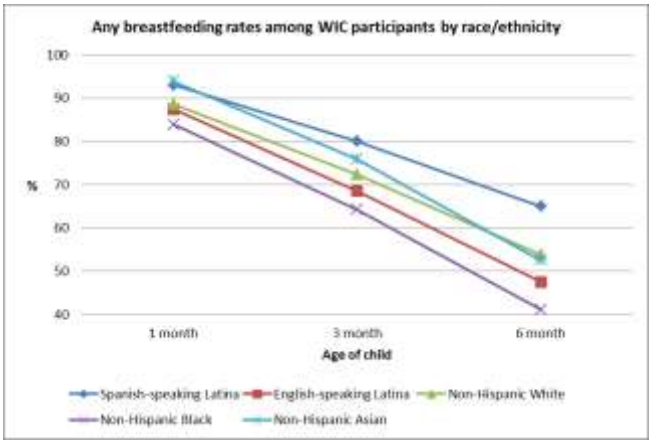
the differences are not statistically significant. The racial/ethnic difference in exclusive breastfeeding rates decreases over time with the difference between Spanish-speaking Latinas and English-speaking Latinas being only approximately 2 percentage points at 6 months postpartum (**Figure 6.4**).

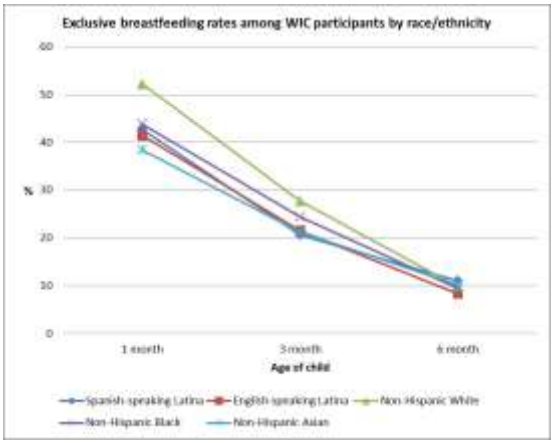
Table 6.4 Any and exclusive breastfeeding rates (%) at 1, 3 and 6 months postpartum among WIC-participating women by maternal race/ethnicity

Breastfeeding outcomes	All (N=4232)	Spanish-speaking Latina (n=1798)	English-speaking Latina (n=1852)	Non-Hispanic White (n=184)	Non-Hispanic Black (n=299)	Non-Hispanic Asian (n=99)	P-value
Any bf at 1 month	89.7	93.0 [a]	87.4 [b]	88.6 [ab]	83.9 [b]	93.9 [ab]	<0.0001
Any bf at 3 month	73.4	80.0 [a]	68.5 [b]	72.3 [ab]	64.2 [b]	75.8 [ab]	<0.0001
Any bf at 6 month	54.8	65.0 [a]	47.5 [bc]	53.8 [b]	41.1 [c]	52.5 [abc]	<0.0001
Exclusive bf at 1 mon	42.5	42.7	41.4	52.2	43.8	38.4	0.0645
Exclusive bf at 3 mon	21.6	20.6	21.5	27.7	24.4	21.2	0.1587
Exclusive bf at 6 mon	9.6	11.0	8.3	9.8	9.4	10.1	0.0917

Note: Values that differ in superscript letters within the same row indicate that there is a significant difference between racial/ethnic groups (e.g. a value with a is significantly different from values with b in the same row but not different from other values with a in the same row). Adjusted p-value was used for the pair-wise comparison with a familywise error rate=0.05.

Figure 6.3 Any and exclusive breastfeeding rates at 1, 3 and 6 months postpartum among WIC-participating women by maternal race/ethnicity





4.3.2 Racial/ethnic differences in sociodemographic factors and access to breastfeeding support

Racial/ethnic differences in sociodemographic characteristics are shown in **Table 6.5**. Spanish-speaking Latina mothers were the oldest (30.9±5.8 years) while English-speaking Hispanic mothers were the youngest (26.4±6.1). The percent of mothers who have a college degree was lowest among Spanish-speaking Latina mothers (5%) and highest among Asian mothers (43%). Income was indicated by participation in SNAP. The proportion of households receiving SNAP is highest among Black mothers (71.2%) and lowest among Asian mothers (29.3%). On average, about 9% of the children were born preterm; the proportion of children born preterm did not differ among the five racial/ethnic groups.

Racial/ethnic differences in access to breastfeeding support were observed. Spanish-speaking Latina mothers have the highest percentage of living with partner (83.8%) and but have lower percentage of receiving 3-4 Baby-Friendly hospital practices than White mothers. English-speaking Latina mothers have lower percentage of living with partner and receiving 3-4 Baby-Friendly hospital practices compared to White mothers. Black mothers reported the lowest percentage of living with partner (34.8%) among all groups and lower percentage of receiving 3-4 Baby-Friendly hospital practices compared to White mothers. Asian mothers have the same percentage of living with partner as White mothers but lower percentage of receiving 3-4 Baby-Friendly hospital practices than White mothers. On average, 75% of all mothers did not return to work within 3 months of childbirth. Spanish-speaking Latinas were the least likely to return to work within 3 months of childbirth (83%). English-speaking Latina (13%) and Black (12%) women were the most likely to return to a workplace that did not provide breastfeeding support.

Table 6.5 Prevalence (%) of sociodemographic characteristics and access to breastfeeding support of WIC-participating women by maternal race/ethnicity

Variable	All (N=4232)	Spanish-speaking Latina (n=1798)	English-speaking Latina (n=1852)	Non-Hispanic White (n=184)	Non-Hispanic Black (n=299)	Non-Hispanic Asian (n=99)	P-value
Socio-demographics							
Mother's age at childbirth (Mean±SD)	28.6±6.3	30.9±5.8 [a]	26.4±6.1 [b]	29.1±5.8 [c]	27.0±6.0 [b]	29.8±5.8 [ac]	<0.0001
Mother's educational attainment							
Less than high school [R]	33.9	59.5 [a]	16.5 [b]	7.6 [c]	14.0 [b]	4.0 [c]	<0.0001
High school graduate	28.6	26.0	31.4	22.8	31.8	23.2	
Some college	27.8	9.4	42.0	41.8	41.8	29.3	
College grad or above	9.7	5.1	10.1	27.7	12.4	43.4	
Household receiving SNAP	47.2	50.2 [a]	41.0 [bd]	50.5 [ab]	71.2 [c]	29.3 [d]	<0.0001
Preterm birth	8.8	9.2	8.3	8.7	9.4	11.1	0.7626
Access to breastfeeding support							
Family support	69.6	83.8 [a]	61.3 [b]	70.7 [b]	34.8 [c]	70.7 [b]	<0.0001
Number of Baby-Friendly practices							
0-2 practices [R]	46.7	50.1 [a]	43.6 [b]	40.2 [ab]	48.8 [ab]	51.5 [ab]	0.0005
3-4 practices	53.3	49.9	56.4	59.8	51.2	48.5	
Workplace support							
Return without support [R]	10.2	7.2 [a]	13.2 [b]	7.1 [b]	11.7 [b]	9.1 [b]	<0.0001
Return with support	14.8	9.6	18.7	18.5	17.7	22.2	
Didn't return within 3 m	75.0	83.2	68.1	74.5	70.6	68.7	

Note: 1. Means and proportions represent raw data, without imputation. 2. Superscript letter R in the column indicates reference category. 3. Values that differ in superscript letters within the same row indicate that there is a significant difference between racial/ethnic groups (e.g. a value with *a* is significantly different from values with *b* in the same row but not different from other values with *a* in the same row). Adjusted p-value was used for the pair-wise comparison with a familywise error rate=0.05.

4.3.3 Racial/ethnic differences in any breastfeeding at 6 months explained by access to breastfeeding support

Our causal mediation analysis estimated the racial/ethnic difference in breastfeeding duration that is attributable to differential access to breastfeeding support from family, hospital

and workplace. **Figure 6.4** and **Table 6.6** summarized these estimates for each racial/ethnic minority group compared to the reference group, White mothers.

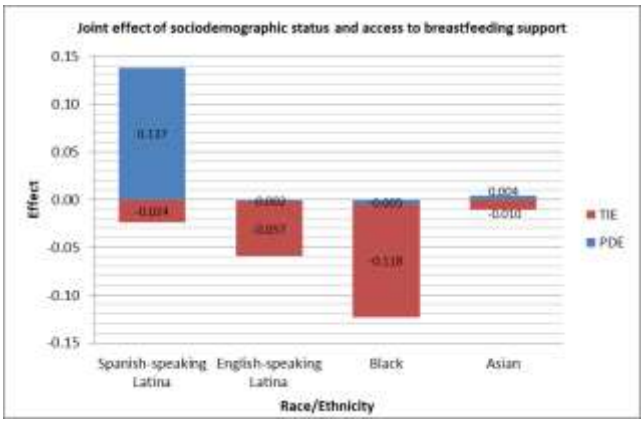
For Black mothers, their rate of any breastfeeding rate at 6 months is 12.4 percentage points lower than that of White mothers. The disadvantaged sociodemographic status and lower access to breastfeeding among Black mothers together contributed to 95% (11.8 percentage points) of this White-Black gap in breastfeeding rates at 6 month. The access to breastfeeding support alone, not involving sociodemographic characteristics, can explain approximately two-thirds (8.5 percentage points) of the White-Black differences. If an intervention had been implemented to ensure that Black mothers had same level of breastfeeding support as White mothers do but all other factors remained the same, the gap of breastfeeding rates at 6 months between White and Black mothers would narrow down by two-thirds (8.7 percentage points).

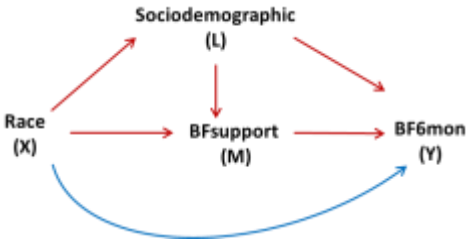
For English-speaking Latina mothers, their rate of any breastfeeding rate at 6 months is 5.9 percentage points lower than that of White mothers. Similarly, the disadvantaged sociodemographic status and poorer access to breastfeeding together explained 96% (5.7 percentage points) of the breastfeeding outcome difference between English-speaking Latina and White mothers. The access to breastfeeding support alone, not involving sociodemographic characteristics, can explain approximately one-third (2.1 percentage point) of the differences in the breastfeeding rates. If an intervention had been implemented to ensure that English-speaking Latina mothers had same level of breastfeeding support as White mothers do but all other factors remained the same, the racial/ethnic difference in breastfeeding rates between White and English-speaking Latina mothers would decrease by one-third (2.2 percentage points).

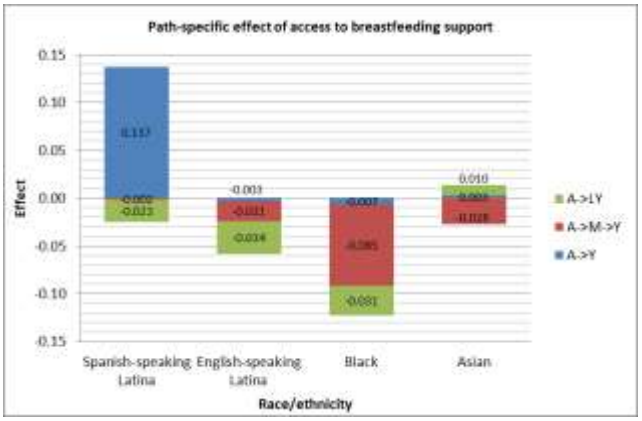
For Spanish-speaking Latina mothers, their rate of any breastfeeding at 6 months is 11.3 percentage points higher than that of White mothers. Their advantage in breastfeeding duration cannot be explained either by sociodemographic characteristics or access to breastfeeding. If an intervention had been implemented to ensure that Spanish-speaking Hispanic mothers had same level of breastfeeding support as White mothers do but all other factors remained the same, the breastfeeding rate difference between Spanish-speaking Latina mothers and White mothers would remain almost the same.

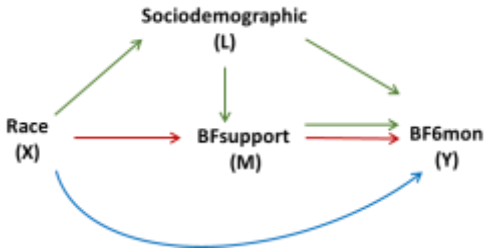
For Asian mothers, their rate of any breastfeeding rate at 6 months is 1 percentage point lower than that of White mothers but the difference is not statistically significant.

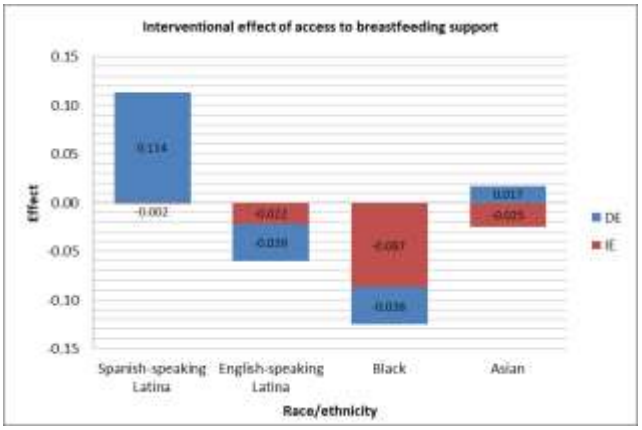
Figure 6.4 Decomposition of racial/ethnic difference in any breastfeeding at 6 months in three ways

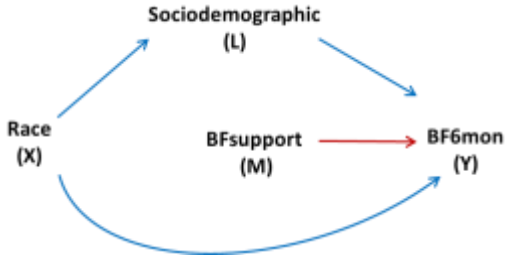












Note: (1) The graph at the top shows the results from the joint effect approach: TIE, total indirect effect, the difference explained by sociodemographic status and access to breastfeeding support together; and PDE, pure direct effect, the difference explained by factors other than sociodemographic status or breastfeeding support. (2) The graph in the middle shows the results from the path-specific effect approach: A→M→Y, the difference explained by breastfeeding support but not involving sociodemographic characteristics; A→LY, the difference explained by sociodemographic characteristics; A→Y, the difference explained neither by sociodemographic characteristics nor by breastfeeding support. (3) The graph at the bottom shows the results from the interventional effect approach: IE, the racial/ethnic difference that would be eliminated had the racial/ethnic group received the same level of breastfeeding support as White mothers; DE, the racial/ethnic difference that would remain intact had the racial/ethnic group received the same level of breastfeeding support as White mothers.

Table 6.6 Decomposition of racial/ethnic differences mediated by access to breastfeeding support

Effect	Spanish-speaking Latina			English-speaking Latina			Black			Asian		
	Estimate	95% CI		Estimate	95% CI		Estimate	95% CI		Estimate	95% CI	
Total effect (TE)	0.113	0.033	0.192	-0.059	-0.137	0.019	-0.124	-0.216	-0.032	-0.010	-0.128	0.107
Joint effect of L& M												
Pure direct effect (PDE)	0.137	0.062	0.213	-0.002	-0.078	0.073	-0.005	-0.104	0.094	0.004	-0.114	0.123
Total indirect effect (TIE)	-0.024	-0.058	0.009	-0.057	-0.083	-0.031	-0.118	-0.170	-0.066	-0.010	-0.059	0.038
Total direct effect (TDE)	0.160	0.081	0.238	0.005	-0.075	0.084	-0.025	-0.137	0.087	0.013	-0.109	0.135
Pure indirect effect (PIE)	-0.046	-0.092	0.000	-0.064	-0.102	-0.026	-0.099	-0.171	-0.028	-0.022	-0.072	0.028
Path-specific effect												
A→Y	0.137	0.061	0.213	-0.003	-0.078	0.072	-0.007	-0.106	0.093	0.003	-0.116	0.122
A→M→Y	-0.002	-0.022	0.019	-0.021	-0.040	-0.002	-0.085	-0.138	-0.033	-0.028	-0.070	0.015
A→LY	-0.023	-0.047	0.001	-0.034	-0.050	-0.017	-0.031	-0.047	-0.014	0.010	-0.011	0.032
Interventional effect												
Interventional effect through M (IE)	-0.002	-0.024	0.020	-0.022	-0.041	-0.002	-0.087	-0.139	-0.035	-0.025	-0.068	0.018
Direct effect not through M (DE)	0.114	0.039	0.188	-0.039	-0.114	0.037	-0.038	-0.139	0.062	0.017	-0.101	0.135

Note: (1) Reference group for all comparisons: Non-Hispanic White mothers. (2) 95% confidence interval (CI) obtained via bootstrapping. (3) TE, total effect, the difference in incidence of any breastfeeding at 6 months between a specific racial/ethnic group and the reference group (White); TIE, total indirect effect, the difference in rates of any breastfeeding at 6 months explained by sociodemographic characteristics and breastfeeding support together (joint mediator), accounting for the possible interaction between race/ethnicity and the joint mediator; PDE, pure direct effect, the difference in rates of any breastfeeding at 6 months explained by factors other than sociodemographic characteristics or access to breastfeeding support; PIE, pure indirect effect, the difference in rates of any breastfeeding at 6 months explained by sociodemographic characteristics and breastfeeding support, not accounting for the possible interaction between race/ethnicity and the joint mediator. (4) Path-specific effect: A→M→Y, the difference explained by breastfeeding support but not involving sociodemographic characteristics; A→LY, the difference explained by sociodemographic characteristics; A→Y, the difference explained neither by sociodemographic characteristics nor by breastfeeding support. (5)Interventional effect: IE, the racial/ethnic difference that would be eliminated had the racial/ethnic group received the same level of breastfeeding support as White mothers; DE, the racial/ethnic difference that would remain intact had the racial/ethnic group received the same level of breastfeeding support as White mothers.

Discussion

Consistent with findings among general population [18, 19] and among low-income mothers [67, 207], there is racial/ethnic difference in breastfeeding rates among WIC participating mothers in Los Angeles County. Black mothers had significantly lower breastfeeding duration than all other racial/ethnic groups. While other studies usually examine Latina mothers as one homogenous group [68, 207], our study found that there are significant difference in breastfeeding rates between Spanish-speaking Latina mothers and English-speaking Latina mothers. While English-speaking Hispanic mothers had rates of breastfeeding outcomes similar to Black mothers, Spanish-speaking Latina mothers had higher rates of any breastfeeding at 6 months. A study that examined breastfeeding rates of Foreign-born Mexican women also found this subgroup of Latina mothers had relatively high breastfeeding rates [67]. The racial/ethnic gap in any breastfeeding rate was widening over time, which is more than 20 percentage points at 6 months postpartum between Spanish-speaking Latinas and Blacks. The difference in exclusive breastfeeding rates across these racial/ethnic groups was not statistically significant.

The central finding of this study is that the differential access to breastfeeding support from family, hospital and workplace across racial/ethnic groups explained a substantial proportion of the racial/ethnic difference in breastfeeding, particularly for the gap between White and Black mothers, and between White and English-speaking Latina mothers. The lack of access to breastfeeding support alone accounted for approximately two-thirds of the White-Black gap and one-third of the White-English-speaking Latina gap in the rates of any breastfeeding at 6 months. This finding highlighted the importance of designing programs and policies to improve Black and English-speaking Latina mothers' access to breastfeeding support such as health

professional support to deal with lactation problems, enhancing partner's support, prolonging maternity leave and providing accommodations for breastfeeding in workplaces.

The study also revealed that the racial/ethnic disparities in breastfeeding rates are closely connected to the racial/ethnic disparities in sociodemographic characteristics including socioeconomic status, maternal age at birth and birth outcomes. For Black mothers and English-speaking Latina mothers, sociodemographic characteristics and breastfeeding support accounted for almost all the differences in breastfeeding duration. According to the fundamental cause theory [177, 178] and our conceptual model, both the lower sociodemographic characteristics and lack of access to breastfeeding support may be a result of racism. Short-term solutions to intervene on one of the causal pathway (e.g. improving access to breastfeeding support) may not solve the racial/ethnic disparities in health in the long run as the pathway might be replaced by another mechanism. Therefore, while we may take immediate actions to improve breastfeeding support in disadvantaged groups, we should not ignore the long-term solution to reduce racial/ethnic disparities in health, i.e. eliminating the root cause by addressing the structural racism.

This study found that the higher breastfeeding rates among Spanish-speaking Latina mothers cannot be attributed to either sociodemographic characteristics or breastfeeding support. The finding is consistent with a more general 'Latino paradox' phenomena that Latino Americans tend to have health outcomes comparable or even better than their White counterparts do despite their disadvantages in socioeconomic status [220]. However, the significantly lower breastfeeding rates among English-speaking Latinas suggest that during the acculturation and assimilation process, the health advantage resulting from traditional resources (e.g. cultural

norms) and ethnically-based social support diminished. Future studies may further investigate on the influence of these health protective factors on breastfeeding and how to preserve them while we make efforts to advance these groups economically. Some examples of the factors may include family history of breastfeeding [68], peer support [221] and cultural norms [8, 66, 77].

For Asian mothers, their breastfeeding rate at 6 months is comparable to that of White mothers. Since Asian mothers in general population have higher breastfeeding rates than White mothers [6, 7], it might be useful to examine whether the self-selection bias, i.e. mothers who intended to formula feeding are more likely to enroll in the WIC, are more evident among Asian mothers. In addition, the small sample size of this group hinders a detection of any mediation effect through either sociodemographic characteristics or breastfeeding support. Given the scarcity of breastfeeding research on this group in the United States, future studies with larger sample size may add valuable insights about this group.

To author's knowledge, this study is the first to quantify the contribution of access to breastfeeding support (and sociodemographic characteristics) to the racial/ethnic difference in breastfeeding duration. Overall, the study findings highlighted the important contribution of access to breastfeeding support to the racial/ethnic difference in breastfeeding behavior, especially for the White-Black gap and the White-English-speaking Latina gap in breastfeeding duration. The study findings contributed to the efforts to explore the mechanisms and pathways of racial/ethnic disparities in health promotion behaviors such as breastfeeding. While various studies [207, 222] have suggested that lack of support from family, health professionals and workplace may be one of the key reasons for early cessation of breastfeeding, this study, for the first time, quantified how much of the observed racial/ethnic differences in breastfeeding

duration could be explained by the racial/ethnic differences in access to breastfeeding support. Applying the G-computation causal mediation analysis method, the author decomposed the total racial/ethnic difference in breastfeeding practices into various components and estimated the contribution of sociodemographic characteristics, access to breastfeeding support and other factors to the racial/ethnic difference in breastfeeding. These estimates may help inform breastfeeding promotion professionals and policy makers about selection of intervention strategies and evaluation criteria.

However, this study has several limitations. First, this study is based on the survey data of WIC participants so the study findings may not be generalizable to other populations. The factors influencing racial/ethnic differences and their relative importance in different populations may vary. Second, this study estimated the contributions of breastfeeding support from three sources, i.e. health professionals, family and workplace, altogether. Thus the contribution of each type of breastfeeding support was not estimated separately. Future studies that offer these estimates may provide useful information on which type of support is more important for reducing racial/ethnic disparities in breastfeeding practices. Third, some key breastfeeding support services (e.g. peer counseling) and community/societal level factors (e.g. cultural norms, paid maternity leave) could not be examined in this study due to the limitation of data availability. To investigate whether these factors also contributed to the racial/ethnic differences in breastfeeding, studies are needed to collect data on these factors across racial/ethnic groups. Fourth, there is a possibility of recall bias in breastfeeding behaviors. However, validation studies suggest that mother's recall on breastfeeding duration is accurate for up to three years after childbirth [196]. For this study we included only mothers of children aged 6 to 35 months in order to reduce the recall bias.

Chapter 7: Translating breastfeeding intervention research into practice in communities: The usefulness of agent-based modeling

Background

It is well established that breastfeeding is beneficial to both children and mothers [3] and promoting breastfeeding is one of the most effective strategies to reduce child mortality [4]. The American Academy of Pediatrics recommends that infants be breastfed for at least 1 year [2]. Only 35% of U.S. infants born in 2017 met this recommendation [6]. Healthy People 2020 set an objective of increasing the proportion of infants who are breastfed at 1 year to 54% [223]. To achieve this goal, effective programs and policies need to be implemented to increase initiation and duration of breastfeeding, especially in socially disadvantaged populations which have low breastfeeding rates [6].

What evidence-based interventions are currently available? The strong evidence on the benefits of breastfeeding has propelled the implementation of many breastfeeding promotion programs in the United States and elsewhere in the world [10]. In a guide developed for decision makers to choose appropriate breastfeeding interventions, the U.S. Centers for Disease Control and Prevention (CDC) recommended six effective interventions: maternal care practices, support for breastfeeding in the workplace, peer support, educating mothers, professional support, media and social marketing [30]. The U.S. Preventive Services Task Force made similar recommendations on effective interventions and emphasized that the most effective interventions to increase breastfeeding duration include both prenatal and postnatal components [224].

Despite these recommendations and the accumulating evidence on the efficacy and effectiveness of some of these interventions [22-29], choosing the most appropriate and effective

intervention or combination of interventions for a given population and community continues to be challenging [225, 226]. With the myriad of available intervention approaches, and varying efficacy levels of interventions in varying contextual settings, there is a need for applying implementation science principles to current research to facilitate decision-making.

In intervention research, the randomized control trial (RCT) design is usually considered the 'gold standard' method for evaluating interventions. However, a RCT usually involves a narrowly defined target population and a tightly controlled environment, limiting its generalizability to other populations or real world community settings. For example, evaluation of the Baby-Friendly Hospital Initiative (BFHI) using a RCT conducted in Belarus showed that it increased breastfeeding rates at 3 months and throughout the first years [133]. Given the highly centralized Belarusian health care systems and significantly longer hospital stay for childbirth (6-7 days) which allow intensive interventions to facilitate establishment of breastfeeding, it would be unrealistic to expect the BFHI intervention would obtain the same effect in the United States where women have a much shorter hospital stay for childbirth (an average of 2 days). A quasi-experimental study using data from five American states did not find differences in breastfeeding duration among women who deliver in facilities with BFHI accreditation and those who deliver in non-BFHI facilities [167].

Intervention research using weaker study designs such as the quasi-experimental design or the observational longitudinal design have contributed to the evidence base. In fact, breastfeeding interventions that involve the provision of workplace support have been evaluated using only observational study designs. A Cochrane review in 2007 found no RCTs of the effectiveness of workplace support interventions [227]. An observational study aiming to

evaluate the impact of two corporate lactation programs in California reported that a significantly higher proportion of mothers who participated in lactation programs (75%) breastfed for at least 6 months compared to a national sample of mothers (10%) [148]. Given there was no control group and participants self-selected into the program, this finding must be interpreted with caution.

Given the broad evidence base for breastfeeding promotion approaches, how can implementation science principles be applied to accelerate the translation of existing research? A goal of translating research is to have an efficacious intervention scaled up to have population impact. The process of scaling up requires depth of knowledge about the conditions under which an intervention was found efficacious so as to support the adaptation of the intervention to local conditions. Under the RE-AIM framework [165], assessing reach, effectiveness, and adoption allows for implementation and maintenance of an intervention. Most evaluation studies focus on just one intervention strategy or a combination of strategies limiting the ability to evaluate the population impact of various combinations of strategies. Yet health behaviors are often influenced by multiple factors interacting in a complex system.

Breastfeeding is an example of a behavior that is influenced by many factors acting at multiple levels and at different stages of the perinatal period in a complex system [8-10]. Therefore, multifaceted interventions targeting multiple levels of influences and covering both prenatal and postnatal stages are often necessary to achieve lasting improvement in breastfeeding rates. The socioecological framework provides a strong rationale for developing such interventions [174, 175]. However, the literature is still scarce on studies that evaluate the combined effect of multiple interventions especially when they lead to a synergistic effect [228].

Traditional statistical modeling methods face limitations in modeling health behaivors embedded in a complex system. The determinants of these behaviors such as breastfeeding are usually multifaceted, inter-dependent and non-linear. For example, a mother's breastfeeding behavior is often influenced by how other mothers normally feed their children; at the same time, the individual mother's decision on breastfeeding also influences others and the environment. This feedback loop, a common feature of complex system, is difficult to model with traditional linear statistical models. Over the past decade, systems science approaches such as agent-based modeling (ABM) has gained popularity and recognition in the population health field for their potential to model complex and dynamic systems and simulate the population impact of various interventions under different scenarios [229].

In this study, we will illustrate the utility of agent-based modeling (ABM) for predicting the population impact of breastfeeding promotion interventions by applying an ABM built specifically to evaluate the impact of various breastfeeding promotion strategies [166]. Predicting population impact requires knowledge of reach [230] and involves asking "what if?" questions such as:

What would be the breastfeeding rates among low-income women such as WIC participants, if 90% of them had received professional support for breastfeeding?

What if 80% of them had received peer support?

What if 60% of them had received both interventions?

Answers to questions such as these will facilitate decision-making with regard to the selection of interventions, and can be obtained by estimating potential outcomes under various hypothetical scenarios using simulation modeling approaches such as ABM.

Agent-based modeling

Agent-based modeling is "a computational method that enables a researcher to create, analyze, and experiment with models composed of agents that interact within an environment" (p.2) [231]. An agent-based model typically consists of autonomous individuals (agents) that interact with each other and with their environment.

The past decade has seen growing interest in applying systems science thinking and tools such as ABM to population health issues [229, 232, 233]. Compared to traditional variable-based statistical equations and macro-simulation methods, ABM possesses features that make it particularly useful in modeling complex population health issues [231, 233, 234]. For example, they allow researchers to model heterogeneous individuals (agents) and capture dynamic interactions among agents in a complex system such as a breastfeeding mother and her interactions with family, health professionals, and peers. Agent-based modeling also allows agents in the model to 'adapt and learn' as they do in reality. Such models, therefore, are able to capture history-dependent behaviors. For example, ABM allows for the consideration of the biological implausibility for a woman to decide to breastfeed later if she did not initiate breastfeeding soon after delivery. Finally, an agent-based model is 'flexible' in that it is easy to adjust the levels of description and aggregation to allow for questions to be answered under a different scenario.

Building an agent-based model includes the following six steps: (1) conceptual design: identifying the purpose of the model and developing a conceptual model; (2) model specification: building the computational model by identifying agents, their attributes and their environment; (3) parameterization: specifying the agent attributes, decision rules, and rules for them to interaction

with environments; (4) calibration and validation of the model: (5) application of the model: conducting a series of "what-if" experiments by systematically varying parameters and assumptions; and (6) sensitivity analysis to understand the robustness of the model and its results. Tutorials that detail the methods and steps of agent-based modeling and simulation are available elsewhere [235, 236].

Many platforms are available for researchers to build an agent-based model. A comprehensive list and comparison of these platforms is provided by Kravari and Bassiliades [237]. The commonly used platforms include: NetLogo (http://ccl.northwestern.edu/netlogo/), Repast (https://repast.github.io/index.html), JASON (http://jason.sourceforge.net/wp/), and AnyLogic (https://www.anylogic.com/).

An example: Developing an agent-based model to estimate the population impact of breastfeeding interventions

Working with a research team, I recently developed an agent-based model to estimate the population impact of five selected breastfeeding promotion interventions on breastfeeding rates among WIC-participating mothers in Los Angeles County [166]. This ABM simulated a cohort of WIC-participating women with different sociodemographic characteristics and modelled their breastfeeding experiences during the first 6 months postpartum. The model was used to predict breastfeeding rates under various scenarios in which five hypothetical interventions (improving knowledge through education, implementing Baby-Friendly Hospital Initiative practices, providing postpartum breastfeeding counseling, strengthening partner support, and fostering

supportive workplace environments) were implemented singly or in combination with each other and at different coverage levels.

The model was developed using the simulation software AnyLogic (version 8.3.2). Details of the development of this model are provided in the paper [166], a copy of which is available as an appendix to this dissertation (**Appendix S7-1**). We will focus our discussion more on the conceptual model, computational model specification and interpretation of the results to illustrate what ABM approach can offer to improve understanding of breastfeeding behaviors in complex social systems and to facilitate the decision making on selection of community interventions to promote breastfeeding.

Conceptual model

As shown in the conceptual model for this study (**Figure 7.1**), breastfeeding behavior is a dynamic process and is influenced by a complex of factors [9, 193, 238]. These include intent to breastfeed which is usually formed during pregnancy as well as factors that influence this intent including sociodemographic characteristics such as age, educational attainment, race/ethnicity and household income; knowledge about and attitude toward breastfeeding; and social norms regarding breastfeeding [96, 97, 239]. The final decision to breastfeed is made during a woman's hospital stay for childbirth. Prenatal-intent-to-breastfeed and delivery at a designated Baby-Friendly hospital increase the likelihood that a woman will initiate breastfeeding [96, 97, 137, 186]. After returning home from the hospital, women need support from health professionals, family members (especially the partner) and others in her social networks to maintain breastfeeding throughout the first 6 months [12, 74]. For some women who return to work within 6 months after childbirth, workplace support such as the provision of break times and lactation

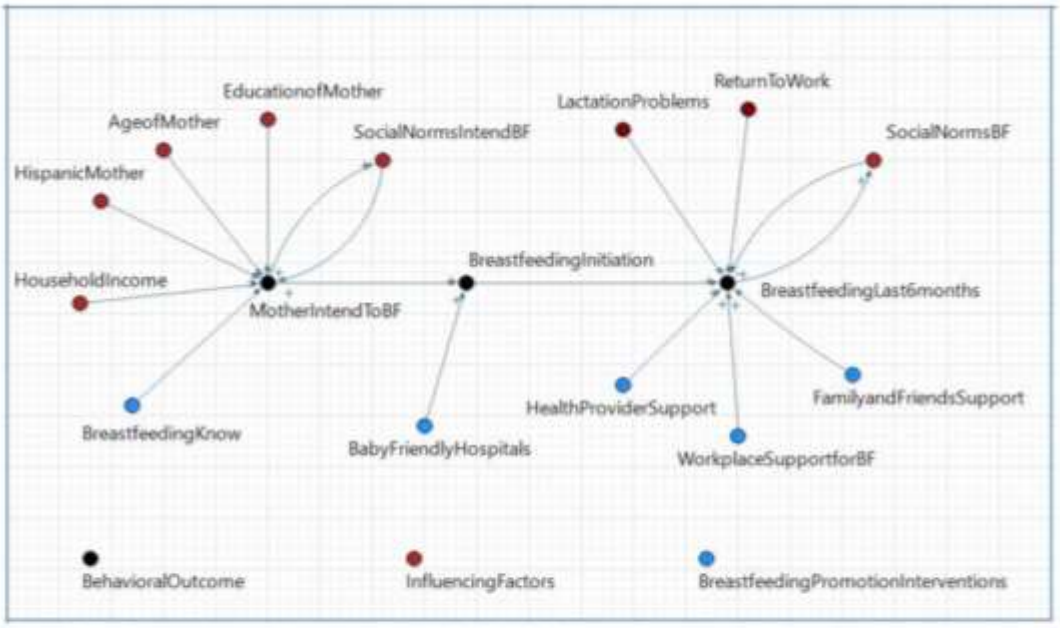
rooms is critical for women to sustain breastfeeding [240, 241]. Three prevalent health behavioral theories that explain the breastfeeding behaviors were incorporated into the model:

(1) The Theory of Reasoned Action and the Theory of Planned Behavior [93, 242] which suggests a woman's intent to breastfeed is the most important predictor for initiation of breastfeeding. Women's sociodemographic characteristics, knowledge about and attitudes toward breastfeeding and perceived social norms influence their intent to breastfeed.

(2) The socioecological model identified that breastfeeding behavior is shaped by multiple levels of influence: intrapersonal (e.g. knowledge/attitude), interpersonal (e.g. family support), organizational (e.g. hospital practices), community (e.g. social norms) and public policy [172, 174, 175]. Furthermore, the influences at various levels are not independent of but interact with each other [174, 175]. For example, individual woman's breastfeeding decision may be influenced by social norms in her community and in turn her breastfeeding behavior also shapes social norms in the community.

(3) The homophily principle in social networks [243] – people tend to form network ties with individuals similar to themselves – suggest that women's personal networks are homogeneous with regards to their sociodemographic characteristics (e.g. race/ethnicity) as well as breastfeeding behaviors.

Figure 7.1 Conceptual model for the breastfeeding ABM



Note: 1. The diagram was created using AnyLogic (v8.3.2). 2.Definitions of acronyms that are not easily decipherable: BreastfeedingKnow: Breastfeeding knowledge; BreastfeedingLast6months: Breastfeeding through 6 months postpartum; MotherIntendToBF: Mother's intent to breastfeed; SocialNormsIntendBF: Social norms on intention to breastfeed; SocialNormsBF: Social norms on breastfeeding. 3.An arrow in a causal loop diagram represents a link between two variables which we assume to be causal. The pluses represent a positive relation between two variables. The feedback loop between a mother's breastfeeding intention and social norms indicates that a woman's breastfeeding intention positively influence social norms on breastfeeding (represented by peers' breastfeeding intentions), which in return, enhances a woman's intention to breastfeed. The arrows between breastfeeding states represent possible transitions between states.

Source: Jiang et al., 2020 [166]

Computational model

Based on our research objective and conceptual model, we built a computational model consisting of a cohort of WIC-participating pregnant women (n=4,646). Women are the only agents in this model. We defined their attributes including age, race/ethnicity, education, and household income which are known factors relevant to breastfeeding behaviors. Women form their social network with other women in the same racial/ethnic group. Data from the 2014 WIC survey were used to specify these attributes for each woman. Please refer to Chapter 4 for a detail description of the dataset.

The model simulates breastfeeding decisions and experiences of each woman over a period of 6 months, from the end of her pregnancy to 6 months after childbirth, during which she makes decisions on feeding plans at the end of pregnancy, on initiation of breastfeeding immediately after childbirth, and on when to switch from exclusive breastfeeding to partial breastfeeding and when to stop breastfeeding in the postpartum period. Each woman assesses her situation and makes these decisions individually. The rules guiding decision making at each stage are summarized in **Table 7.1**. The algorithms and parameters used to inform these decisions are provided in the published paper in the Appendices (**Appendix S7-1**).

Table 7.1 Rules for decision-making regarding breastfeeding behaviors

Decision	**Rules**
Intention to breastfeeding (prenatal stage)	• A woman's probability of intent to breastfeeding is a function of sociodemographic characteristics (age, race/ethnicity, education, and household income), knowledge/attitudes towards breastfeeding, and the intention of other women in her social network.
Initiation of breastfeeding (immediately after childbirth)	• A woman's probability of initiating breastfeeding is a function of her intent to breastfeeding and whether she delivers the baby in a Baby-Friendly hospital.
Switching from exclusive to partial breastfeeding or stopping breastfeeding (postpartum stage)	• When a woman experience lactation problem, if she has support from both health professionals and partner, she will continue her original breastfeeding status; if she has support from only one source, either health professionals or partner, she may switch from exclusive to partial breastfeeding or from partial breastfeeding to formula feeding; if she has no support from either health professionals or partner, she may stop breastfeeding. • When a woman returns to work, if the workplace provide accommodations for breastfeeding, she will continue her original breastfeeding status; if not, from exclusive to partial breastfeeding or from partial breastfeeding to formula feeding. • For women who did not experience lactation problem and did not return to work within 6 months, it is also possible for them to switch from exclusive to partial breastfeeding, from partial breastfeeding to formula feeding, or from exclusive breastfeeding to formula feeding for other reasons.

Interpretation of results

After being calibrated and validated, the computational model was used to predict breastfeeding rates under various intervention scenarios. **Table 7.2** shows the predicted rates of breastfeeding initiation and any breastfeeding at 6 months when the coverage of each intervention was increased from baseline level to 95%. The results show that increasing the coverage of the five selected interventions produced various levels of improvement in breastfeeding initiation and duration in the target population. Specifically, improving breastfeeding knowledge and increasing the availability of the Baby-Friendly Hospital Initiative increased breastfeeding initiation rates by approximately one percentage point. However, neither of these two interventions showed a significant impact on breastfeeding rates at 6 months. Postpartum breastfeeding counseling, partner support and a supportive workplace environment each improved breastfeeding rates at 6 months from 55.6% to 57.1%, 59.5% and 59.3%, respectively.

Table 7.2 Breastfeeding rates (%) under five hypothetical interventions with 95% coverage

Interventions	**Breastfeeding initiation**	**Breastfeeding at 6 months**	**Baseline coverage**	**Percent intervened on to achieve 95% coverage**
No intervention	92.96	55.62	-	0
Improving breastfeeding knowledge	93.84	56.24	67	28
Baby-Friendly Hospital Initiative	93.71	56.04	11	84
Postpartum professional counseling	93.02	57.09	78	17
Postpartum partner support	92.96	59.53	68	27
Supportive workplace environment	93.08	59.28	52	43

Note: The baseline coverage for the five interventions was informed by the WIC 2014 survey. The percent intervened on to achieve 95% coverage was calculated by subtracting the baseline coverage from 95% for each intervention.

To examine the population impact of various intervention packages (made up of multiple interventions) under different coverage levels, we simulated impact of various intervention packages at 80%, 90% and 95% coverage (**Table 7.3**). Compared to scenarios for which we increased coverage level of a single intervention, increasing the coverage levels of multiple interventions significantly improved breastfeeding rates at 6 months. For example, if 95% of mothers of WIC-participating infants in Los Angeles County could have received all five interventions in 2014, the breastfeeding rates would have increased 12.6 percentage point (from 55.6% at baseline to 68.2%) and 10182 more mothers of WIC-participating infants would have breastfed through 6 months.

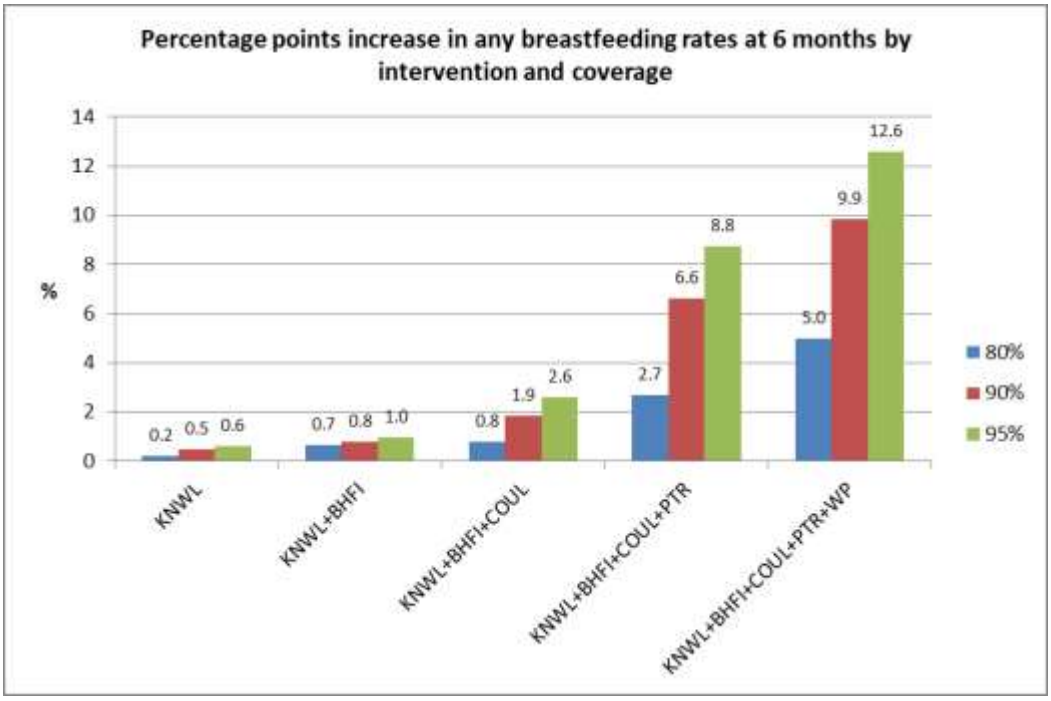
A synergistic effect of multiple interventions was observed from the predicted outcomes (**Table 7.3** and **Figure 7.2**). For example, when the coverage of all five interventions delivered in a package was increased from the baseline level to 95%, the predicted any breastfeeding rate at 6 months increased by 12.6 percentage points (equivalent to 10182 beneficiaries). In comparison, the sum of the effects of these five interventions when delivered separately amounts to only 10.1 percentage points (equivalent to 8165 beneficiaries).

Table 7.3 Percentage point increase in breastfeeding rates at 6 months and number of beneficiaries under various interventions at 80%, 85% and 95% coverage

Interventions	At 80% coverage		At 85% coverage		At 95% coverage	
	% increase	# beneficiary	% increase	# beneficiary	% increase	# beneficiary
KNWL	0.2	178	0.5	397	0.6	502
BFHI	0.6	510	0.5	389	0.4	340
COUL	0.4	332	1.2	956	1.5	1191
PTR	1.7	1385	3.1	2503	3.9	3167
WP	2.4	1936	3.4	2722	3.7	2965
KNWL+BHFI	0.7	527	0.8	656	1.0	794
KNWL+BHFI+COUL	0.8	648	1.9	1515	2.6	2106
KNWL+BHFI+COUL+PTR	2.7	2163	6.6	5362	8.8	7096
KNWL+BHFI+COUL+PTR+WP	5.0	4034	9.9	7979	12.6	10182

Note: (1) KNWL=improving breastfeeding knowledge, BFHI=Baby-Friendly Hospital Initiative practices, COUL= postpartum breastfeeding counseling, PTR=strengthening partner support, WP=fostering supportive workplace environment. (2) Percentage point change in breastfeeding rates at 6 months was calculated by subtracting the baseline breastfeeding rate at 6 month (55.6%) from predicted breastfeeding rates under each intervention scenario. (3) Number of beneficiaries, defined as how many more WIC-participating mothers in Los Angeles County would breastfeed at 6 months compared to baseline, was calculated by multiplying the percentage point increase in breastfeeding rates at 6 months by total number of mothers of WIC-participating infants in 2014 in Los Angeles County (~81000). (4) The number of mothers of WIC-participating infants in 2014 in Los Angeles County was obtained from LA County WIC Data website: https://lawicdata.org/data-research/topics/demographics/

Figure 7.2 Percentage point increase in any breastfeeding rates at 6 months by intervention package and coverage



Note: KNWL=improving breastfeeding knowledge, BFHI=Baby-Friendly Hospital Initiative practices, COUL= postpartum breastfeeding counseling, PTR=strengthening partner support, WP=fostering supportive workplace environment.

Discussion

In this study, we discussed the challenges facing local health professionals and decision makers in selecting appropriate interventions to promote breastfeeding in communities. Breastfeeding behavior is influenced by a complex web of factors. Hence, multifaceted interventions to promote breastfeeding are more likely to have population impact. However, it is difficult to decide which factors to intervene on or to estimate the population impact of selected interventions. Systems science approaches, particularly agent-based modeling, seems a promising solution to these challenges but remains relatively new to researchers and practitioners

in the population health field. We thus briefly introduced this approach and provided an example of a previously developed agent-based model on breastfeeding to illustrate the utility of ABM in modeling health behaviors embedded in complex systems and predicting population impact of multifaceted interventions.

Under various intervention scenarios, we found that improving breastfeeding knowledge and increasing the availability of the Baby-Friendly Hospital Initiative increased breastfeeding initiation rates while postpartum breastfeeding counseling, partner support and a supportive workplace environment are more effective in improving breastfeeding rates at 6 months. Furthermore, increasing the coverage levels of multiple interventions simultaneously significantly improved breastfeeding rates at 6 months and the combined effect was larger than the sum of effect of individual interventions. At 95% coverage level of all five interventions, the breastfeeding rates would have increased around 13 percentage point and more than 10,000 more mothers of WIC-participating infants would have breastfed through 6 months in Los Angeles County.

The findings from the example breastfeeding ABM offer rich information for health professionals and decision makers to weigh alternative intervention options so may facilitate their decision making concerning appropriate interventions. First, if resources permit, it is more impactful to select an intervention package instead of a single intervention given the presence of synergic effect from implementing multiple interventions simultaneously. Second, education and hospital practices during the short hospital stay for childbirth may increase rates of breastfeeding initiation but other interventions providing continuous support to women during the postpartum are more effective in prolonging breastfeeding duration. This finding highlighted the importance

of including both prenatal and postnatal components in the intervention design to increase breastfeeding duration [224]. Third, when estimating intervention effect in the real world, issues related to implementation such as a realistic coverage level have to be taken into account in the decision making process. For example, to increase the breastfeeding rates at 6 months by 2.5 percentage points (approximately 2,000 more mothers breastfeeding through 6 months), we can deliver either a three-intervention package at 95% coverage or a four-intervention package at 80% coverage. While aiming at the 95% coverage option may allow us to reach the marginalized women and benefit them, the 80% coverage option may be more feasible to achieve in a community setting.

The model building process itself is helpful for researchers and other stakeholders to advance their understanding of complex health behaviors. As Bonabeau [244] noted, "ABM is a mindset more than a technology" (p.7280). ABM involves describing each individual agent's behavior, their interaction with one another and environment, and outcome emerges at the system level. Behavioral theories such as socioecological model and social networks which are difficult to be represented in traditional statistical equations can be easily incorporated in the ABM since the model is a natural description of a system. Since ABM seems closer to the reality compared to statistical equations, it is less challenging to engage stakeholders such as health practitioners or target populations in conceptual design of an ABM.

However, there are also some caveats with application of ABM in population health. First, ABM is not for all research questions involving a system. It is generally most useful when the problem of interest is impacted by dynamics and feedback. For example, when agents display a "learning and adapt" behavior, the ABM approach might be suitable [244, 245]. Second, it is

important to balance parsimony and accuracy when selecting level of description and the amount of details for the model [244, 246]. Since ABM uses a bottom-up approach describing behaviors and rules at individual level, it is very easy for a model to become too detailed and fail to serve the research purpose. Third, one of the advantages of ABM is that it captures interactions between agents, and between agent and environment, allowing emergent phenomenon to be produced. However, if too many interactions are built into the model, the model becomes too complicated to understand and the results become too difficult to interpret. Lastly, although ABM allows us to use evidence from various sources such as RCTs, expert opinions, and empirical data to parameterize the model, the quality of the evidence needs to be carefully evaluated before incorporating it into the model. Sensitivity analysis can be helpful in this case to check the robustness of results with varying parameter values and assumptions.

Chapter 8: Conclusion

Although breastfeeding is beneficial for women, children, families and society as a whole [4], its rates in developed countries including the United States are relatively low. In the United States, over half of American mothers initiate breastfeeding, but the majority do not breastfeed long enough to meet the recommendations of the World Health Organization and the American Academy of Pediatrics [1, 2]. In 2017, only 26% of U.S. infants were *exclusively* breastfed through 6 months and 35% were breastfed through 12 months [6]. Socioeconomic and racial and ethnic disparities in breastfeeding practices have persisted over the years, with women from the lowest socioeconomic class having the lowest breastfeeding rate [62].

This dissertation study investigated factors influencing breastfeeding practices and the impact of breastfeeding interventions among low-income women enrolled in the federal nutrition assistance program, Special Supplemental Nutrition Program for Women, Infants and Children (WIC) in socio-economically and ethnically diverse Los Angeles County (LAC). The specific aims were to: (1) assess the influences of breastfeeding support from family, hospitals and workplaces on breastfeeding duration; (2) determine the extent to which racial/ethnic disparities in breastfeeding duration could be explained by breastfeeding support; and (3) estimate the population impact of multifaceted breastfeeding promotion interventions.

The findings highlighted the important role of breastfeeding support from family, birthing hospitals and workplaces in prolonging breastfeeding duration in this population. Living with a partner, receiving each of four Baby-Friendly hospital practices (feeding the infant only breast milk in the hospital, initiating breastfeeding within one hour after delivery, not receiving free formula packages, and providing mothers with a phone number to call for help with

breastfeeding) and having accommodations for breastfeeding at the workplace, were found to be significantly associated with longer breastfeeding duration.

Furthermore, this dissertation found that differential access to breastfeeding support from family, hospitals and workplaces accounted for a substantial proportion of racial/ethnic disparities in breastfeeding outcomes in five racial/ethnic groups (Spanish-speaking Latina, English-speaking Latina, Non-Hispanic White, Non-Hispanic Black and Non-Hispanic Asian). Lack of access to breastfeeding support explained approximately two-thirds of the difference in any breastfeeding rates at 6 months between White mothers and Black mothers, and one-third of the difference between White mothers and English-speaking Latina mothers.

Finally, this dissertation demonstrated the usefulness of systems science approaches, specifically agent-based modeling, for facilitating the translation of breastfeeding intervention research into practice. A breastfeeding agent-based model (ABM) was used to illustrate the application of agent-based modeling for estimating the population impact of various breastfeeding interventions including strengthening breastfeeding support from family, hospitals and workplaces. It showed that improving knowledge and increasing the availability of Baby-Friendly Hospital Initiative practices improved breastfeeding *initiation* rates but providing breastfeeding counseling, family support and a supportive workplace environment are more effective in improving breastfeeding *duration*. Multifaceted interventions that target breastfeeding determinants at multiple levels and cover both prenatal and postnatal periods are especially effective in improving breastfeeding *duration*.

Findings from this dissertation contribute to the growing literature on the social determinants of breastfeeding practices, potential causal mechanisms of racial/ethnic disparities,

and the population impact of multiple breastfeeding promotion interventions; and have implications for healthcare, family and workplace policies. For example, the identification of English-speaking Latina mothers in addition to Black mothers as a subgroup at risk for low breastfeeding rates, may help health professionals and decision makers be more targeted in their efforts to promote breastfeeding. Assessing the contributions of various sources of breastfeeding support (family, health care system and workplace) to breastfeeding maintenance informs the development of programs and policies for reducing racial/ethnic disparities in the percent of mothers who meet infant feeding recommendations. This dissertation also illustrated how systems sciences approaches, particularly agent-based modeling, can be used to facilitate the dissemination and implementation of efficacious interventions for promoting breastfeeding and other health behaviors embedded in a complex system. In particular, the projections of population-level outcomes under various intervention scenarios can be used to inform decision-making regarding the targeting of at-risk communities, the selection of appropriate intervention strategies, and the allocation of resources to achieve desired levels of program reach.

Future studies are needed to overcome several limitations of this dissertation and provide further insight into effective strategies for promoting breastfeeding among mothers in socially disadvantaged populations. First, operationalization of breastfeeding support from family, hospitals and workplace was limited by data availability. For example, family support was measured by a single measure, living with a partner, and many other aspects of family support for breastfeeding were not considered. For example, the attitude of partners toward breastfeeding, and the support of other family members with child care and household chores may influence how long a mother breastfeeds. Qualitative studies may help guide the election of relevant aspects of breastfeeding support. Second, our investigation of the contribution of breastfeeding

support from family, hospitals and workplaces to racial/ethnic disparities in breastfeeding rates at 6 months did not evaluate the unique contributions of each source of support under varying contexts. For example, investigating the contributions of each type of support among Spanish-speaking mothers, who had better breastfeeding outcomes that all other racial/ethnic groups, may offer new ideas about intervention strategies to promote breastfeeding. Such information will be helpful for developing interventions tailored to varying needs. Third, the breastfeeding ABM described in this study may be further refined by incorporating findings from newly collected WIC survey data and recent studies on breastfeeding determinants and intervention effects. Using community-based participatory research principles, stakeholders including decision makers may be engaged in this process to identify the most relevant research questions for advancing knowledge about the translation of research into practice.

Appendices

Appendix S5-1: Breastfeeding rates among WIC-participating mothers in the Los Angeles County, 2011-2016

Breastfeeding rates	Year					
	2011 (n=475)	2012 (n=907)	2013 (n=432)	2014 (n=439)	2015 (n=956)	2016 (n=478)
Ever initiate breastfeeding	93.5	94.2	94.7	93.8	95.2	93.5
Any breastfeeding at 1 month	86.1	85.1	85.6	84.5	85.0	80.5
Any breastfeeding at 3 months	73.1	69.6	69.2	69.5	71.2	66.9
Any breastfeeding at 6 months	55.8	49.9	51.6	55.1	55.0	49.0
Any breastfeeding at 9 months	41.1	36.5	37.5	41.0	40.5	37.0
Any breastfeeding at 12 months	35.2	30.3	32.2	36.7	34.4	30.3
Exclusive breastfeeding at 1 month	34.9	39.3	38.0	43.5	44.4	41.0
Exclusive breastfeeding at 3 months	25.7	22.1	17.1	28.5	24.4	16.7
Exclusive breastfeeding at 6 months	13.1	8.8	6.5	16.4	12.3	7.9

Note: WIC = Special Supplemental Nutrition Program for Women, Infants and Children.

Appendix S5-2: Breastfeeding rates by maternal age, race/ethnicity, education and income among WIC-participating mothers in Los Angeles County (n=3,687)

Sociodemographic characteristics	Any breastfeeding rates						Exclusive breastfeeding rates		
	Initiation	1 month	3 months	6 months	9 months	12 months	1 month	3 months	6 months
Mother age at childbirth									
<20 years old	95.5	79.1	58.5	34.5	23.6	19.4	39.4	18.5	6.7
20-29 years old	94.4	83.6	68.3	51	36.7	30.1	42.1	23.5	11.7
>=30 years old	93.9	87	74.7	58.7	44.8	39.4	39	22.5	10.6
P-value (Chi-square test)	0.5379	0.0003	<0.0001	<0.0001	<0.0001	<0.0001	0.1725	0.1354	0.0234
Mother racial/ethnic group									
Latina (Spanish-speaking)	94.9	88.6	76.6	62.7	48.8	42.7	41.7	21.8	12
Latina (English-speaking)	94.1	82.2	65.2	45	31.5	26.1	39	22.4	9.3
NH-White	92.7	82	68	49.3	36	30.7	48.7	30	12
NH-Black	91.2	75.4	58.8	40.4	25.7	17.6	40.8	23.5	10.7
NH-Asian	100	91	80.8	57.7	41	34.6	35.9	25.6	14.1
P-value (Chi-square test)	0.0221	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	0.1236	0.2155	0.1246
Mother educational attainment									
Less than high school	93.2	84.2	70.4	56.6	43.2	38.7	37.6	19.4	9.9
High school graduate	94.1	82.1	66.3	46.9	34.1	28.8	40.6	22.3	10.5
Some college or associate degree	95.5	86.9	71.6	51.1	36.1	28.8	42.6	25.6	10.8
College grad or above	95.2	87.5	76.1	61	45.6	37.3	45.6	27.1	14.8
P-value (Chi-square test)	0.1136	0.0100	0.0023	<0.0001	<0.0001	<0.0001	0.0190	0.0008	0.0697
Household income									
SNAP recipient	93.7	82.5	67.1	50.6	37.2	32.2	39.9	21.3	10.2
Non-SNAP recipient	94.9	86.7	72.9	54.7	40.4	33.7	41.3	23.9	11.4
P-value (Chi-square test)	0.121	0.0004	0.0001	0.0143	0.0462	0.3271	0.4114	0.0655	0.2256

Note: WIC = Special Supplemental Nutrition Program for Women, Infants and Children. SNAP = Supplemental Nutrition Assistance Program.

Appendix S6-1: Variables and simulation protocol for exposure X, exposure-induced mediator-outcome confounder L, mediator M, and outcome Y

Variable	Simulation protocol
X	Race/ethnicity: 0= NH-White (reference), 1= Spanish-speaking Hispanic, 2=English-speaking Hispanic, 3=NH-Black, 4=NH-Asian X1: Spanish-speaking Hispanic (Yes/No) X2: English-speaking Hispanic (Yes/No) X3: NH-Black (Yes/No) X4: NH-Asian (Yes/No) *P*(X0)=0.0435, *P*(X1) = 0.4249, *P*(X2)=0.4376, *P*(X3)=0.0707, *P*(X4)=0.0234
L	L1: age, mother's age at childbirth, continuous, in years L2: education, mother's education level, 0=less than high school (reference), 1=high school graduate, 2=some college, 3=college graduate and above L2a: edu1, high school graduate (Yes/No) L2b: edu2, some college (Yes/No) L2c: edu3, college graduate and above (Yes/No) L4: income, household receiving SNAP, 1=SNAP recipient, 0=non-SNAP recipient L5: fterm, birth outcome, binary, 1=full term birth, 0=preterm birth
M	M1: hs, health care system support, 1=high (3-4 Baby-Friendly practices received), 0=low (0-2 practices received) M2: fs, family support, 1=living with a partner, 0=not living with a partner M3: workplace support, 0=return to workplace within 3 months without workplace accommodations (reference), 1=return to workplace within 3 months with workplace accommodations, 2= did not return to work within 3 months M3a: ws1, return to workplace within 3 months with workplace accommodations (Yes/No) M3b: ws2, did not return to work within 3 months (Yes/No)
Y	Any breastfeeding at 6 months: whether the mother still breastfeed her child at 6 months postpartum (Yes/No)
Equation for *X*	$\mathrm{X} \sim \mathrm{C}\ (1,\ \ 0.0435, 0.4249, 0.4376, 0.0707, 0.0234)$
Equation for *L*	$\mathrm{L1} \sim \mathrm{N}\ (29.0566 + 1.8641 \cdot x1 - 2.6241 \cdot x2 - 2.0884 \cdot x3 + 0.7397 \cdot x4,\qquad 5.9643)$

	L2a ~ B (1, $\exp(1.0986 - 1.9256 \cdot x1 - 0.4557 \cdot x2 - 0.2824 \cdot x3 + 0.6488 \cdot x4)/ (1 + \exp(1.0986 - 1.9256 \cdot x1 - 0.4557 \cdot x2 - 0.2824 \cdot x3 + 0.6488 \cdot x4) + \exp(1.7047 - 3.5503 \cdot x1 - 0.7729 \cdot x2 - 0.6141 \cdot x3 + 0.2744 \cdot x4) + \exp(1.2928 - 3.7573 \cdot x1 - 1.7852 \cdot x2 - 1.4195 \cdot x3 + 1.0804 \cdot x4)))$ L2b ~ B (1, $\exp(1.7047 - 3.5503 \cdot x1 - 0.7729 \cdot x2 - 0.6141 \cdot x3 + 0.2744 \cdot x4) / (1 + \exp(1.0986 - 1.9256 \cdot x1 - 0.4557 \cdot x2 - 0.2824 \cdot x3 + 0.6488 \cdot x4) + \exp(1.7047 - 3.5503 \cdot x1 - 0.7729 \cdot x2 - 0.6141 \cdot x3 + 0.2744 \cdot x4) + \exp(1.2928 - 3.7573 \cdot x1 - 1.7852 \cdot x2 - 1.4195 \cdot x3 + 1.0804 \cdot x4)))$ L2c ~ B (1, $\exp(1.2928 - 3.7573 \cdot x1 - 1.7852 \cdot x2 - 1.4195 \cdot x3 + 1.0804 \cdot x4)/ (1 + \exp(1.0986 - 1.9256 \cdot x1 - 0.4557 \cdot x2 - 0.2824 \cdot x3 + 0.6488 \cdot x4) + \exp(1.7047 - 3.5503 \cdot x1 - 0.7729 \cdot x2 - 0.6141 \cdot x3 + 0.2744 \cdot x4) + \exp(1.2928 - 3.7573 \cdot x1 - 1.7852 \cdot x2 - 1.4195 \cdot x3 + 1.0804 \cdot x4)))$ L4 ~B (1, $\text{expit}(0.0217 - 0.0151 \cdot x1 - 0.3864 \cdot x2 + 0.8852 \cdot x3 - 0.9029 \cdot x4)$) L5 ~ B (1, $\text{expit}(2.4950 + 0.0691 \cdot x1 + 0.0757 \cdot x2 - 0.0598 \cdot x3 - 0.3004 \cdot x4 - 0.0104 \cdot age + 0.0886 \cdot edu1 + 0.1410 \cdot edu2 + 0.3233 \cdot edu3 - 0.0123 \cdot income)$)
Equation for *M*	M1 ~ B $\left(1, \text{expit}(-0.3262 - 0.2993 \cdot x1 - 0.1277 \cdot x2 - 0.3266 \cdot x3 - 0.4675 \cdot x4 - 0.0070 \cdot age + 0.0385 \cdot edu1 + 0.1139 \cdot edu2 + 0.2341 \cdot edu3 - 0.0272 \cdot income + 0.9002 \cdot fterm)\right)$ M2 ~ B $\left(1, \text{expit}(0.8786 + 0.7619 \cdot x1 - 0.4192 \cdot x2 - 1.5072 \cdot x3 + 0.0026 \cdot x4)\right)$ M3a ~ B (1, $\exp(0.1682 - 0.6643 \cdot x1 - 0.5793 \cdot x2 - 0.3725 \cdot x3 - 0.1824 \cdot x4 + 0.0282 \cdot age - 0.0154 \cdot edu1 + 0.1663 \cdot edu2 + 0.1456 \cdot edu3 - 0.5029 \cdot income + 0.0674 \cdot fterm) / (1 + \exp(0.1682 - 0.6643 \cdot x1 - 0.5793 \cdot x2 - 0.3725 \cdot x3 - 0.1824 \cdot x4 + 0.0282 \cdot age - 0.0154 \cdot edu1 + 0.1663 \cdot edu2 + 0.1456 \cdot edu3 - 0.5029 \cdot income + 0.0674 \cdot fterm) + \exp(2.9718 - 0.2301 \cdot x1 - 0.7480 \cdot x2 - 0.6482 \cdot x3 - 0.2793 \cdot x4 - 0.00292 \cdot age - 0.6448 \cdot edu1 - 0.7396 \cdot edu2 - 0.6086 \cdot edu3 + 0.2421 \cdot income - 0.0256 \cdot fterm)))$

	M3b ~ B (1, $\exp(2.9718 - 0.2301 \cdot x1 - 0.7480 \cdot x2 - 0.6482 \cdot x3 - 0.2793 \cdot x4 - 0.00292 \cdot age - 0.6448 \cdot edu1 - 0.7396 \cdot edu2 - 0.6086 \cdot edu3 + 0.2421 \cdot income - 0.0256 \cdot fterm) / (1 + \exp(0.1682 - 0.6643 \cdot x1 - 0.5793 \cdot x2 - 0.3725 \cdot x3 - 0.1824 \cdot x4 + 0.0282 \cdot age - 0.0154 \cdot edu1 + 0.1663 \cdot edu2 + 0.1456 \cdot edu3 - 0.5029 \cdot income + 0.0674 \cdot fterm) + \exp(2.9718 - 0.2301 \cdot x1 - 0.7480 \cdot x2 - 0.6482 \cdot x3 - 0.2793 \cdot x4 - 0.00292 \cdot age - 0.6448 \cdot edu1 - 0.7396 \cdot edu2 - 0.6086 \cdot edu3 + 0.2421 \cdot income - 0.0256 \cdot fterm)))$
Equation for *Y*	Y ~ B (1, expit $(-2.7649 + 1.0781 \cdot x1 + 0.6619 \cdot x2 + 0.3667 \cdot x3 + 1.6668 \cdot x4 + 0.0279 \cdot age - 0.1488 \cdot edu1 + 0.2173 \cdot edu2 + 0.4199 \cdot edu3 - 0.0190 \cdot income - 0.0763 \cdot fterm + 1.2936 \cdot m1 + 0.4882 \cdot m2 + 1.2411 \cdot m3a + 0.9061 \cdot m3b - 0.4748 \cdot x1 \cdot m1 - 0.4307 \cdot x2 \cdot m1 - 0.0647 \cdot x3 \cdot m1 - 0.4049 \cdot x4 \cdot m1 - 0.0284 \cdot x1 \cdot m2 - 0.2679 \cdot x2 \cdot m2 + 0.2780 \cdot x3 \cdot m2 - 0.2429 \cdot x4 \cdot m2 - 0.4736 \cdot x1 \cdot m3a - 0.6405 \cdot x2 \cdot m3a - 0.8656 \cdot x3 \cdot m3a - 1.9669 \cdot x4 \cdot m3a - 0.0763 \cdot x1 \cdot m3b - 0.1585 \cdot x2 \cdot m3b - 0.5470 \cdot x3 \cdot m3b - 1.1961 \cdot x4 \cdot m3b))$

Note: X, exposure variable; Y, outcome variable; M, mediators of interest; L, exposure-induced mediator-outcome confounder. Expit is the inverse function of the log-odds or logit function.

Appendix S6-2: Equations used to simulate potential confounders, mediators and outcomes in step 2 of the G-computation marginal structural model

Approach 1, joint effect of L and M

L model, M model and Y model from step 1

$$\mathbf{E(L|x;\gamma) = \gamma_L + \gamma_X \cdot x} \qquad \mathbf{E(M|x,l;\alpha) = \alpha_M + \alpha_X \cdot x + \alpha_L \cdot l} \qquad \mathbf{E(Y|x,l;\beta) = \beta_Y + \beta_X \cdot x + \beta_L \cdot l + \beta_M \cdot m + \beta_{XM} \cdot x \cdot m}$$

Equations used to simulate potential L, M and Y in step 2

Effect	Simulating L^C	Simulating M^C	Simulating Y^C
TE	$L_x = \gamma_L + \gamma_X \cdot x + \varepsilon_L$	$M_{x\_l_x} = \alpha_M + \alpha_X \cdot x + \alpha_L \cdot l_x + \varepsilon_M$	$Y_{TE} = \beta_Y + \beta_X \cdot x + \beta_L \cdot l_x + \beta_M \cdot m_{x\_l_x} + \beta_{XM} \cdot x \cdot m_{x\_l_x} + \varepsilon_Y$
PDE	$L_0 = \gamma_L + \gamma_X \cdot 0 + \varepsilon_L$	$M_{0\_l_0} = \alpha_M + \alpha_X \cdot 0 + \alpha_L \cdot l_0 + \varepsilon_M$	$Y_{PDE} = \beta_Y + \beta_X \cdot x + \beta_L \cdot l_0 + \beta_M \cdot m_{0\_l_0} + \beta_{XM} \cdot x \cdot m_{0\_l_0} + \varepsilon_Y$
TDE	$L_1 = \gamma_L + \gamma_X \cdot 1 + \varepsilon_L$	$M_{1\_l_1} = \alpha_M + \alpha_X \cdot 1 + \alpha_L \cdot l_1 + \varepsilon_M$	$Y_{TDE} = \beta_Y + \beta_X \cdot x + \beta_L \cdot l_1 + \beta_M \cdot m_{1\_l_1} + \beta_{XM} \cdot x \cdot m_{1\_l_1} + \varepsilon_Y$
PIE	$L_x = \gamma_L + \gamma_X \cdot x + \varepsilon_L$	$M_{x\_l_x} = \alpha_M + \alpha_X \cdot x + \alpha_L \cdot l_x + \varepsilon_M$	$Y_{PIE} = \beta_Y + \beta_X \cdot 0 + \beta_L \cdot l_x + \beta_M \cdot m_{x\_l_x} + \beta_{XM} \cdot 0 \cdot m_{x\_l_x} + \varepsilon_Y$
TIE	$L_x = \gamma_L + \gamma_X \cdot x + \varepsilon_L$	$M_{x\_l_x} = \alpha_M + \alpha_X \cdot x + \alpha_L \cdot l_x + \varepsilon_M$	$Y_{TIE} = \beta_Y + \beta_X \cdot 1 + \beta_L \cdot l_x + \beta_M \cdot m_{x\_l_x} + \beta_{XM} \cdot 1 \cdot m_{x\_l_x} + \varepsilon_Y$

Note: TE: total effect; PDE: pure direct effect; TDE: total direct effect; PIE: pure indirect effect; TIE: total indirect effect.

Approach 2, path-specific effect

L model, M model and Y model from step 1

$$\mathbf{E(L|x;\gamma) = \gamma_L + \gamma_X \cdot x} \qquad \mathbf{E(M|x,l;\alpha) = \alpha_M + \alpha_X \cdot x + \alpha_L \cdot l} \qquad \mathbf{E(Y|x,l;\beta) = \beta_Y + \beta_X \cdot x + \beta_L \cdot l + \beta_M \cdot m + \beta_{XM} \cdot x \cdot m}$$

Equations used to simulate potential L, M and Y in step 2

Effect	**Simulating $\mathbf{L^C}$**	**Simulating $\mathbf{M^C}$**	**Simulating $\mathbf{Y^C}$**
TE	$L_x = \gamma_L + \gamma_X \cdot x + \varepsilon_L$	$M_{x\_l_x} = \alpha_M + \alpha_X \cdot x + \alpha_L \cdot l_x + \varepsilon_M$	$Y_{TE} = \beta_Y + \beta_X \cdot x + \beta_L \cdot l_x + \beta_M \cdot m_{x\_l_x} + \beta_{XM} \cdot x \cdot m_{x\_l_x} + \varepsilon_Y$
A→Y	$L_0 = \gamma_L + \gamma_X \cdot 0 + \varepsilon_L$	$M_{0\_l_0} = \alpha_M + \alpha_X \cdot 0 + \alpha_L \cdot l_0 + \varepsilon_M$	$Y_{A\to Y} = \beta_Y + \beta_X \cdot x + \beta_L \cdot l_0 + \beta_M \cdot m_{0\_l_0} + \beta_{XM} \cdot x \cdot m_{0\_l_0} + \varepsilon_Y$
A→LY	$L_x = \gamma_L + \gamma_X \cdot x + \varepsilon_L$	$M_{1\_l_x} = \alpha_M + \alpha_X \cdot 0 + \alpha_L \cdot l_x + \varepsilon_M$	$Y_{A\to LY} = \beta_Y + \beta_X \cdot 1 + \beta_L \cdot l_x + \beta_M \cdot m_{1\_l_x} + \beta_{XM} \cdot 1 \cdot m_{1\_l_x} + \varepsilon_Y$
A→M→Y	$L_0 = \gamma_L + \gamma_X \cdot 0 + \varepsilon_L$	$M_{x\_l_0} = \alpha_M + \alpha_X \cdot x + \alpha_L \cdot l_0 + \varepsilon_M$	$Y_{A\to M\to Y} = \beta_Y + \beta_X \cdot 1 + \beta_L \cdot l_0 + \beta_M \cdot m_{x\_l_0} + \beta_{XM} \cdot 1 \cdot m_{x\_l_0} + \varepsilon_Y$

Note: Effect A→LY is a combination of effects through path A→L→Y and path A→L→M→Y.

Approach 3, interventional effect

L model, M model and Y model from step 1

$$\mathbf{E(L|x;\gamma) = \gamma_L + \gamma_X \cdot x} \qquad \mathbf{E(M|x;\alpha) = \alpha_M + \alpha_X \cdot x} \qquad \mathbf{E(Y|x,l;\beta) = \beta_Y + \beta_X \cdot x + \beta_L \cdot l + \beta_M \cdot m + \beta_{XM} \cdot x \cdot m}$$

Equations used to simulate potential L, M and Y in step 2

Effect	**Simulating $\mathbf{L^C}$**	**Simulating $\mathbf{M^C}$**	**Simulating $\mathbf{Y^C}$**
TE	$L_x = \gamma_L + \gamma_X \cdot x + \varepsilon_L$	$M_{x\_l_x} = \alpha_M + \alpha_X \cdot x + \alpha_L \cdot l_x + \varepsilon_M$	$Y_{TE} = \beta_Y + \beta_X \cdot x + \beta_L \cdot l_x + \beta_M \cdot m_{x\_l_x} + \beta_{XM} \cdot x \cdot m_{x\_l_x} + \varepsilon_Y$
IE	$L_1 = \gamma_L + \gamma_X \cdot 1 + \varepsilon_L$	$M_x = \delta_M + \delta_X \cdot x + \varepsilon_M$	$Y_{IE} = \beta_Y + \beta_X \cdot 1 + \beta_L \cdot l_1 + \beta_M \cdot m_x + \beta_{XM} \cdot 1 \cdot m_x + \varepsilon_Y$
DE	$L_x = \gamma_L + \gamma_X \cdot x + \varepsilon_L$	$M_0 = \delta_M + \delta_X \cdot 0 + \varepsilon_M$	$Y_{DE} = \beta_Y + \beta_X \cdot x + \beta_L \cdot l_x + \beta_M \cdot m_0 + \beta_{XM} \cdot x \cdot m_0 + \varepsilon_Y$

Note: IE: indirect effect through mediator; DE: direct effect not through mediator.

Appendix S7-1

Chapter 7 of this dissertation is based on findings of Jiang L, Li X, Wang MC, Osgood N,Whaley SE, Crespi CM (2020) Estimating the population impact of hypothetical breastfeeding interventions in a low-income population in Los Angeles County: An agent-based model. *PLoS ONE15(4)*: e0231134. https://doi.org/10.1371/journal.pone.0231134. A copy of the published paper and supplementing information is provided here.

RESEARCH ARTICLE

Estimating the population impact of hypothetical breastfeeding interventions in a low-income population in Los Angeles County: An agent-based model

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Data Availability Statement: Data cannot be made publicly available since the data contain potentially sensitive information so that public availability would compromise participant privacy. The data is maintained by the third party, PHFE WIC Program. Interested researchers can replicate our study findings in their entirety by directly obtaining the data from PHFE WIC and requesting access to the data through the online form (http://lawicdata.org/requests/) and following the protocol in our Methods section and the supplement. The authors

Abstract

Background

Breastfeeding has clear benefits. Yet, breastfeeding practices fall short of recommendations in low-income populations including participants of the Special Supplemental Nutrition Pro-gram for Women, Infants, and Children (WIC). To promote breastfeeding, it is important to understand breastfeeding-related behaviors such as initiation and maintenance within the context of a complex societal system. For individual women, making choices about infant feeding (whether to breastfeed or formula-feed a newborn, or when to stop breastfeeding) is a dynamic process involving interactions with health professionals, family, peers and work-places. Integrating behavioral change theories with systems science tools such as agent-based modeling can help illuminate patterns of breastfeeding behaviors, identify key factors affecting breastfeeding behaviors within this complex dynamic system, and estimate the population impact of hypothetical interventions.

Methods

An agent-based model (ABM) was developed to investigate the influences of multiple levels of factors affecting breastfeeding behaviors among WIC participants. Health behavioral change theories were applied and stakeholder input obtained to improve the model, particu-larly during the conceptual design and model specification steps. The model was then used to identify critical points for intervention and assess the effects of five common interventions (improving knowledge through education, implementing Baby-Friendly Hospital Initiative practices, providing postpartum breastfeeding counselling, strengthening partner support, and fostering supportive workplace environments.)

did not have any special access privileges that others would not have over the data that we used in this study.

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Competing interests: The authors have declared that no competing interests exist.

Results

The ABM developed in this study produced outcomes (i.e., breastfeeding rates) that were concordant with empirical data. Increasing the coverage of the five selected interventions produced various levels of improvement in breastfeeding practices in the target population. Specifically, improving breastfeeding knowledge had a positive impact on women's *intent to* breastfeed, while increasing the availability of the Baby-Friendly Hospital Initiative improved breastfeeding *initiation* rates. However, neither of these two interventions showed a signifi-cant impact on breastfeeding *maintenance*, which was supported by postpartum breast-feeding counseling, partner support and a supportive workplace environment. These three intervention strategies each improved breastfeeding rates at 6 months from 55.6% to 57.1%, 59.5% and 59.3%, respectively. Increasing the coverage of multiple interventions simultaneously had a synergistic effect on breastfeeding *maintenance* with their effects being greater than the cumulative effects of increasing the coverage of these interventions individually.

Conclusion

The ABM we developed was helpful for understanding the dynamic process of decision-making regarding infant feeding modalities in a low-income population, and for evaluating the aggregated population-level impact of breastfeeding promotion interventions.

Introduction

Breastfeeding has many health and other benefits for both mother and baby and is recom-mended as the optimal feeding practice for infants, world-wide [1–3]. In the United States, low-income women are less likely to breastfeed and meet the recommended breastfeeding duration [4]. For example, women from households with income less than 100% federal pov-erty level have breastfeeding rates that are 24% lower at 6 months and 26% lower at 12 months than the national average [4]. Considerable efforts have been made by the Special Supplemen-tal Nutrition Program for Women, Infants, and Children (WIC), a major federal nutrition assistance program for low-income families, to promote breastfeeding. While a few studies have reported on evaluations of breastfeeding promotion programs in the WIC population [5–8], more translational research is needed to determine which intervention strategies are most effective.

The socioecological framework [9] can be applied to help us understand how individual, interpersonal, and societal/structural level factors interact to influence breastfeeding behaviors, namely, a mother's decision to initiate, maintain or stop breastfeeding. These factors include knowledge and education at the individual level, family and peer support at the interpersonal level, and social norms and workplace policies at the societal/structural level [10]. Importantly, these factors are not independent of each other–a mother's breastfeeding behavior reflects a dynamic process featuring learning and adaptation through interactions with others and the environment; at the same time, her behavior may also influence others and the environment.

The fact that a mother's breastfeeding practices are embedded in such a complex system presents considerable challenges for predicting the potential effects of certain interventions (e.g., educational and workplace support programs) and selecting the most effective

intervention strategies. Traditional analytic methods that assume independence (of measurements/data points) and static effects may not capture the dynamic interactions among the various factors. Practical and ethical constraints also render the application of experiments to evaluate the impact of 'real world' interventions almost impossible.

Over the past decade, the National Institutes of Health have encouraged the application of systems science methods such as agent-based modeling in public health research to advance our understanding of causality regarding health conditions and facilitate breakthroughs to improve population health [11]. Agent-based modeling is "a computational method that enables a researcher to create, analyze, and experiment with models composed of agents that interact within an environment" [12]. In an agent-based model, individual entities (agents) and their interactions with each other and with their environment are directly represented. Compared to traditional variable-based statistical equations, agent-based modeling methods hold several advantages [12–14]. First, they allow researchers to model heterogeneous individuals (agents) and the dynamic interactions among agents in a complex system (say, a breastfeeding mother and her interactions with family, healthcare, and co-workers). Second, they allow the agents in the model to 'adapt and learn' as they do in reality. Such models, therefore, are able to capture history-dependent behaviors. For example, breastfeeding later is not possible if one has stopped earlier, or never initiated in the first place. Third, behavioral theories about process can be relatively easily represented in the model through explicit decision rules for individual actions. Fourth, agent-based models represent multiple levels of analysis in a natural way that allows for the investigation of the aggregated effects of interventions at the population level that result from individual decision-making and practices. Fifth, agent-based models allow us to set up and run experiments using various input values (parameters) in order to study the possible outcomes of hypothetical interventions and answer many "what if . . ." policy questions. Lastly, the visual presentation of results produced by an agent-based model serves as an effective communication tool for disseminating research findings and influencing policy decisions.

Agent-based modeling methods have long been used in other disciplines and are increasingly used in public health research [12, 14, 15]. Some recent investigations applying this analytical tool in the field of public health suggest that it holds promise for investigating causal mechanisms of health problems and evaluating the effects of policy and program interventions [16–19]. However, these models are mostly built on single decision rules or focus on a single intervention. Agent-based models that examine complex behaviors by incorporating multiple influencing factors from various levels have not been fully explored.

The objective of this study is to develop an ABM for investigating the multiple factors that influence breastfeeding practices, and to use the model to evaluate the impact of a set of hypothetical interventions in the WIC population in Los Angeles County. The specific aims are to: (1) build an agent-based simulation model which incorporates behavioral theories and includes individual and environmental factors that may influence breastfeeding behaviors in a low-income population; and (2) estimate the population impact of a set of hypothetical interventions on breastfeeding to inform selection of effective intervention strategies for promoting breastfeeding in a low-income population.

Methods

This study developed an ABM using the simulation software AnyLogic (version 8.3.2). The ABM represents infant feeding decisions and practices of a cohort of low-income women during the first 6 months postpartum. This study focuses on modeling the breastfeeding practices of primiparous women. Primiparous women have significantly different breastfeeding

experiences than multiparous women; and the breastfeeding experience of the first child is closely associated with breastfeeding practices for subsequent births [20, 21]. The ABM is used to identify critical points for intervention and to assess the effects on breastfeeding of several common interventions (improving knowledge, implementing Baby-Friendly Hospital Initiative practices, providing postpartum breastfeeding counselling, strengthening partner support, and fostering a supportive workplace environment) at the population level. The following section provides details about each step of the model building and testing process. A supplement provides additional detailed information.

Model scope and conceptual design

We simulated a cohort of primiparous women with different socio-demographic characteristics and modeled their breastfeeding experience during the first 6 months postpartum using the conceptual framework shown in Fig 1. The development of this framework was informed by a literature review of key health behavioral change theories that apply to breastfeeding and consultation with content experts, including a professional lactation expert, a pediatrician, and a nutritionist.

The conceptual framework, in the form of a causal loop diagram (Fig 1), captures three key stages of the breastfeeding behavioral process–intent to breastfeed (during pregnancy), initiation of breastfeeding (following childbirth), and maintenance of breastfeeding through 6 months (postpartum)–and key factors influencing breastfeeding practices at each stage, including breastfeeding promotion interventions. During pregnancy, sociodemographic characteristics (age, educational attainment, race/ethnicity, and household income), social norms, and knowledge/attitude regarding breastfeeding influence a woman's intent to breastfeed [22–24]. Immediately following childbirth, women make choices regarding whether to breastfeed their infant or not. Prenatal intent to breastfeed and delivery at a baby-friendly hospital are important contributors to breastfeeding initiation at this stage. After returning home from the hospital, women need support from health professionals, family members (especially the partner) and the workplace to overcome barriers (such as lactation problems and returning to work) to maintenance of breastfeeding throughout the first 6 months [25–27].

Model specification

The ABM models breastfeeding intention and experiences of the primiparous cohort at three stages: prenatal, childbirth and postpartum. The model simulates breastfeeding decisions and experiences of each woman over a period of 6 months, i.e., from the end of her pregnancy to 6 months after childbirth, during which she may experience common barriers to breastfeeding and may access various breastfeeding promotion interventions.

Agents

There is only one type of agent in this model: women (expectant mothers and mothers). Women are 'endowed' with sociodemographic characteristics that influence their breastfeeding practices, including age (in years), educational attainment (less than high school, or high school graduate or above), race/ethnicity (Hispanic or Non-Hispanic), and household income ($\leq$100% of federal poverty level or $>$100% of federal poverty level).

Agent behaviors

Women's breastfeeding decisions and status (intent to breastfeed, initiation of breastfeeding, exclusive breastfeeding, partial breastfeeding and no breastfeeding) were captured using state

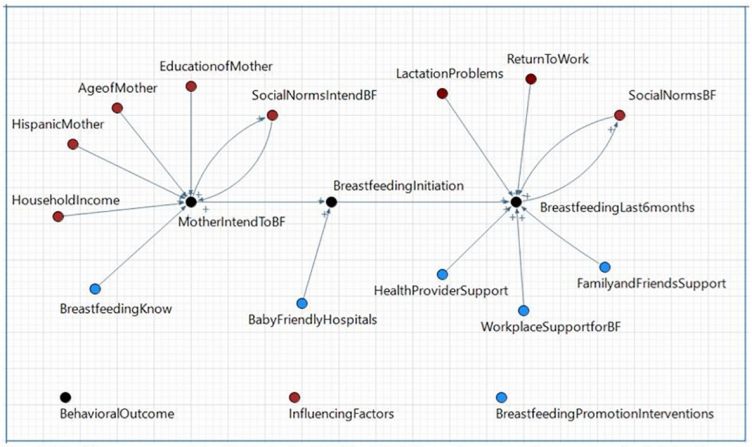

Fig 1. Conceptual framework for the breastfeeding agent-based model.

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charts (Fig 2). A state chart shows the state space (the possible states), the events that cause a transition from one state to another, and the actions that result from state change. The **perinatal stage state chart** (Fig 2A) reflects the various stages, determined by time, through which each pregnant woman progresses, including pregnancy, childbirth and postpartum stage. At each step in the perinatal process, women make decisions about their infant feeding options. During pregnancy, they form their intent to breastfeed or formula-feed based on their sociodemographic characteristics and breastfeeding knowledge. During their hospital stay, usually ranging from 1–2 days after childbirth, they decide whether to initiate breastfeeding their infant or not. After returning home from hospital, from the third day to six months postpartum, they encounter support (such as counselling service by health professionals and encouragement from family members) as well as barriers to breastfeeding (including lactation problems and having to return to work), and make decisions as to whether to continue breastfeeding or not. The **breastfeeding status state chart** (Fig 2B) represents the dynamics of these infant feeding options for each woman during the postpartum stage. Women change their breastfeeding status probabilistically with a specified transition rate or when they encounter

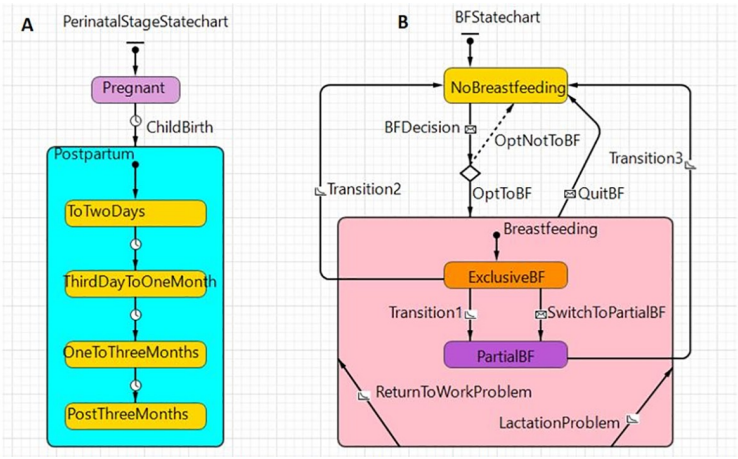

Fig 2. The perinatal stage state chart (A) and breastfeeding status state chart (B).

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barriers to breastfeeding such as lactation problems or having to return to work. The decision-making process for each woman when she encounters lactation problems or has to return to work was modeled using decision trees (S1 Fig and S2 Fig in the S1 Supplement). For example, when a lactation problem arises, a decision tree is used to determine how a woman would decide whether to continue to breastfeed or not. In our ABM, we assume that this decision depends on whether she has support from a professional lactation consultant and/or partner. If she has support from both a lactation consultant and her partner, she will continue to breastfeed as she has been doing (exclusively or partially). If she has support from only one source, she will switch from exclusive breastfeeding to partial breastfeeding or from partial breastfeeding to formula feeding. Three transition rates are included in the breastfeeding state chart to account for other reasons for transition from exclusive to partial to no breastfeeding.

The following five breastfeeding promotion interventions were randomly assigned to agents based on the estimates of exposure derived from literatures and empirical data: (1) breastfeeding education, such as prenatal breastfeeding counseling, to increase breastfeeding knowledge, the effectiveness indicated by a score of breastfeeding knowledge ranging from 0 (little knowledge) to 1 (perfect knowledge); (2) Baby-Friendly Hospital Initiative practices, indicated by birth at a designated Baby-Friendly facility (Yes/No); (3) postpartum breastfeeding counselling, indicated by having access to a lactation consultant after childbirth (Yes/No); (4) strengthening partner support, indicated by living with a partner (Yes/No); and (5) fostering supportive workplace environment, indicated by the workplace providing accommodations for nursing women to maintain breastfeeding such as break time and private rooms for pumping breastmilk (Yes/No).

Network

To calculate the probability of a woman making a particular decision regarding breastfeeding, it was assumed that this decision was based on innate characteristics (e.g. age, education, race/ethnicity) as well as a network of interactions among agents (women) when they form their prenatal breastfeeding intentions and when they need to make infant feeding decisions in the postpartum stage. In formulating this network, we assume that women prefer to network with other women of the same race/ethnicity and that their decisions are influenced by this network of interaction.

Outcome measures

Primary model outcome measures are the prevalence of breastfeeding intention, the incidence of breastfeeding initiation, and breastfeeding rates ('any' and 'exclusive') at 1 month, 3 months and 6 months postpartum. 'Any' breastfeeding was defined as the child having ever been fed breast milk; 'exclusive' breastfeeding was defined as the child having been fed no foods or liquids other than breast milk, not even water [1, 28].

Parameterization

The 2014 Los Angeles County WIC Survey (lawicdata.org/survey) provided the socio-demographic data needed to simulate the cohort for the ABM. All data obtained from the LA County WIC survey were provided in an anonymized format. Fifty-three records in the survey data set were excluded when data on any one of the four sociodemographic characteristics were missing; a total of 4,646 records were included for this study. We randomly selected 75% of the included records (n = 3,845) into a training sample to simulate the agent population and calibrate the model; the remaining 25% (n = 1,161) were used as a testing sample to validate the model. Since socio-demographic characteristics are often correlated with each other,

individual-level data (rather than aggregated distributional data) were used in the model to preserve the correlation among sociodemographic variables and reflect the actual heterogeneity of agents. Data from this 2014 WIC survey were used, together with information from a review of the literature on the effects of selected intervention strategies on breastfeeding practices [29], to estimate parameter values needed for building the ABM. Information to estimate the occurrence of other relevant behaviors such as when women return to work and lactation problems were similarly obtained [30]. A summary of values and data sources of the key parameters used in the model is given in Table 1. Additional details are provided in the supplement.

Calibration and validation of the model

We included three transition rate parameters in the model to account for residual reasons for discontinuing breastfeeding other than lactation problems and returning to work. The parameter values for these three transition rates–(1) transition from exclusive breastfeeding to partial breastfeeding, (2) transition from partial breastfeeding to formula feeding, and (3) transition from exclusive breastfeeding to formula feeding–were determined by calibration. Specifically, the simulated outcomes (exclusive and any breastfeeding rates at 1, 3 and 6 months postpartum) were compared with the observed rates from the training sample data, using the root mean square error (RMSE); parameter values of the model which best replicated the observed outcomes were selected [31].

Experiments

We ran experiments that involved increasing the coverage level of each of the five breastfeeding interventions (breastfeeding education, Baby-Friendly Hospital Initiative practices, postpartum breastfeeding counselling, strengthening partner support, and fostering supportive workplace environment) from baseline to three different levels (i.e. 80%, 90% and 95%) while keeping the coverage of other interventions at the baseline level. We also ran scenarios in which several interventions were implemented simultaneously as a "package". Each experiment was run 100 times with random seeds. For each run, we recorded the proportion of women who initiated breastfeeding and proportions with any or exclusive breastfeeding at 1, 3 and 6 months postpartum. The predicted breastfeeding rates were compared across scenarios to identify the most effective interventions for breastfeeding promotion in this population.

Sensitivity analysis

Sensitivity analyses were conducted to test how varying parameter values of the intervention effect of the selected intervention strategies might affect the simulation results. Two parameters were selected for sensitivity analysis: the intervention effect of breastfeeding education on prenatal breastfeeding intention, and the intervention effect of the Baby-Friendly Hospital Initiative practices on breastfeeding initiation. Estimates for these parameters were not available from randomized control trials, and were derived from the literature and the WIC 2014 survey data.

Results

Model calibration and validation

Our calibration produced a combination of best fit parameter values of the three transition rates (0.016, 0.059 and 0.139 per month), as shown in Table 2.

Table 1. Data sources and values for key parameters.

Parameters	Distribution of initial values	Data source or references
Socio-demographics		
Age	28.1±6.4 (mean ± SD)	WIC 2014 survey
Education	• Less than high school: 36.5%	WIC 2014 survey
	• High school graduate or above: 64.5%	
Household income	• ≤100% federal poverty level: 48.4%	WIC 2014 survey
	• >100% federal poverty level: 51.6%	
Race/ethnicity	• Hispanic: 85.0%	WIC 2014 survey
	• Non-Hispanic: 15.0%	
Occurrence of barriers to breastfeeding maintenance		
Lactation problems	• 0–6 months: 87.4%	Februhartanty, Bardosono and Septiari [30]
Return to work	• 0–2 months: 9.1%	WIC 2014 survey
	• 3–5 months: 14.4%	
	• ≥ 6 months: 13.0%	
	• Not employed: 63.5%	
Baseline coverage of interventions		
BF knowledge	Beta-distribution (Mean: 0.67, SD: 0.10, Range: 0–1)	Mitra et al. [29]
Baby-Friendly Hospital Initiative practices	11.4%	WIC 2014 survey
Postpartum breastfeeding counselling	78.1%	WIC 2014 survey
Postpartum partner support	67.7%	WIC 2014 survey
Supportive workplace environment	52.1%	WIC 2014 survey
Intervention effect		
Improving BF knowledge on breastfeeding intention	Logistic regression coefficient: 1.17	Mitra et al. [29]
Baby-Friendly Hospital Initiative practices on breastfeeding initiation	Logistic regression coefficient: 0.155	WIC 2014 survey

https://doi.org/10.1371/journal.pone.0231134.t001

Using the calibrated values, we investigated whether the model could reproduce the observed outcomes in the testing sample. Fig 3 shows that except for the any breastfeeding rate at 1 month postpartum, all other breastfeeding rates generated by the model fitted well with the empirical data (RMSE = 3.84). Therefore, we used this validated model with the combination of parameter values to run the experiments.

Experiments

Increasing the coverage of the selected interventions improved the breastfeeding rates in the cohort to various extents. Table 3 summarizes the predicted breastfeeding rates in scenarios

Table 2. Best fit parameter values from model calibration.

Parameters for calibration	Initial value	Value tested in calibration	Final value
Transition rate from exclusive breastfeeding to formula feeding	0.018	0.004–0.08	0.016
Transition rate from partial breastfeeding to formula feeding	0.113	0.02–0.5	0.059
Transition rate from exclusive breastfeeding to partial breastfeeding	0.069	0.015–0.3	0.139

Transition rate in this table refers to the proportion of woman who transition from one infant feeding state to another per month.

https://doi.org/10.1371/journal.pone.0231134.t002

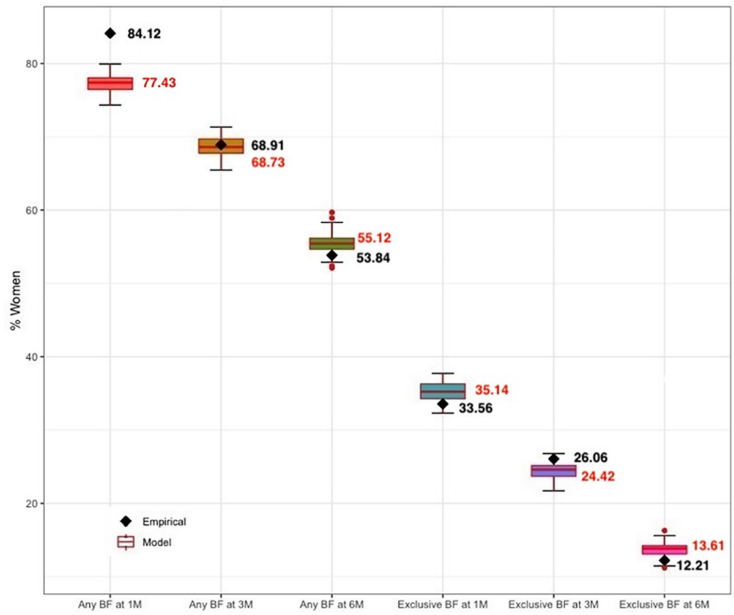

Fig 3. Comparison of model generated breastfeeding rates (boxplot) and observed breastfeeding rates from the testing sample (black diamond) at 1 month, 3 months and 6 months postpartum for the baseline scenario.

https://doi.org/10.1371/journal.pone.0231134.g003

with various hypothetical coverage levels of each of the five interventions described above. For each experiment, the results were calculated based on the average values of 100 runs to reduce stochastic variability.

Improving the breastfeeding-related knowledge/attitude score from the baseline level (mean: 0.67) to the highest level (mean: 0.95) through education increased the percentage of pregnant women who intend to breastfeed from 88.5% to 91.3%, but conferred only minimal positive impact on the breastfeeding initiation rate and any breastfeeding and exclusive breastfeeding rates in the postpartum period. Increasing the coverage of the Baby-Friendly Hospital Initiative practices led to an increase in the breastfeeding initiation rate (from 93.0% to 93.7%), and only a very slight increase in any breastfeeding and exclusive breastfeeding rates in the later postpartum period. Increasing coverage of the other three postpartum interventions had no impact on breastfeeding intention or initiation but helped to maintain breastfeeding and significantly improved long-term breastfeeding rates. For example, increasing the coverage of partner support from 67.7% (baseline) to 95% leads to an increase in any breastfeeding rate at 6 months, from 55.6% to 59.5%; and exclusive breastfeeding rate at 6 months, from 13.9% to 15.8%.

Table 4 presents the effects of various intervention packages (made up of multiple interventions) on breastfeeding rates. Compared to scenarios with a single intervention, increasing the coverage levels of multiple interventions included in an intervention package significantly improved breastfeeding rates, particularly in the postpartum period. For example, when the coverage of four interventions delivered in a package (improving breastfeeding knowledge, Baby-Friendly Hospital Initiative practices, postpartum breastfeeding counseling, and strengthening partner support) was increased from the baseline level to intervention level 3 (95%), the predicted any breastfeeding rate at 6 months increased by 8.8 percentage points from 55.6% to 64.4%. In comparison, the sum of the effects of these four interventions when delivered separately amounts to only 6.4 percentage points.

Table 3. Breastfeeding rates predicted at various coverage levels of five selected interventions.

Interventions and their coverage levels	Mean prevalence of breastfeeding practices (%)							
	BF intention	BF initiation	Any BF at 1 month	Any BF at 3 month	Any BF at 6 month	Exclusive BF at 1 month	Exclusive BF at 3 month	Exclusive BF at 6 month
Improving breastfeeding knowledge								
Base level (0.67)	88.50	92.96	77.41	68.86	55.62	35.20	24.46	13.86
Intervention level 1 (0.80)	90.05	93.42	77.82	69.20	55.84	35.47	24.64	13.90
Intervention level 2 (0.90)	91.01	93.72	77.99	69.48	56.11	35.59	24.68	13.94
Intervention level 3 (0.95)	91.37	93.84	78.03	69.46	56.24	35.53	24.74	14.03
Baby-Friendly Hospital Initiative practices								
Base level (11.40%)	88.50	92.96	77.41	68.86	55.62	35.20	24.46	13.86
Intervention level 1 (80%)	88.52	93.61	77.96	69.44	56.25	35.50	24.71	13.96
Intervention level 2 (90%)	88.67	93.67	77.99	69.49	56.10	35.65	24.69	13.99
Intervention level 3 (95%)	88.66	93.71	77.89	69.37	56.04	35.54	24.65	13.93
Postpartum professional counseling								
Base level (78.12%)	88.50	92.96	77.41	68.86	55.62	35.20	24.46	13.86
Intervention level 1 (80%)	88.65	92.94	77.58	69.20	56.03	35.52	24.69	13.91
Intervention level 2 (90%)	88.52	92.98	78.35	70.03	56.80	36.48	25.48	14.39
Intervention level 3 (95%)	88.64	93.02	78.62	70.32	57.09	36.86	25.59	14.65
Postpartum partner support								
Base level (67.74%)	88.50	92.96	77.41	68.86	55.62	35.20	24.46	13.86
Intervention level 1 (80%)	88.73	93.04	78.92	70.59	57.33	37.04	25.78	14.62
Intervention level 2 (90%)	88.58	93.05	80.16	71.88	58.71	38.36	26.84	15.31
Intervention level 3 (95%)	88.54	92.96	80.69	72.47	59.53	39.23	27.48	15.75
Supportive workplace environment								
Base level (52.05%)	88.50	92.96	77.41	68.86	55.62	35.20	24.46	13.86
Intervention level 1 (80%)	88.64	93.08	77.54	69.82	58.01	35.32	25.01	14.68
Intervention level 2 (90%)	88.58	93.06	77.83	70.30	58.98	35.74	25.35	15.11
Intervention level 3 (95%)	88.64	93.08	77.75	70.31	59.28	35.61	25.25	15.14

https://doi.org/10.1371/journal.pone.0231134.t003

Sensitivity analysis

Table 5 summarizes the results of sensitivity analyses with varying values of the two parameters, the intervention effect of improving breastfeeding knowledge on prenatal breastfeeding intention (logistic regress coefficients ranging from 1.0 to 1.5), and the intervention effect of the Baby-Friendly Hospital Initiative practices on breastfeeding initiation (logistic regression coefficients ranging from 0.1 to 0.5). The predicted breastfeeding rates with varying values of the two parameters were not significantly different when the coverage of each intervention was set at 95%. Therefore, varying the values of these two parameters did not have a major impact on the breastfeeding rates predicted by the ABM (Table 5).

Discussion

The agent-based model that we developed replicated the empirical data and helped predict individual- and population-level intervention effects. The effects on breastfeeding practices were different for the five selected interventions among WIC participants.

Table 4. Breastfeeding rates predicted at various coverage levels of selected intervention packages.

Intervention packages and their coverage levels	Mean prevalence of breastfeeding practices (%)							
	BF intention	BF initiation	Any BF at 1 month	Any BF at 3 month	Any BF at 6 month	Exclusive BF at 1 month	Exclusive BF at 3 month	Exclusive BF at 6 month
KNWL								
Base level	88.50	92.96	77.41	68.86	55.62	35.20	24.46	13.86
Intervention level 1 (0.80)	90.05	93.42	77.82	69.20	55.84	35.47	24.64	13.90
Intervention level 2 (0.90)	91.01	93.72	77.99	69.48	56.11	35.59	24.68	13.94
Intervention level 3 (0.95)	91.37	93.84	78.03	69.46	56.24	35.53	24.74	14.03
KNWL+BHFI								
Base level	88.50	92.96	77.41	68.86	55.62	35.20	24.46	13.86
Intervention level 1 (0.80)	90.08	93.95	78.26	69.66	56.27	35.64	24.69	13.93
Intervention level 2 (0.90)	91.07	94.36	78.41	69.82	56.43	35.73	24.78	14.04
Intervention level 3 (0.95)	91.36	94.44	78.68	70.09	56.60	35.99	25.07	14.17
KNWL+BHFI+COUL								
Base level	88.50	92.96	77.41	68.86	55.62	35.20	24.46	13.86
Intervention level 1 (80%)	90.00	94.02	78.33	69.84	56.42	35.95	25.02	14.12
Intervention level 2 (90%)	90.91	94.27	79.41	70.89	57.49	36.87	25.74	14.55
Intervention level 3 (95%)	91.47	94.45	79.90	71.55	58.22	37.44	26.15	14.86
KNWL+BHFI+COUL+PTR								
Base level	88.50	92.96	77.41	68.86	55.62	35.20	24.46	13.86
Intervention level 1 (80%)	89.98	93.88	79.94	71.60	58.29	37.75	26.38	14.94
Intervention level 2 (90%)	91.00	94.36	83.41	75.39	62.24	41.67	29.47	17.05
Intervention level 3 (95%)	91.37	94.46	85.16	77.25	64.38	44.43	31.37	18.22
KNWL+BHFI+COUL+PTR+WP								
Base level	88.50	92.96	77.41	68.86	55.62	35.20	24.46	13.86
Intervention level 1 (80%)	89.92	93.93	80.07	72.39	60.60	38.01	27.04	16.04
Intervention level 2 (90%)	90.89	94.33	83.64	76.50	65.47	42.24	30.49	18.51
Intervention level 3 (95%)	91.34	94.49	85.49	78.66	68.19	44.69	32.45	20.05

KNWL: improving breastfeeding knowledge; BFHI: Baby-Friendly Hospital Initiative practices; COUL: postpartum breastfeeding counselling; PTR: strengthening partner support; and WP: fostering supportive workplace environment.

https://doi.org/10.1371/journal.pone.0231134.t004

Among the five individual interventions, increasing coverage of postpartum professional counseling, partner support and supportive workplace environment led to significant improvement in breastfeeding maintenance, i.e., breastfeeding rates at 1 month, 3 months and 6 months postpartum. Since it is common for nursing women to encounter lactation problems, support from health professionals and family members is critical for helping mothers succeed in breastfeeding maintenance. Surprisingly, having a supportive workplace environment showed a positive impact on breastfeeding rates in this population of WIC-enrolled even though only a quarter of women returned to work within 6 months postpartum. This finding supports the efforts of the WIC program to provide breastfeeding support to moms who return to work (e.g. provision of pumps, outreach to employers). For populations where the majority of women return to work soon after childbirth, we might expect an even larger impact of fostering supportive workplace environment. In the United States, where employers are required to provide only unpaid maternity leave of up to 12 weeks to certain eligible workers [32], workplace barriers to breastfeeding (such as the lack of space for pumping breastmilk) must be addressed to support breastfeeding maintenance.

Table 5. Predicted breastfeeding rates with 95% intervention coverage: Sensitivity analysis.

Parameters and their values	Breastfeeding outcomes with universal intervention coverage (95%)							
	BF intention	BF initiation	Any BF at 1 month	Any BF at 3 month	Any BF at 6 month	Exclusive BF at 1 month	Exclusive BF at 3 month	Exclusive BF at 6 month
Causal effect of breastfeeding knowledge/attitude on breastfeeding intention								
1.0	91.07	93.75	78.05	69.54	56.15	35.55	24.75	13.92
1.17 (value in the model)	88.50	92.96	77.41	68.86	55.62	35.20	24.46	13.86
1.25	91.66	93.92	78.14	69.61	56.21	35.38	24.50	13.86
1.5	91.89	94.03	78.09	69.48	56.22	35.62	24.76	13.94
Causal effect of Baby-Friendly Hospital Initiative practices on breastfeeding initiation								
0.1	88.67	93.06	77.30	68.89	55.64	35.38	24.62	13.90
0.155 (value in the model)	88.50	92.96	77.41	68.86	55.62	35.20	24.46	13.86
0.25	88.51	93.07	77.46	68.95	55.70	35.36	24.55	13.86
0.5	88.65	93.23	77.49	68.96	55.59	35.30	24.45	13.74

https://doi.org/10.1371/journal.pone.0231134.t005

Improving prenatal breastfeeding knowledge/attitude had a positive impact on women's intent to breastfeed but not on postpartum breastfeeding outcomes. This result is consistent with a meta-analysis by Guise et al. [33] which found that education programs to improve knowledge/attitude are effective in increasing breastfeeding initiation rates, but have no significant effects on long-term breastfeeding duration. Similarly, increasing coverage of delivery at baby-friendly hospitals improves breastfeeding initiation rate but achieves only modest increases in long-term breastfeeding rates. This finding differs from that of a cluster randomized trial conducted in the Republic of Belarus by Kramer et al. [34]. In that study, Baby-Friendly Hospital Initiative practices were found to be effective in increasing both duration and exclusivity of breastfeeding. However, two unique features of the Belarussian health care system–high centralization and prolonged postpartum hospital stay for childbirth–may explain their finding of a larger intervention effect.

The comparative effectiveness of these interventions also reflects a common feature of complex systems–that of path dependence [35, 36]. The path dependence feature means that the dynamic process is contingent, non-reversible and evolutionary based on its own history [36]. The fact that breastfeeding cannot resume once it is interrupted for more than a few days puts a premium on achieving breastfeeding maintenance uninterrupted throughout the entire postpartum period, across many months. Therefore, postpartum professional counseling and partner support and supportive workplace environment play a critical role in maintaining breastfeeding behavior *all through the postpartum period*. In comparison, the other two interventions, education and Baby-Friendly Hospital Initiative practices, occur at specific periods, in the prenatal period and the immediate period following delivery respectively.

Increasing coverage of multiple interventions simultaneously improved the predicted breastfeeding rates significantly for the postpartum period. The results reflect the synergistic effect of combinations of interventions in a complex system where the whole is greater than the sum of the parts. In this case, the combined effect of multiple breastfeeding promotion interventions is greater than the sum of the individual effect of each intervention.

Application of the agent-based modeling methods in this study brings some advantages over previous research that employed traditional variable-based regression methods. First, this ABM model is dynamic in character. In contrast to the more static regression-based approaches, this key feature allows us to portray the dynamic process of articulated decision-making or evolution of social networks relevant to a woman's infant feeding behaviors within

the first six month postpartum. Second, the modeling of each individual woman's decision-making process allows us to incorporate behavioral theories such as the Theory of Planned Behavior [37, 38] and Social Cognitive Theory [39] in the model, which facilitates our understanding of how these theories work together to predict/explain a behavioral outcome. Third, it is relatively easy to capture the interactions between individuals (through network effects) and between individuals and their environment (e.g., individuals' contact with health care system and workplace) in the simulation model. Fourth, an ABM allows us to explore the behavioral dynamics at the individual level and to assess the effect of interventions at the aggregated population level so that the population-level effect of certain interventions can be obtained directly from the simulation results. Finally, agent-based modeling enables us to run experiments with intervention coverage set at any level, thereby offering richer information for policy makers to weigh alternative intervention options.

There are limitations to this study. First, it was difficult, even impossible in some cases, to extract appropriate parameter values from the literature, since randomized control trials were not available for all parameter estimates. Therefore, we derived some parameter values (e.g., the effect of improving breastfeeding knowledge on breastfeeding intention) from observational studies, which may be biased. For the effect of the three postpartum interventions (breastfeeding counseling, strengthening partner support and fostering workplace supportive environment) for which there is lack of literature to inform the selection of parameter estimates [40], there is the possibility that the intervention effect size may be overestimated. Future research is needed to fill this gap by conducting more rigorous experimental/quasi-experimental studies or applying causal inference methods to generate more robust estimates from existing data. Second, we selected five breastfeeding promotion interventions that are feasible for our target population but this list of interventions is neither exhaustive nor complete. For example, a number of WIC clinics provide *peer counseling* for nursing women but we were not able to include this specific form of counselling as an intervention due to the lack of information on the extent of its use. Data on the coverage of these and other interventions will allow future studies to assess the effects of these interventions. Finally, the conceptualization of this ABM relied mainly on the research team and expert input. Although we made efforts to incorporate opinions from lactation consultants who serve the WIC population, we were not able to involve the target population directly in the conceptualization process due to resource and logistical constraints. It will be useful for future studies to incorporate nursing women's perspectives and experiences in the development of the ABM to improve understanding of the behavioral decision process as it affects the effectiveness of interventions.

Conclusion

Agent-based modeling is a useful tool for understanding the dynamic process of decision-making regarding the effectiveness of various behavioral interventions in a vulnerable low-income population; the use of a socio-ecological framework further allowed the consideration and inclusion of environmental policy interventions. To our knowledge, this is the first study to use agent-based modeling to examine breastfeeding practices and the potential impact of various interventions. By allowing the consideration of many levels of risk and protective factors, and their dynamic interactions, agent-based modeling provides a tool for bringing together decision-makers to understand the population impact of various intervention strategies.

Supporting information

S1 Supplement.
(DOCX)

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Supplement

This supplementary material details the agent-based modeling methods for the paper, "Estimating the population impact of hypothetical breastfeeding interventions in a low-income population in Los Angeles County: An agent-based model" by Linghui Jiang, Xiaoyan Li, May C. Wang, Nathaniel Osgood, Shannon E. Whaley, and Catherine M. Crespi.

In this paper, we developed an agent-based model (ABM) to simulate the breastfeeding experience of a cohort of primiparous women during the first six months postpartum. Then we used the model to predict the prevalence of breastfeeding practices under various scenarios with different coverage levels of breastfeeding promotion interventions.

1. Model structure

Using the simulation software AnyLogic (version 8.3.2), we developed a non-spatial agent-based model in which we simulated a cohort of primiparous women with different sociodemographic characteristics and modeled their breastfeeding experience during the first six months postpartum. Each woman enters the model on the last day of their pregnancy and spends six months in the model. The model time unit is one month. The model operates on discrete time steps and the time step for solving equations is 0.001 month.

The ABM models breastfeeding intention and experiences of this primiparous cohort at three stages, prenatal, childbirth and postpartum, using two state charts and two decision trees. State charts are state transition diagrams that identify states and describe event- and time-driven transitions from one state to another. One state chart (Fig 2A) is used to specify perinatal stage (prenatal, childbirth, postpartum) and the duration of each stage, and the other (Fig 2B) is used to represent women's breastfeeding status in the childbirth and postpartum stages (exclusive, partial and no breastfeeding) and transitions between these breastfeeding states.

Breastfeeding intention is formed at the prenatal stage and calculated on the last day of pregnancy based on a woman's sociodemographic characteristics, breastfeeding knowledge score and the influence of her peers. Once her child is born, the woman makes a decision about whether or not to initiate breastfeeding based on her prenatal breastfeeding intention and access to Baby-Friendly Hospital Initiative services. If breastfeeding is initiated, it begins as exclusive breastfeeding. Two major barriers to breastfeeding may occur, lactation problems and having to return to work, in the first six months postpartum. These barriers occur probabilistically. When encountering one of these barriers, the woman may assess the situation and adjust her breastfeeding status which was modeled using a decision tree. A decision tree is a tree-like graph that depicts a sequence of decisions and their possible consequences. Three transition rates are included in the breastfeeding status state chart to account for other reasons that women transition from exclusive to partial to no breastfeeding. In the model, each woman is also connected with some of her peers and her breastfeeding intention and decisions are influenced by her interactions with peers.

2. Agent attributes and assignment of initial values

Pregnant women are the agents in this model. The 2014 Los Angeles County WIC survey data (lawicdata.org/survey) informed the simulation of the agent population (primiparous

women). The agents were associated with both fixed attributes (sociodemographic characteristics) and modifiable attributes (experiencing barriers to breastfeeding, and access to breastfeeding promotion interventions). This section provides the definition of each attribute and describes how the initial values of the attributes are assigned.

2.1 Sociodemographic characteristics

Four sociodemographic characteristics of agents (pregnant women) were defined, age, race/ethnicity, educational attainment and household income. Table S-1 provides description of each sociodemographic characteristic attribute. Age is a numerical variable and the other three attributes (race/ethnicity, educational attainment and household income level) are categorical, consistent with the operationalization of these variables in the 2014 Los Angeles County WIC survey (http://lawicdata.org/survey/).

Individual-level data from the 2014 Los Angeles County WIC survey were imported to assign the initial values of sociodemographic characteristics to each agent. Fifty-three records were excluded due to missingness on any one of the four sociodemographic characteristics; a total of 4,646 records from the survey data were included. We randomly selected 75% of the included records (n=3,845) into a training sample to simulate the agent population and calibrate the model; the remaining 25% records (n=1,161) were used as a testing sample to validate the model. Although age and household income may change with time, the duration of our model is only 6 months during which the changes are most likely 'ignorable' and will not have an impact on the model output. We thus model all four of the sociodemographic characteristics including age and household income as fixed attributes, i.e., the values of these attributes do not change with time. The distributions of the initial values for the sociodemographic characteristics are presented in table S-1.

Table S-1 Sociodemographic characteristics of agents and distribution of the initial values

Attribute	Operational definition	Distribution of initial values	Data source
Age	Women's age at childbirth, continuous variable (years)	28.1±6.4 (mean ± SD)	WIC 2014 survey training sample
Education	Women's highest educational attainment, categorical variable	• Less than high school: 36.5% • High school graduate or above: 64.5%	WIC 2014 survey training sample
Household income	Household income relative to federal poverty level (FPL), categorical variable	• ≤100% FPL: 48.4% • >100% FPL: 51.6%	WIC 2014 survey training sample
Race/ethnicity	Self-reported race/ethnic groups, categorical variable	• Hispanic: 85.0% • Non-Hispanic: 15.0%	WIC 2014 survey training sample

2.2 Network

There is evidence that peer influence plays an important role in women's decision making about infant feeding methods [1-4]. In this ABM, each woman was connected with an average of three peers. The number of connected peers followed a truncated normal distribution N (3, 1^2) with a minimum value of 0 and a maximum value of 6. The greatest integer function "floor ()" was used to return an integer from the distribution for each agent which specifies the number of their connected peers. The mean number of connected peers was derived from a study by Buckner and Matsubara [5]. For each agent, which peers to connect with depends on a preference score based on race/ethnicity. Peers from the same racial/ethnic group were assigned higher preference scores.

2.3 Experiencing barriers to breastfeeding maintenance

After initiating breastfeeding, some women may encounter barriers to maintaining breastfeeding. Experiencing lactation problems and having to return to work are the two major reasons for early termination of breastfeeding throughout the first 6 months postpartum [6-8]. Agents are randomly assigned to experience these two problems each month. The proportion of women who may experience each problem varies by month. The rates of occurrence of lactation problems and returning to work are based on the study by Februhartanty, Bardosono and Septiari [9] and the 2014 WIC survey data, respectively. The definitions of the two problems and the estimated percentages of women experiencing each problem are provided in Table S-2.

Table S-2 Barriers to breastfeeding maintenance and assignment of the initial values

Attribute	**Operational definition**	**Occurrence in each month**	**Data source**
Experiencing lactation problems	Whether a mother experienced any lactation problems during the first 6 months postpartum (Yes/No)	● 1st month: 70% ● 2nd month: 3.4% ● 3rd month: 3.4% ● 4th month: 3.4% ● 5th month: 3.4% ● 6th month: 3.4%	Februhartanty, Bardosono and Septiari [9]
Having to return to work	Whether a mother has to return to work during the first 6 months postpartum (Yes/No)	● 1st month: 3% ● 2nd month: 3% ● 3rd month: 3% ● 4th month: 4.8% ● 5th month: 4.8% ● 6th month: 4.8%	WIC 2014 survey

2.4 Access to breastfeeding promotion interventions

We examined the effects of women's access to five categories of breastfeeding promotion interventions in this model (Table S-3): 1) educational interventions, such as prenatal breastfeeding counseling, to increase breastfeeding knowledge, indicated by a score of breastfeeding knowledge ranging from 0 (little knowledge) to 1 (perfect knowledge); 2) Baby-

Friendly Hospital Initiative practices, indicated by birth at a designated Baby-Friendly facility; 3) postpartum breastfeeding counselling, indicated by having a consultant or a telephone number to call for help after childbirth; 4) support from partner for breastfeeding, indicated by living with her partner; and 5) supportive workplace environment, indicated by the workplace providing accommodations for nursing women to maintain breastfeeding such as a break time and a lactation room.

The baseline coverage of these interventions was informed by literature review and the 2014 WIC survey data. Each agent was randomly assigned a knowledge score ranging from 0 to 1 which followed a Beta distribution. The study by Mitra et al [10] informed the estimation of the mean (0.67) and standard deviation (0.10) of breastfeeding knowledge; and these values were used to compute the parameters of the Beta distribution. The estimated percentages of agents having access to the other four interventions in baseline scenarios are 11.4%, 78.1%, 67.7% and 52.1, respectively, based on the 2014 WIC survey data. Agents were randomly assigned to access these interventions.

Table S-3 Definition and estimated baseline coverage of breastfeeding promotion interventions

Intervention	**Operational definition of access to the intervention**	**Baseline distribution/ coverage**	**Data source**
Increasing BF knowledge	A score of breastfeeding related knowledge ranging from 0 (little knowledge) to 1 (perfect knowledge)	Beta distribution (Mean: 0.67, SD 0.10, range: 0-1)	Mitra et al [10]
Baby-Friendly Hospital Initiative practices	Whether a woman gives birth in a designated Baby-Friendly facility (Yes/No)	11.4%	WIC 2014 survey
Postpartum breastfeeding counselling	Whether a woman has a consultant or a telephone number to call for help with breastfeeding (Yes/No)	78.1%	WIC 2014 survey
Postpartum family support	Whether a woman lives with her partner (Yes/No)	67.7%	WIC 2014 survey
Supportive workplace environment	Whether the workplace have accommodations for nursing women to maintain breastfeeding such as a break time or a lactation room (Yes/No)	52.1%	WIC 2014 survey

3. Model dynamics and outcomes

This section describes the algorithms and assumptions associated with the model dynamics. The model dynamics pertain to three outcome measures that are assessed in the model:

breastfeeding intention at prenatal stage, breastfeeding initiation at childbirth stage, and breastfeeding status at each month during the first six months postpartum.

3.1 Breastfeeding intention

Breastfeeding intention, whether a pregnant woman intents to breastfeed her child or not, was assessed on the last day of pregnancy, when the model starts. It is a dichotomous variable (Yes/No). Based on her sociodemographic characteristics, breastfeeding knowledge score and the influence from her peers, a woman's initial breastfeeding intention was calculated and assigned in the following four steps.

Step 1: A logistic regression equation was applied to predict probability of intending to breastfeed based on sociodemographic characteristics and breastfeeding knowledge score.

$$P_{int:agent} = \frac{e^{XB}}{1 + e^{XB}}$$

$$= \frac{e^{1.64-0.22Age20-0.07Age2030+0.54Hispanic+0.52HSgrad-0.43Income+1.17(Knowledge-0.67)}}{1 + e^{1.64-0.22Age20-0.07Age2030+0.54Hispanic+0.52HSgrad-0.43Income+1.17(Knowledge-0.67)}}$$

Note:

(1) Age20: binary variable, 1= age < 20, 0 otherwise; Age2030: binary variable, 1= age 20-30, 0 otherwise; Hispanic: binary variable, 1=Hispanic, 0 otherwise; Hsgrad: binary variable, 1= high school graduate or above, 0 otherwise; income: binary, 1= household income ≤100% Federal Poverty Level, 0 otherwise; Knowledge: continuous variable, values ranging 0-1.
(2) The logistic regression coefficients for sociodemographic variables were estimated from the WIC 2014 survey data.
(3) The logistic regression coefficient for breastfeeding knowledge was derived from a study by Mitra et al [10].

Step 2: Calculate the mean probability of intending to breastfeed of an agent's peers with whom she is directly connected.

$$P_{int:peer} = \frac{\sum_1^n P_n}{n}$$

Note:

(1) n is the number of an agent's connected peers
(2) P_n is each peer's probability of intending to breastfeed calculated in step 1.

Step 3: Calculate the final probability of intention to breastfeed, which is the average of an agent's original probability (step 1) and the mean probability of her connected peers (step 2).

$$P_{int} = \frac{P_{int:agent} + P_{int:peer}}{2}$$

Step 4: Using the Bernoulli distribution (in AnyLogic, the randomTrue function), each agent is randomly assigned to intend to breastfeed with probability P_{int} as calculated in step 3.

3.2 Breastfeeding initiation

For each agent, the probability of initiating breastfeeding was calculated immediately after childbirth and an initiation status (Yes/No) was assigned as follows:

Step 1: A logistic regression equation was applied to predict the probability based on breastfeeding intention and delivery at a Baby-Friendly hospital:

$$P_{ini} = \frac{e^{XB}}{1 + e^{XB}} = \quad = \frac{e^{0.73+2.50BFint+0.155BFHI}}{1 + e^{0.73+2.50BFint+0.155BFHI}}$$

Note:
(1) BFint: binary variable, 1= intent to breastfeed, 0 otherwise; BFHI: binary variable, 1=delivery in a Baby-Friendly hospital, 0 otherwise.
(2) The logistic regression coefficients were estimated from the WIC 2014 survey data.

Step 2: Using a Bernoulli distribution, each agent is randomly assigned to initiate breastfeeding with probability P_{ini} as calculated in step 1.

3.3 Breastfeeding status during the first six months postpartum

If an agent chooses to initiate breastfeeding after childbirth, she is assumed to start with exclusive breastfeeding. Her breastfeeding status, exclusive breastfeeding, partial breastfeeding or no breastfeeding (formula feeding), is assessed monthly during the first six months postpartum. During this period, some women experience one or two major barriers to breastfeeding, i.e. lactation problems, such as breast engorgement and insufficient milk supply, and having to return to work. When a lactation problem occurs, a nursing woman will go through a decision tree (Figure S-1). Based on her access to professional consultant and family support, the woman may continue to breastfeed, or breastfeed less, or stop breastfeeding. When a nursing woman has to return to work within the first six months postpartum, she will go through another decision tree (Figure S-2). Based on her access to workplace support for breastfeeding, she may continue to breastfeed, or breastfeed less, or stop breastfeeding.

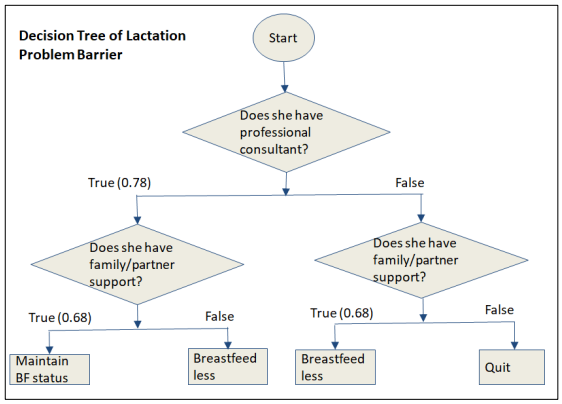

Figure S-1: Decision tree for nursing women experiencing lactation problems

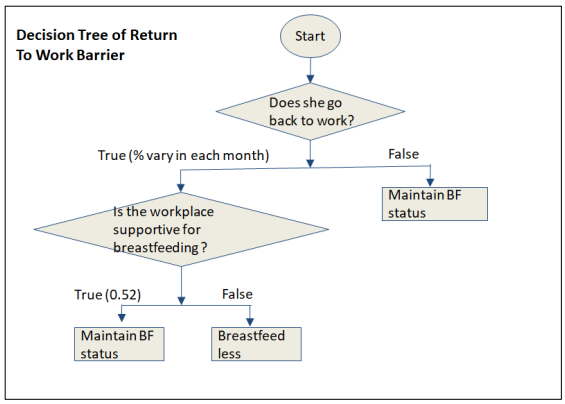

Figure S-2: Decision tree for nursing women who have to return to work

To account for other reasons that women change their breastfeeding status, we included three transition rates in the model, i.e. transition from exclusive breastfeeding to partial breastfeeding ($P_{EBF \rightarrow PBF}$), transition from exclusive breastfeeding to formula feeding ($P_{EBF \rightarrow NBF}$), and transition from partial breastfeeding to formula feeding ($P_{PBF \rightarrow NBF}$). The transition rates in the first month are higher than those in the following months. The estimated transition rates are derived from a study by Jiang et al [11] and we calibrated the values using empirical data.

Table S-4 Three breastfeeding status transition rates and assignment of the initial values

Transitions	**Monthly transition rate**
Transition from exclusive breastfeeding to partial breastfeeding	• 2^{nd} – 6^{th} month: $P_{EBF \rightarrow PBF}$ =0.069 • 1^{st} month: 4.6*$P_{EBF \rightarrow PBF}$ =4.6*0.069=0.32
Transition from exclusive breastfeeding to formula feeding	• 2^{nd} – 6^{th} month: $P_{EBF \rightarrow PBF}$=0.018 • 1^{st} month: 2.4*$P_{EBF \rightarrow PBF}$ =2.4*0.018=0.04
Transition from partial breastfeeding to formula feeding	• 2^{nd} – 6^{th} month: $P_{PBF \rightarrow NBF}$=0.113 • 1^{st} month: 3.4*$P_{PBF \rightarrow NBF}$ =3.4*0.113=0.38

4. Outcomes at the population level

The aggregated outcomes at the population level, measured as the prevalence of breastfeeding intention, the incidence of breastfeeding initiation, and the prevalence of any breastfeeding and exclusive breastfeeding at 1 month, 3 month and 6 months postpartum, were compared with the observed outcomes from the 2014 WIC survey data to validate the model.

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