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Fostering health related behavioral change during pregnancy: a diffusionist approach

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Abstract
Inducing behavior change in public health aims to modify individual habits to prevent disease and promote well-being. Pregnancy is a critical period where the health of both mother and fetus are closely linked, making it essential to adopt behaviors such as taking folic acid and receiving recommended vaccinations. Drawing on the diffusion of innovation theory, these behavior changes can be viewed as "innovations", influenced by both individual and social factors.

This study applies the Bass diffusion model to analyze and guide social marketing strategies in healthcare, using a real-world dataset to assess its effectiveness. The findings highlight the importance of combining institutional communication with peer-to-peer interactions to encourage healthy maternal behaviors. This approach suggests that social factors and interpersonal networks play a crucial role in promoting behavior change, supporting the development of more effective public health policies.

Keywords Bass Model · Behavioural change · Diffusion of innovation · Pregnancy · Social marketing

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1 Literature review

A change in behavior represents a shift from the individual's habitual pattern of action toward a novel kind of practice or thinking. The mechanisms and the pace according to which new behaviors (also called "innovations," meaning that they represent a new course of action in the individual's usual conduct) spread across a community of individuals has long been studied in the light of the diffusion of innovations theory (Orlando et al. 2013; Rogers 1962; Strang and Meyer 1993). At its core, the diffusion of innovations theory posits that several key factors influence the adoption of new ideas or behaviors. These factors include the characteristics of the innovation itself, the communication channels through which it is disseminated, the social networks and interpersonal relationships of individuals, and the perceived benefits and barriers associated with adopting the innovation. The ground idea of diffusionism is that the interplay of social influence mechanisms, such as communication campaigns, interpersonal information exchange, social norms, and emulative processes, shapes individual conduct and, eventually, the macro-level dynamics.

According to Rogers (1983), individuals' characteristics play a role in the speed of adoption. Adopters can be categorized into five groups, represented by a bell-shaped curve (Fig. 1). The first group, "innovators," comprises the initial 2.5% of individuals who courageously embrace innovation and are considered pioneers. The "early adopters," making up the next 13.5%, are stakeholders in the social system who lead others toward change. They seek information and guidance from innovators, and their acceptance serves as an endorsement. The "early majority," falling between one standard deviation and the median on the curve, exhibit higher interest in new ideas but adopt them after witnessing others' successful experiences. They rely on personal communication channels and learn from close associates. The early majority is more risk-averse than early adopters, taking more time to evaluate before adopting the innovation. The "late majority" embraces the innovation after the left half of the population on the curve. They are often more conservative and cautious, even though the majority has accepted the innovation. Limited resources or inadequate information lead to delays in adoption due to uncertainty and caution. The final group, known as "laggards," consists of conservatives or vulnerable individuals with limited resources, inadequate information, unstable incomes, or social isolation. They lag behind due to neglect from the social system (Lien and Jiang 2017).

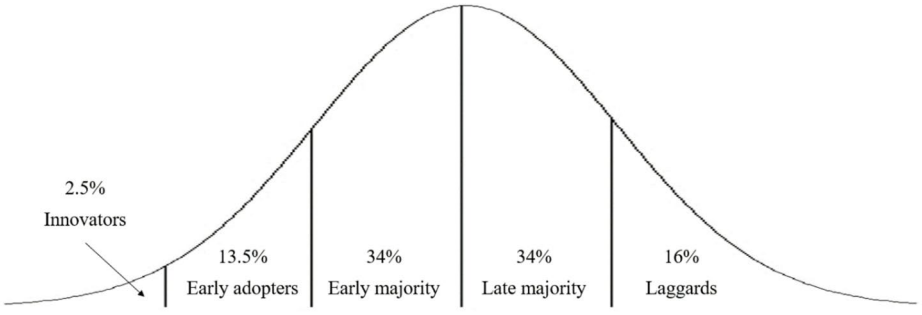

Fig. 1 Adopters categorization on the basis of innovativeness. Source: authors' elaboration based on Rogers (1983).

When applied to public health policies, diffusionism provides a framework for designing effective strategies to promote the adoption of health-related innovations and behaviors among individuals and communities (Balas and Chapman 2018). By understanding the different stages of the adoption process, public health practitioners can tailor their messaging and interventions to target specific segments of the population. For example, early adopters and opinion leaders can be engaged to promote the adoption of healthy behaviors and serve as role models within their social networks (Orlando et al. 2018). This approach leverages the influence and credibility of influential individuals to accelerate the diffusion of health-related innovations, as happened in Haiti, where a United States Agency for International Development (USAID) initiative utilized village voodoo practitioners, who are highly trusted by Haitian villagers, to promote HIV prevention education in rural areas. The involvement of these practitioners resulted in a significant increase in meeting attendance, surpassing campaign objectives by 124% (Barker 2004).

The diffusion of innovations theory helps identify potential barriers and facilitators to the adoption of health-related behaviors or interventions. Furthermore, it emphasizes the role of interpersonal communication and social networks in driving the adoption process. Public health policies can leverage social networks to disseminate health-related information, encourage behavior change, and create social norms that support healthy behaviors. By identifying influential individuals or groups within a community (Orlando et al. 2018), policymakers can design interventions that tap into existing social connections and utilize peer influence to spread health-related innovations. In Mali, for instance, a study conducted in 1999 focused on information-seeking behavior and the perception of source credibility among 500 Malian youth regarding reproductive health. The study found that youths primarily relied on friends and siblings as their trusted sources of information, resulting in a lack of accurate knowledge. Health agents and teachers, who were considered credible sources, were not perceived as easily accessible or trustworthy by the youths (Barker 2004). In Nepal, where vitamin A deficiency contributes to high rates of infant and maternal mortality, the diffusion of kitchen gardens among households was implemented. This approach relied on neighbor social modeling to encourage households to adopt vegetable and fruit gardening practices. The diffusion of kitchen gardens led to improved knowledge, positive attitudes, increased vegetable and fruit production and consumption, and positive changes in vitamin A nutrition (Barker 2004). In South Africa, since 2009, the national mass media and community mobilization campaign Brothers for Life (BFL) targets men over the age of 30 to promote HIV testing, voluntary medical male circumcision (VMMC), male involvement in the prevention of mother-to-child transmission of HIV (PMTCT) and prevention of gender-based violence. Through storytelling and thanks to the participation of local celebrities, BFL connected other men to the experiences of their peers and encouraged them to decide to proceed with the procedure (https://genderjustice.org.za).

Moreover, diffusionism helps identify and target different segments of the population based on their propensity to adopt new behaviors or interventions. Innovators and early adopters are more likely to embrace new health-related ideas, while the majority of the population may require additional incentives or support to adopt such behaviors. By understanding these segments, public health policies can develop tailored strategies to address each group's specific needs and characteristics, thereby optimizing the diffusion process. Hence, as stated by Lien and Jiang 2017; it is crucial to acknowledge the barriers that hinder the adoption process. For instance, despite the evidence highlighting the significant

impact of healthy habits and improved environmental conditions on health, certain patients (whom Rogers termed "laggards") persist in maintaining their unhealthy habits instead of embracing recommended lifestyle modifications. This resistance to change represents a barrier in the adoption process. Since laggards usually inhabit problematic social and economic environments, hindering the adoption of healthy behaviors (Lien and Jiang 2017), they are particularly exposed to the risk of developing diseases or worsening their general well-being. Therefore, the identification of the different adopters' categories should not disregard the assessment of the socioeconomic contexts and the normative beliefs where they are embedded.

Lastly, the diffusion of innovations theory also emphasizes the importance of monitoring and assessing the effectiveness of public health policies and interventions. By measuring the rate and extent of adoption, policymakers can gauge the success of their initiatives and make necessary adjustments to enhance diffusion. This iterative process of monitoring and evaluation helps refine strategies and improve the impact of public health policies over time.

Overall, applying the diffusionist paradigm to promote healthy behaviors allows to identify and influence the social factors determining the health conditions of individuals. Indeed, according to social epidemiology, health conditions are viewed as the result of the complex interplay between social, individual, and biological factors (Honjo 2004). As stated by Emmons (2000), health behaviors in society are not randomly distributed but exhibit social patterns, which means that the social context, intended as the social network each individual is embedded, plays a significant role in shaping health behaviors.

Based on these premises, this study aims to offer public health providers a comprehensive theoretical framework (i.e., the diffusion of innovation theory) and viable methodology (i.e., the Bass diffusion model) which, following social epidemiology, take into account the social factors that influence the adoption of healthy behaviors during pregnancy. This framework and methodology can be valuable for planning effective social marketing campaigns targeting pregnant women.

1.1 The role of social marketing in shaping health behavior during pregnancy

In recent years, there has been a significant surge in interest, research, and implementation of social marketing strategies by policymakers, professionals, and healthcare operators worldwide. As defined by Kotler and Zaltman (1971), social marketing involves designing, implementing, and controlling programs aimed at influencing the acceptability of social ideas, encompassing elements such as product planning, pricing, communication, distribution, and marketing research.

While early attempts to define and justify social marketing have faced criticism from Andreasen (1994), who argues that they caused confusion, a more comprehensive definition emerges. Andreasen proposes that social marketing involves adapting commercial marketing technologies to programs designed to influence the voluntary behavior of target audiences, with the ultimate goal of improving personal welfare and that of society as a whole.

Social marketing interventions have proven successful in numerous areas (Firestone et al. 2017), such as improving diet, incentivizing vaccination, increasing physical activities, and addressing substance abuse issues like alcohol, tobacco, and illicit drugs (Bussolo et al. 2023; Gordon et al. 2006; Piper et al. 2021a, b; Price 2001; de Walque et al. 2022). It is increasingly recognized that individual actions play a crucial role in preventing various

health problems, including obesity, heart disease, cancer, diabetes, accidents, smoking, and drug addiction. To ensure the success of national health programs or projects, it is essential to raise awareness among individuals about their own health issues and the implications of their actions. Simply providing healthcare services without proper utilization and engagement signifies a program's failure (Formoso et al. 2007). Therefore, social marketing is crucial in motivating individuals toward health-promoting behaviors and encouraging their active participation in healthcare programs (Radha 2011).

Within the healthcare industry, social marketing has been instrumental in analyzing barriers to the dissemination of clinical guidelines. For instance, Morris and Clarkson (2009) conducted a case study on the implementation of an antibiotic guideline, which aimed to reduce ineffective prescriptions in primary care.

One specific target audience that social marketing has focused on is pregnant women. Of all periods of life, pregnancy is the one when both the health of the mother and the developing fetus are at stake, and addressing the social determinants of health becomes particularly important (Procter and Campbell 2014). Social factors such as family embeddedness, social contacts, and social support systems can significantly impact a woman's ability to adopt and maintain healthy behaviors during pregnancy (Bottorff et al. 2006; Nguyen et al. 2012). Recognizing the significance of social determinants in shaping maternal health is crucial for developing effective interventions and policies that address the unique needs and challenges faced by pregnant women. By understanding the impact of social determinants of behavior during pregnancy, public health initiatives can better tailor their efforts to provide comprehensive support, resources, and interventions that empower women to adopt and maintain healthy behaviors during pregnancy. Among others, recommended health related behaviors during pregnancy include engaging in regular prenatal care, maintaining a balanced and nutritious diet (Barchitta et al. 2018a) and assuming folic acid (Barchitta et al. 2020), staying physically active within appropriate limits, avoiding harmful substances such as tobacco and alcohol (Maugeri et al. 2021), and undergo specific vaccinations (Barchitta et al. 2021).

Researchers have conducted studies on how to employ social marketing strategies to generate behavior change, promoting virtuous behavior and discouraging harmful practices during pregnancy. For example, in Iran, where an increase in unnecessary caesarean sections became a health problem, a social marketing intervention was implemented to promote normal childbirth and discourage unnecessary caesarean births (Darsareh et al. 2018). The "B Butterfly" campaign was developed using concepts and techniques from commercial marketing. It focused on encouraging women in early pregnancy to reconsider their preference for caesarean delivery and choose vaginal delivery instead. By applying social marketing techniques, the campaign aimed to influence women's decision-making processes and highlight the benefits and safety of vaginal delivery.

Similarly, social marketing was employed in Sunderland to raise awareness among pregnant women about a smoking cessation program. Through insights gathered from focus groups, barriers to smoking cessation were addressed using social marketing principles (Lowry et al. 2004). The study aimed to assess the effectiveness of a smoking cessation intervention by comparing the enrollment of women in a specialized support program with similar programs in neighboring areas. The results indicated that the recruitment of pregnant and non-pregnant smokers into the new NHS smoking cessation program in Sunderland increased during the intervention phase compared to areas where different interventions for pregnant women were implemented. The intervention was successful in generating innova-

tive ideas, shaping the development of a user-friendly service, and motivating women to seek smoking cessation support during pregnancy. The target population responded positively to the approach, and healthcare professionals found value in the role-playing exercises involving professional actors.

Positive outcomes have also been achieved through social marketing interventions to promote breastfeeding and reduce smoking during pregnancy in the Northeast of England. These interventions surpassed the targets set by government-local health authority agreements, demonstrating the effectiveness of social marketing in influencing behavior change and increasing participation in targeted programs (Lowry et al. 2009). The intervention yielded positive results as it surpassed the targets set for breastfeeding and smoking cessation. This success indicates that the social marketing approach employed in the intervention effectively influenced behavior change and increased participation in breastfeeding and smoking cessation programs among the targeted population. By implementing targeted communication campaigns, educational initiatives, and tailored interventions, the intervention successfully motivated individuals to adopt breastfeeding and seek support for quitting smoking during pregnancy. These outcomes are significant as they improve maternal and child health, considering the numerous benefits of breastfeeding and the risks associated with smoking during pregnancy.

In Richmond, Virginia, a social marketing study was conducted to address the high risk of premature birth and infant mortality among pregnant African American women associated with cigarette smoking. The study aimed to increase the utilization of quitlines, which are telephone-based smoking cessation counseling services that are often underutilized (Kennedy et al. 2013). To achieve this, a social marketing campaign called "One Tiny Reason to Quit" (OTRTQ) was launched in 2009, specifically targeting pregnant African American women in Richmond. The campaign utilized various channels and resulted in significant increases in calls during both phases compared to before and after the campaign. The results indicated significant increases in the number of calls from pregnant women during both phases of the campaign compared to the pre- and post-campaign periods, as well as the previous summer. Moreover, a higher proportion of the calls during the campaign came from African American women. These findings suggest that the campaign successfully motivated pregnant African American women to seek support through the quitline.

In several cases practical strategies, as the nudges (i.e. subtle changes to the design of the environment or the framing of information that can influence behavior), have been exploited in the context of wider health campaigns, to foster healthy conducts (Kim et al. 2018; Meeker et al., 2016). There is significant potential to use nudges in health care to improve patient outcomes and transform health care delivery (Thaler and Sunstein 2008; Vlaev et al. 2016).

Overall, social marketing has emerged as a powerful approach to address various health issues and promote behavior change among different target populations. The reviewed studies highlight the effectiveness of social marketing interventions in promoting positive health behaviors, such as normal childbirth, smoking cessation, and breastfeeding. By leveraging commercial marketing principles and techniques, social marketing campaigns have successfully influenced voluntary behavior, leading to improved personal welfare and societal well-being.

The next part of the work is structured as follows: Sect. 2 briefly describes the data exploited in the empirical application: (1) the Italian National Institue of Health *("Istu-*

tuto Superiore di Sanità" - ISS) survey waves and (2) the "*Mamma & Bambino*" cohort, a program aimed at studying the behavior and well-being of pregnant women in the city of Catania (Sicily); Sect. 3 illustrates the methodology, combining a brief introduction of the diffusion of innovation theory and the explanation of the traditional Bass diffusion model. In our thoughts, this theory, together with the Bass model, could uncover the social drivers guiding the spread of novel healthy behaviors among pregnant women in accordance with the social epidemiologic approach; Sect. 4 presents the results including, firstly, the Bass model estimation based on the ISS data, secondly, several scenario simulations based on the modulation of the Bass model and, finally, simulated scenarios applied to real-world data referring to the diffusion of folic acid among the pregnant women recruited under the "*Mamma & Bambino*" project; Sect. 5 discusses the implications of these findings in planning health campaigns aimed at fostering virtuous behavioral change among pregnant women; Sect. 6 draws the main conclusions and the last section reports the implications for the policy making.

2 Data

2.1 The Italian National institue of health ("Istututo superiore Di Sanità" - ISS) survey waves

Pregnancy is a crucial period for maternal and infant health, where various factors such as lifestyle choices (e.g., diet, smoking, physical activity, vaccinations), environmental exposures, and sociodemographic determinants all play a significant role in determining the well-being of both mother and child (Barchitta et al. 2020; Maugeri et al. 2019). Identifying genetic and epigenetic markers that can influence these relationships is vital for developing innovative public health strategies to promote health and prevent adverse outcomes.

While continuous annual series describing the instantaneous or cumulative adoption of health related behaviours during pregnancy are not available, we rely on repeated national surveillance waves and historical estimates to provide temporal anchors for estimating the Bass model. In particular, we exploited the data published by the Italian ISS for periconceptional folic acid supplementation and non-smoking prevalence during pregnancy. According to the ISS survey waves conducted in 2008–2009, 2010–2011, 2018–2019 and 2022 (ISS 2012; ISS 2019; ISS 2022), appropriate periconceptional use at 34.75% in 2008–2009, 23.45% in 2010–2011, 30.22% in 2018 and 32.10% in 2022. For smoking, the adherence to the non-smoking norm during pregnancy was 92.83% in 2010–2011 and 93.60% in 2022 (Table 1). These temporal benchmarks allow us to constrain plausible ranges of p and q, when estimating the Bass model in the first part of the empirical application.

2.2 The "Mamma & Bambino" cohort

The "Mamma & Bambino" program was recently launched in Southern Italy, in the metropolitan city of Catania (Fig. 2), to explore the impact of preconception, perinatal, and early-life exposures on maternal and infant health. In 2024, in the municipality of Catania the mean number of siblings per woman was 1.33 and the crude birth rate 7.9 per thousand inhabitants, as recorded by Istat. At the provincial level, in 2023 the mean age at first partum

Table 1 Adoptions of health related behaviours in periconceptional period (acid folic intake) and during pregnancy (adeherence to the non-smoking rule) among the respondents of the Italian ISS survey waves. Source: authors' elaboration on Italian ISS data.

Year	*N*° respondents	Acid folic intake	%
Folic acid assumption			
2008	3,531	1,227	34.75
2010	3,411	800	23.45
2018	11,765	3,555	30.22
2022	35,550	11,412	32.10
Non smoking adherence			
2010	4,953	4,598	92.83
2018	30,000	28,140	93.80
2022	35,550	33,275	93.60

Fig. 2 Geographical setting of the metropolitan city of Catania in the Italian territorial framework. Note: grey boundaries for the provincial territories (NUTS-2 Eurostat areas)

was 30.55 and the total fertility rate (TFR) equal to 1.36 (source: www.demo.istat.it) In this context, the "Mamma & Bambino" program aims to gather information through surveys and telephone interviews with pregnant women during delivery and follow-up assessments planned at 1 and 2 years after delivery.

To date, under the "*Mamma & Bambino*" project, about 1,098 mothers, who did not have pre-existing medical conditions (such as autoimmune and/or chronic diseases) or pregnancy complications (such as preeclampsia, gestational hypertension, and diabetes), were recruited (Magnano et al., 2021). The study protocol adhered to the Declaration of Helsinki and has received approval from the ethics committees of the involved institutions, namely the Ethics Committee of the "*Azienda Ospedaliero-Universitaria Policlinico-Vittorio Emanuele*" and the Ethics Committee "Catania 1" (protocol numbers: 47/2014/VE; 48/2015/EMPO; 186/2015/EMPO; 197/2016/EMPO; 213/2017/EMPO; 231/2018/EMPO; 263/2019/EMPO).

From 2014 until now, pregnant women referred to the "*Azienda Ospedaliera Universitaria Policlinico G. Rodolico-San Marco*" (Catania, Italy) have been enrolled during their

prenatal obstetric counseling, specifically between the 4th and 20th gestational weeks (with a mean of 16th week). During recruitment, trained epidemiologists administered a structured questionnaire to collect information on sociodemographic variables and the vaccination status of future mothers.

Employment status was recorded, distinguishing between employed and unemployed individuals (including students and housewives) (Barchitta et al. 2018b). Educational level was categorized as low-medium (primary school or ≤ 8 years of education) or high (high school education or greater, i.e., >8 years of education). Smoking status was classified as non-smokers (including ex-smokers) and current smokers. Body mass index (BMI) was calculated and categorized based on World Health Organization criteria from 1995. Data on type of delivery, intrauterine fetal death, congenital malformations, and plurality were also recorded at delivery. Biological samples were collected from both mothers (peripheral blood) and children (amniotic fluid and cord blood) (Barchitta et al. 2018b). Further information can also be found at the website http://www.birthcohorts.net.

Surveys and data collection programs such as the "*Mamma & Bambino*" program represent a crucial data and information source the healthcare administrators should exploit to plan awareness campaigns and to evaluate the actual effectiveness of social marketing strategies implemented to foster virtuous behaviors among women during pregnancy. On the other end, the awareness of the sociological and contextual socioeconomic dynamics influencing women's adherence to a specific campaign or medical prescriptions, basically a change in their usual behavioral pattern, should inform and shape the data collection process.

A potential limitation of this type of study concerns the possibility of self-selection bias. Participation in the survey was voluntary, which may imply that more health-conscious or socially engaged individuals were overrepresented in the sample. This selective participation could lead to systematic differences between respondents and the broader population of pregnant women living in Catania, potentially affecting the generalizability of the findings.

Exploiting the limited publicly available "Mamma & Bambino" data, we simulate the penetration of the innovative dietary behavior according to different levels of p and q, as a second step of the empirical application. Letting the internal and the external components of diffusion vary, we provide five different scenarios of adoption.

3 Methodology

3.1 The bass diffusion model to explain behavioral change

One of the most widespread mathematical models implemented so far to operationalize the diffusionist theory is the Bass diffusion model (Bass, 1969). The Bass model builds upon the foundational concepts of the diffusion of innovations theory and, in particular, takes into account the different categories of adopters identified in the diffusion of innovations theory, particularly innovators and imitators (for a detailed discussion, see Mahajan et al. 1990). It incorporates the idea that adoption is influenced by both internal predispositions (in the case of the innovators) and external social influence (as for the imitators). The original Bass model and its several extensions proposed in the last decades have found wide application in market research studies to analyze the spread of new ideas, products, and behaviors within a population. According to this model, the diffusion rate is influenced by two types

of communication: external communication, such as mass media advertising or awareness campaigns, and internal communication, which includes social influence, word of mouth, and imitation. As aforementioned, these two drivers of diffusion give rise to two categories of adopters: innovators, who are primarily influenced by external sources, and imitators, who adopt based on their interaction with previous adopters. A first-order differential equation represents the Bass model:

$$Y'(t) = \left(p + \frac{q}{m} Y(t)\right)(m - Y(t)) = p(m - Y(t)) + q\frac{Y(t)}{m}(m - Y(t)) \quad (1)$$

where the rate of adoption, $Y\prime(t)$ is proportional to the remaining susceptible population $(m - Y(t))$, namely the potential adopters of the innovation, where m represents the constant total susceptible population, i.e., the maximum number of adoptions within the life cycle or, in other terms, the carrying capacity, and $Y(t)$ represents the cumulative adoptions at time t (Fig. 3a). By rearranging the left-hand side of Eq. (1), we observe that the instantaneous adoptions, $Y\prime(t)$, are the result of the sum of the external component governed by the parameter p and the internal component modulated by q (Fig. 3b). The parameter p, known as the coefficient of innovation, represents the impact of external influence, while the parameter q, the coefficient of imitation, reflects the interpersonal influence individuals exert on each other. The external component is most active during the initial phase of the diffusion process, where the early adopters (innovators) form the initial group of adopters (Fig. 3a-b). Over time, they inform others or demonstrate (even through the sole action or showing their new status) the benefits derived from adopting the new behavior, thereby stimulating the adoption by the other category of adopters (imitators) who are influenced by interpersonal interaction mechanisms. Larger values of the coefficient of external influence p are associated with sharp exponential diffusion curves, indicating a strong influence of external factors on the diffusion of health policy innovations. Smaller values of the constant q are associated with gradual S-shaped cumulative diffusion curves over time, while higher values produce steep S-shaped curves. The traditional Bass model and its extensions (Bitonti et al. 2021; Bitonti 2022; Bunea et al. 2020; Guidolin and Mortarino 2010) have not only been applied empirically in marketing studies but also in the field of health studies. For instance, it has been used to analyze the diffusion of oral contraception

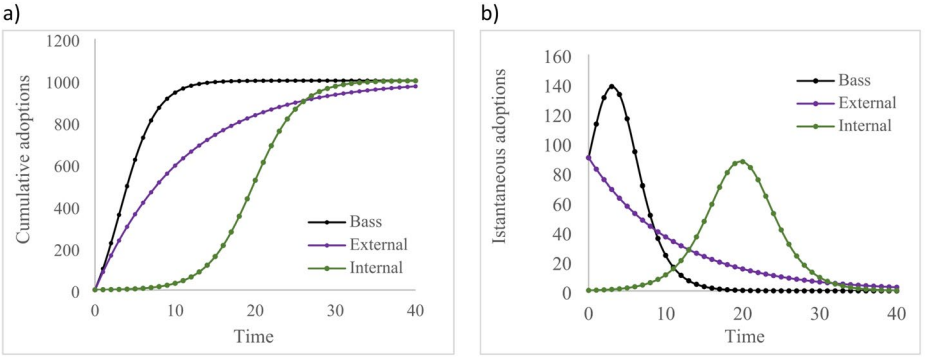

Fig. 3 Bass-type diffusion (black) compared with that of its external (purple) and internal (green) components. **a** Cumulative adoptions Y(t). **b** Instantaneous adoptions Y′(t). Source: authors' own elaboration.

(Sharif and Ramanathan 1981), understand vaccination propensity and inform public health policies (Kahana and Yamin 2021; Onofrio et al. 2012), and investigate the dissemination of disease-related information during epidemic outbreaks (Gündüç 2019).

The Bass model can be used to identify the stage of the diffusion process at which the studied innovation is located, but it can also serve as a predictive tool to inform the strategic planning of health-related campaigns, such as those targeting women during pregnancy. In particular, drawing different assumptions on the size of the total susceptible population (m) or hypothesizing several paces of diffusion by calibrating the coefficients of the Bass model (p and q) could allow the healthcare providers to evaluate future courses of action, efficiently allocate funds on awareness campaigns, and understand which driver of adoption is more convenient to leverage.

In the specific case of pregnant women, the total susceptible population could be estimated considering the historical birth rate trend registered in the catchment area of each hospital and the past levels of treatments supplied to pregnant women. On the other side, it should be noted that the specific values of p and q can vary depending on the context and characteristics of the innovation being modeled. In particular, the shapes of both cumulative and instantaneous adoption curves are determined by the values of these two parameters (Orbach 2016). Their values are typically estimated through data fitting or empirical studies specific to the industry, market, or product under consideration. However, some works exploit parameters estimated in one market in another (Massiani and Gohs 2015); this can relate to technologies (for instance, coefficients estimated from hybrid vehicles sale volumes are applied to forecast the market diffusion of battery electric vehicles), but also geographically, from one country to another (Jensen et al. 2014; Park et al. 2011).

Several studies have exploited the Bass model to analyze the diffusion of new items and products as electric vehicles. In contrast, few works still have fitted the model to innovative practices and behaviors in the healthcare context, as the one discussed here. Nevertheless, to settle our diffusion scenarios, we might rely on parameter estimates related to the diffusion of other public policies, which do not necessarily refer to healthcare. Boushey (2012) provided the coefficient estimates for the diffusion path of different US public policies. The work fitted the Bass model to the diffusion of mandatory motorcycle helmet legislation, the Amber Alert, charter school legislation, and restaurant smoking bans, whose coefficient estimates are reported in Table 2. Apart from the very high q value estimated for the Amber Alert, the range of the two parameters will be considered here to provide meaningful scenarios for the diffusion of health-related innovations during pregnancy.

Moreover, according to some research, which empirically explored the domain of existence for the two parameters, p and q range in the interval $[0, 1]$, with $p \ll q$, $0.01 < p < 0.1$, and $0.1 < q < 0.7$ (Orbach 2016; Srinivasan and Mason 1986).

Compared to alternatives such as logistic regression, agent-based modelling, or social network analysis, the Bass model offers parsimony and interpretability. It reduces diffusion

Table 2 Boushey's (2012) bass model estimates for different public policy innovation diffusion rates

Policy	Bass model parameters	
	p	q
Mandatory motorcycle helmet, 1967-85	0.314	0.957
Amber Alert, 1999–2006	0.000	3.012
Charter schools enabling legislation, 1991–2004	0.018	0.625
Restaurant smoking ban, 1981–2000	0.014	0.192

Source: Boushey (2012)

to two levers (p, external influence; q, imitation/social contagion) that map directly onto policy strategies: clinical reminders and reimbursement mechanisms vs. peer-support interventions. This makes it particularly well-suited to the aggregate surveillance data available.

3.2 Bass model estimation procedure

To model the temporal dynamics of the adoption of health-related behaviours, we estimated two separate Bass diffusion models for (i) the uptake of folic acid supplementation during periconceptional period and (ii) adherence to the "no smoking during pregnancy" guideline. In both cases, the model expresses the cumulative proportion of adopters $F(t)$ as a logistic function governed by an innovation parameter p and an imitation parameter q, with population size m fixed to the total number of women at risk (Table 1). For the folic acid case, annual data on the number of women adopting supplementation at four time points (2008, 2010, 2016, and 2022) were used to estimate p and q through nonlinear least squares (NLS), using the Levenberg–Marquardt algorithm and multiple random initializations ($n=10$) to reduce sensitivity to local minima. Multiple model estimations were performed using different sets of initial parameter values to account for the nonlinearity and potential multimodality of the likelihood surface. The best-fitting model was selected as the one that minimized the sum of squared errors (SSE) between the observed and model-predicted cumulative adoption values across all available time points.

In contrast, for the "no smoking" case, only two cumulative observations were available (2010 and 2022). To address the under-identification problem, we reformulated the estimation by fixing a set of values for the imitation-to-innovation ratio $r = q/p$ and, for each value of r, numerically solving for the total adoption rate $k = p + q$ that simultaneously satisfied the cumulative adoption levels in 2010 and 2022. For each multiple random initialization (n=10), the implied p and q were recovered. This approach yields a family of parameter pairs consistent with the two observed points, allowing for sensitivity analyses across different behavioural diffusion profiles. Model selection was based on a different rationale compared to the previous case, due to the limited number of observed data points and the resulting under-identification problem. Here, a family of candidate models was generated by fixing different values of the imitation-to-innovation ratio ($r = q/p$) and numerically solving for the total adoption rate ($k = p + q$) to match the observed cumulative values in 2010 and 2022. Each candidate model reproduces the empirical points exactly by construction, so the preferred model was selected by comparing the implied diffusion trajectories and choosing the scenario that provided the most plausible temporal dynamics, i.e. parameter values consistent with realistic behavioural diffusion patterns (moderate innovation, strong imitation). This two-step approach allowed us to select a representative model in each case, despite the differing data availability and identification structures.

For both models, elasticities of cumulative adoption at the last observed year with respect to p and q were computed using finite differences ($\pm 1\%$) while maintaining the baseline adoption level fixed through appropriate recalibration of the time shift. This procedure allows the relative importance of innovation and imitation effects to be assessed even under data constraints, providing insight into the mechanisms driving behavioural change over time. The estimation procedures were performed in the R computing environment (R Core Team 2025) and the scripts are available upon request to the authors. The elasticity of cumulative adoption with respect to the innovation parameter p at time $t$is defined as:

$$\epsilon_{Y,p}(t) = \frac{\partial Y(t;p,q)}{\partial p} \cdot \frac{p}{Y(t;p,q)} \tag{2}$$

Similarly, the elasticity with respect to the imitation parameter q is:

$$\epsilon_{Y,q}(t) = \frac{\partial Y(t;p,q)}{\partial q} \cdot \frac{q}{Y(t;p,q)} \approx \frac{Y(t;p,q(1+\delta)) - Y(t;p,q)}{\delta\, Y(t;p,q)} \tag{3}$$

The elasticity values provide meaningful insights into the mechanisms underlying the diffusion of health-related behaviours. A high elasticity with respect to the imitation parameter (q) indicates that the cumulative adoption curve is particularly sensitive to social contagion effects: marginal increases in q would lead to disproportionately large gains in overall adoption, suggesting that interpersonal transmission, peer reinforcement, and the progressive normalisation of behaviours are the key drivers of change. In such contexts, interventions that strengthen social influence, such as peer counselling, community engagement, or embedding behavioural recommendations within routine clinical interactions, may be particularly effective.

Conversely, a higher elasticity with respect to the innovation parameter (p) implies that the initial external stimuli, including information campaigns, clinical guidelines, or individual awareness, play a dominant role in shaping adoption trajectories. This pattern suggests that policy levers targeting early adoption and individual decision-making, such as targeted communication strategies or one-to-one counselling at critical time points, may have a greater impact.

Elasticity values approaching zero reflect a situation in which adoption is already near saturation, so that further increases in either parameter would have limited marginal effects. This is particularly relevant for mature behavioural changes, where policy efforts might need to shift from promoting initial uptake to sustaining adherence or reaching resistant subgroups.

4 Empirical results

4.1 Estimating the bass model for acid folic intake and non-smoking prevalence during pregnancy

Table 3 reports the estimated parameters of the Bass diffusion models for folic acid intake and for adherence to the "no smoking during pregnancy" norm. The results reveal marked differences in both the magnitude of the parameters and their elasticities. For folic acid, the estimated imitation parameter q is substantially higher than the innovation parameter p, with a mean q of 0.809 compared to a mean p of 0.001 (estimations run under 10 different initializiations). This parameter structure is characteristic of socially driven diffusion processes, where adoption accelerates primarily through interpersonal transmission, peer influence, and clinical reinforcement rather than spontaneous individual uptake. The elasticity values reinforce this interpretation: the cumulative adoption is over eight times more sensitive to changes in q ($\epsilon_q = 3.057$) than to changes in p ($\epsilon_p = 0.347$). This indicates that policies amplifying imitation mechanisms — such as integrating supplementation advice

Table 3 Bass model parameters estimation. Source: authors' elaboration on Italian ISS data.

parameter	mean	sd	mean elasticity	sd mean elasticity
Folic acid				
p	0.001	0.001	0.347	0.131
q	0.809	0.183	3.057	1.668
p/q	0.001		0.114	
Non-smoking prevalence				
p	0.022	0.015	0.105	0.053
q	0.236	0.038	0.455	0.094
p/q	0.093		0.231	

into routine clinical pathways or leveraging social networks — could have disproportionately large effects on adoption levels.

In contrast, the parameter estimates for non-smoking prevalence display a different profile. Both p and q are higher in absolute terms (mean $p = 0.022$; mean $q = 0.236$) than in the folic acid case, but the elasticities are an order of magnitude lower ($\epsilon_p = 0.105$; $\epsilon_q = 0.455$). This pattern is consistent with a mature diffusion process approaching saturation, where additional increases in either innovation or imitation parameters yield limited marginal effects on cumulative adoption. The relatively larger elasticity of q compared to p still suggests a residual role for social reinforcement, but overall the process appears less sensitive to parameter shifts, reflecting that most of the potential behavioural change has already occurred. This contrast illustrates how the stage of the diffusion process, but also the type of behaviour considered (i.e., smoking is strictly linked to problems of physical and psychological dependence and hence hard to eradicate), critically shapes the policy relevance of innovation vs. imitation mechanisms.

4.2 Simulated scenarios of diffusion of innovations among pregnant women of the "Mamma & Bambino" project

Considering the parameter estimates provided in the works mentioned in the "Methodology" section, we develop different diffusion scenarios (Fig. 4) by calibrating the Bass model parameters (m, p, and q) and discussing the possible implications of each case. Three different scenarios are illustrated while holding the value of a parameter at a time: the optimistic scenario (in black), with high market potential (Figs. 4a-b) or high pace of diffusion guided by the external (Figs. 4c-d) or internal (Figs. 4e-f) dynamics. It represents a successful product or behavior which presumably interests a large part of the population and spreads according to a high investment in mediatic communication and imitative processes; the prudential scenario (in light grey) presents the opposite conditions with respect to the first one, namely a slow product diffusion due to small market potential (as in the case of highly innovative products or practices), scarce commitment in communication by external sources of information, or low level of inter-human emulation (attributable e.g., to the non-visibility of the conduct or the presence of misinformation or fear to engage in the new behavior); the mild scenario (in dark grey), which represents the middle way between the previous ones.

Modulating the pace of diffusion according to different levels of the Bass model parameters is it possible to draw different considerations:

- the correct estimation of the carrying capacity (m) determines the extent of the social marketing effort needed to effectively reach the target population (see Fig. 4a-b);

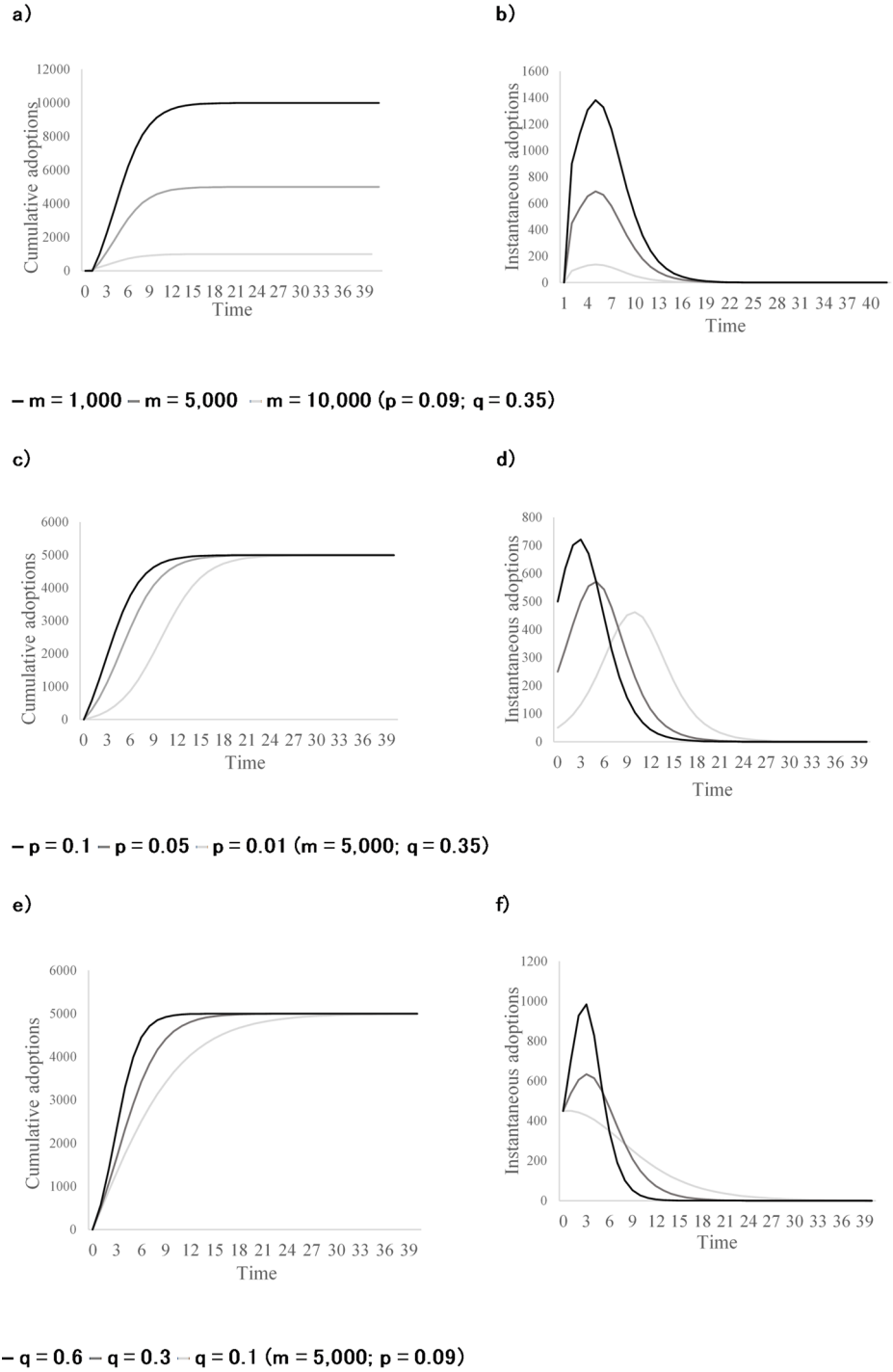

Fig. 4 Cumulative (a-c-d) and instantaneous (b-d-f) Bass adoption curves, according to different parameter calibrations. Source: authors' own elaboration.

- the social marketing campaigns, working as an external source of communication in Bass terms, can impact the level of parameter p. High levels of p can accelerate the avalanche effect by triggering the inter-human communication and hence can influence the timing of occurrence of the peak of adoption (see the maxima of the curves in Fig. 4c);
- the extent of the adoption peak is modulated by the rate (q) at which the innovation spreads according to personally mediated contacts (Fig. 4e-f). Therefore, identifying innovations whose diffusion mostly relies on inter-human communication or imitation is of utmost importance to efficiently allocate resources among planned or ongoing awareness campaigns. Health-related practices usually vary in respect of their "visibility" (e.g., vaccines are administered at the clinics guaranteeing the patient's privacy while smoking is a visible conduct to engage in). The diffusion of some recommended virtuous practices for pregnant women, for example, vaccinations, is challenged by fear, hesitancy, or misinformation. Thorough and correct information about recommended innovations during pregnancy varies based on their complexity and the perceived risk of engaging in the given conduct. In similar cases, expecting a slow and weak role of word-of-mouth and imitation in the diffusion process is reasonable. Therefore, clinicians should extensively implement innovation-tailored health programs to promote awareness and correct information via external information channels.

In the case of the "*Mamma & Bambino*" cohort, according to the study published by Barchitta et al. (2020), in 2019, the project counted 397 pregnant women, 140 (about 35,3%) out of which met the recommendation of 600 µg/day of acid folic intake during pregnancy. Hypothesizing that the total of the potential pregnant women targeted by the clinicians' recommendations about folate intake is held at $m = 1000$ (and given that 2019 represents the 5th time period since the data collection started in 2015), then it is possible to simulate the penetration of the innovative dietary behavior according to different levels of p and q. In particular, letting the internal and the external components of diffusion vary, we provide the number of instantaneous adoptions (which also informs if the diffusion is near to its forecasted peak and whether it has already been reached or has to be) for five different scenarios, exploiting Eq. 1:

1. in the "low external communication" scenario (Fig. 5a), the instantaneous adoptions reach 51 units;
2. in the "high external communication" scenario (Fig. 5b), the instantaneous adoptions count 128 units;
3. in the "low imitation" scenario (Fig. 5c), the amount of instantaneous adoptions is 89;
4. in the "high imitation" scenario (Fig. 5d), the instantaneous adoptions reach 150 individuals;
5. in the "mild" scenario, where both p and q maintain a moderate level (Fig. 5e), instantaneous adoptions are 120.

According to the simplistic (yet illustrative) cases shown in Fig. 5, word-of-mouth and imitation play a key role in determining the level of adoption of folic acid for each period. Indeed in the cases with a high level of q, the peak of adoption is supposed to verify in the near future, while the opposite occurs with low q values. In other words, the same increment of p or q entails different contributions to speed up the diffusion, with q boosting the process

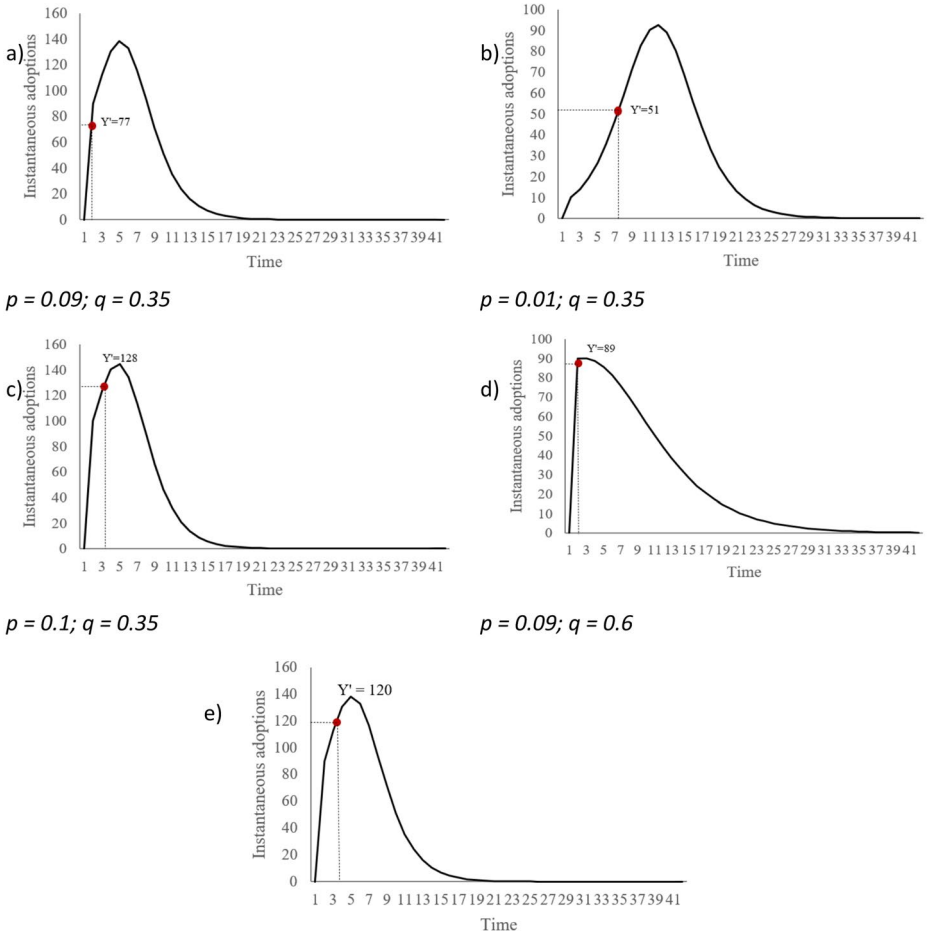

Fig. 5 Simulated scenarios based on the adoptions of folic acid among the women in the "Mamma & Bambino" cohort, as registered in 2019. Source: authors' own elaboration on data published in Barchitta et al. (2020).

much more than p. This is due to the exponential growth according to which innovation could spread *via* social contacts among individuals, in our case the pregnant women.

Therefore, choosing health marketing strategies that leverage inter-human communication is critical to ensure behavioral change towards healthy practices during pregnancy.

5 Discussion

In the first part of the analisys, the estimated Bass diffusion parameters highlight contrasting diffusion dynamics between folic acid supplementation and non-smoking behavior during pregnancy, reflecting their distinct positions along the behavioral adoption curve. The mark-

edly higher imitation coefficient (q) relative to the innovation coefficient (p) in the folic acid case underscores that this practice remains socially mediated, with adoption predominantly driven by interpersonal communication, clinical counseling, and peer reinforcement rather than by spontaneous individual decisions. This finding aligns with the theoretical expectation that preventive and less visible health behaviors, such as micronutrient intake, rely heavily on relational trust and network effects for their diffusion. Conversely, the higher absolute values but lower elasticities observed for the non-smoking behavior suggest a more mature diffusion phase, in which external interventions yield diminishing returns as the majority of women already conform to the behavioral norm. The limited responsiveness to further increases in either p or q implies that smoking cessation during pregnancy has largely stabilized, and residual pockets of resistance are likely attributable to deep-seated psychosocial or dependency-related factors rather than to communication inefficiencies. Ovrall, these results emphasize the importance of tailoring health communication strategies to the behavioral maturity stage: while social reinforcement and peer-based initiatives are crucial for accelerating the uptake of emerging preventive practices like folic acid supplementation, maintaining high compliance with well-established norms such as non-smoking requires sustained structural support and individualized interventions targeting hard-to-reach subgroups. The present analysis represents the first attempt, to the authors' knowledge, to estimate the Bass model's parameters and relative elasticities for health-related behaviours.

The simulation scenarios provided in the second part of the application enabled us to illustrate the model's main characteristics and validity in assessing the effectiveness of health programs targeting pregnant women. The application of the Bass model to the diffusion of folic acid among the pregnant women recruited under the "Mamma & Bambino" project provided a simplistic yet explicative tool to demonstrate and discuss the implementation of the model to analyze real-world dynamics. The simulation scenarios indicated that leveraging imitation and word of mouth processes, health policymakers have the potential to facilitate behavior change and improve maternal and newborn health status (Rogers 2002; Casterline 2001; Montgomery and Casterline 1996; Vitali and Billari 2017). Sociological theories such as diffusionism (Rogers 2002) and social influence propose that the adoption of new behaviors, ideas, and knowledge can be influenced by social interactions within networks like family, workplace, and peer groups (Casterline 2001; Montgomery and Casterline 1996; Vitali and Billari 2017). The underlying concept is that novel behaviors can spread throughout a population as a result of social contagion, facilitated by interpersonal communication and imitation of others. This phenomenon has been observed in various health-related behaviors such as food choices (Pachucki et al., 2011), obesity (Christakis and Fowler 2007), smoking (Christakis and Fowler 2008), alcohol consumption (Rosenquist et al. 2010), vaccinations (Konstantinou et al. 2021), improper antibiotic use (Cuevas et a., 2021), and even adherence to social distancing during the COVID-19 pandemic (Holtz et al. 2020). In the case of pregnant women, healthcare providers can foster interaction between women who engage in healthy behaviors and those who do not, for instance, through the organization of antenatal education groups. Different studies have found that emulation is particularly influential among peers or individuals who share similar life experiences (Aral and Nicolaides 2017; Fowler and Christakis 2009; Mcpherson et al. 2001).

Nevertheless, caution should be taken when working with tools like the Bass model. Massiani and Gohs (2015) state that researchers face challenges when selecting appropriate parameter values for the Bass model. Eligible parameter values exhibit significant varia-

tions, making determining the most suitable values difficult. Existing literature values are subject to discussion and show wide variability, while ad hoc estimates provide inconclusive results. One particularly concerning issue is the sensitivity of ad hoc estimates of the Bass model's p parameter to the assumed market potential, denoted as m. When different plausible values of m are considered, the estimated value of p can vary significantly. This sensitivity indicates that the choice of m substantially impacts the estimated value of p. Given these findings, it is essential to exercise caution when using the Bass model and its parameter estimates. Users should be aware of the limitations and uncertainties associated with parameter estimation in the Bass model, especially when drawing policy recommendations based on its results.

Further consolidation of research efforts in this field is needed to address these issues. Researchers should work towards establishing more standardized and reliable parameter estimation techniques. Additionally, improving confidence in ad hoc estimates could enhance the usability of the Bass model. Until such advancements occur, it is crucial to interpret the Bass model's results with caution and consider alternative approaches or additional evidence when making important policy decisions. Having considered these concerns, the work intended to provide a starting point to generate hypotheses for future research to explore more in-depth the dynamics of the adoption of healthy behaviors during pregnancy.

6 Conclusions

Building upon the social epidemiological considerations that social and biological factors influence health status, the work aimed to propose a novel way to study the diffusion of health-related practices recommended during pregnancy: those of the diffusion of innovation theory via the application of the Bass model, which stresses the presence of social drivers of behavioral change. This approach has the potential to enhance the understanding of the social factors that influence the uptake of healthy practices and may contribute to the development of more effective strategies for promoting and encouraging healthy behaviors during pregnancy. In this sense, social marketing campaigns implemented by healthcare providers can act as a successful tool to promote virtuous practices among pregnant women.

Pregnancy is a crucial moment in the life of future mothers, impacting the well-being of both women and their offspring. Clinicians recommend several healthy behaviors during pregnancy, ranging from vaccinations to dietary habits and smoking cessation (Athearn et al. 2004; Heering et al., 2010; Morales et al. 2020; Schneider et al. 2010). Data collection and targeted surveys, such as the "*Mamma & Bambino*" project implemented in selected healthcare facilities in Catania (Sicily), represent a valid operative practice an effective social marketing strategy should rely on. Similar procedures allow clinicians to get information on the status of pregnant women in real-time and serve as the basis for planning future communication strategies and evaluating the performances of those already established. Nevertheless, understanding the diffusion mechanisms underlying the spread of pregnancy-related practices, as highlighted by the diffusion of innovation theory, should guide healthcare providers' data collection and analysis process. For instance, to adequately fit a Bass model to evaluate and predict the diffusion of flu vaccines during pregnancy, data collectors should register the date of vaccination rather than the sole vaccination status. Overall, proper data collection, knowledge of the social and contextual influences on adoption, and

implementation of ad-hoc methods of analysis play a key role in planning effective social marketing campaigns.

6.1 Policy implications

The empirical estimation and simulation exercises jointly underscore the value of diffusion-based modelling as a decision-support tool for public health planning during pregnancy.

The estimation results for folic acid and non-smoking behaviors reveal that health practices differ markedly in their diffusion maturity, requiring distinct policy approaches. For emerging or socially mediated behaviors such as folic acid supplementation, characterized by low innovation and high imitation parameters, policy actions should strengthen interpersonal and community-level channels that facilitate social learning and information exchange. This includes embedding supplementation counselling within prenatal care routines, promoting peer-support networks among expectant mothers, and engaging healthcare providers as trusted intermediaries in message transmission. Conversely, for consolidated behaviors like non-smoking during pregnancy – where adoption levels are close to saturation and elasticity to innovation or imitation is minimal – resources should target residual inequality and resistance through individualized counselling, addiction support, and context-specific interventions rather than broad awareness campaigns.

Overall, the Bass framework concerns the timing and mechanisms through which behavioural change can be stimulated. By locating each behaviour along its diffusion trajectory, the model allows policymakers to distinguish between practices that remain in an early phase—close to the point at which adoption accelerates most rapidly—and those that have already entered a mature stage characterised by slower growth. This distinction is relevant because interventions launched near the inflection point of the adoption curve are theoretically more capable of producing perceptible shifts in uptake. Moreover, the relative weight of the innovation parameter (p) and the imitation parameter (q) provides additional interpretative insight: behaviours primarily driven by external influence respond more strongly to structured institutional communication, clinical guidance, and media campaigns, whereas behaviours governed by imitation rely on interpersonal networks, peer dynamics, and the progressive internalisation of social norms. In this sense, the finding that folic acid intake is still at an early diffusion stage and more strongly shaped by external stimuli, while non-smoking during pregnancy appears more mature and socially reinforced, highlights the need to adjust the balance between informational efforts and socially mediated strategies depending on the behavioural domain. It is worth to be noted that these considerations should not be interpreted as operational recommendations, but rather as conceptual cues illustrating how diffusion-based modelling can support more nuanced reflection on the timing, relevance, and nature of policy levers.

The simulated scenarios for the *"Mamma & Bambino"* cohort further demonstrate how varying the parameters of external communication (p) and social imitation (q) can meaningfully alter the pace and magnitude of behavioral uptake. Policies that enhance the perceived visibility and social desirability of recommended behaviors can accelerate adoption by amplifying imitation effects, while well-designed media and institutional campaigns can serve as initial triggers for diffusion. These results suggest that effective maternal health strategies should operate on a continuum: initiating behavioral change through targeted external communication and sustaining it through network-based reinforcement and social

contagion mechanisms. More broadly, integrating Bass-type diffusion modelling into maternal health policy design could enable ex-ante evaluation of campaign effectiveness, allowing decision-makers to optimize timing, intensity, and audience segmentation in social marketing initiatives aimed at improving pregnancy outcomes.

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Data availability All data generated or analysed during this study are included in this published article.

Declarations

Conflict of interest The authors have no competing interests to declare that are relevant to the content of this article.

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