Measuring the progress of the timeliness childhood immunization compliance in Vietnam between 2006-2014: A decomposition analysis

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Abstract

Vietnam launched the national Expanded Program on Immunization in 1981. Since then, this program has contributed significantly to the improvement of child health and to the reduction of child mortality rate. Despite of the fact that the coverage of the national EPI keeps expanding, the number of children who complied with the recommended immunization schedule remains low. This article studies the progress of the timeliness childhood immunization compliance among children between 0-5 years of age in Vietnam from 2006 to 2014 and analyzes the socio-economic factors that account for the changes of the compliance rate during this period. The dataset is extracted from the Multiple Indicator Cluster Survey in 2006 and 2014. We first identify the socio-economic factors that impact on the vaccination compliance rate using a logistic regression model. Next, we apply the decomposition method to determine the contribution of each factor on the evolution of the timeliness childhood immunization compliance. The progress of the timeliness childhood immunization has been positive and the major contribution comes from the structure effect (unmeasured effect). Rural areas show a stronger improvement as of 2014. Among the socio-economic factors, mother education and birth order are the ones that have the larger influence on the childhood immunization compliance rate. However, these factors have different implications in urban and rural areas. These findings are critical to the current context of Vietnam where the government is designing a strategy focusing on the effectiveness rather than the traditional coverage indicator.

Keywords: Vaccination, timeliness childhood immunization compliance, decomposition, logistic model, MICS data, Vietnam.

1 Introduction

Immunization is one of the most powerful and cost-effective of all health interventions (Maurice and Davey, 2009). The World Health Organization (WHO) estimated that every year, immunization averts two to three millions deaths. This attainment can be achieved with a very lucrative investment: every $1 invested in immunization will bring a return of $16 (WHO, 2016). Immunization, together with other health interventions, is an effective tool to reduce the mortality rate. According to UNICEF, 17% of deaths of children under five are vaccine-preventable. Not only having the power to save children's life, immunization gives them an opportunity to thrive and reach their full potentials. The Expanded Programme on Immunization (EPI) was introduced by the WHO in 1974. As of 2010, WHO estimated that 85% of children under one year of age have received Diphtheria, Tetanus, and Pertussis Vaccine (DTP) doses (WHO, 2013).

Vietnam started the national EPI in 1981. The Vietnam national EPI program has been a great achievement of the Vietnam health sector. The high rate of immunization coverage largely contributed to the achievement of Millennium Development Goal 4: Reduce Child Mortality Rate and Goal 5: Improve Maternal Health (Vietnam, 2015) and remains a powerful tool in reaching the Sustainable Development Goals by 2030. Statistics by National Institute of Hygiene and Epidemiology (NIHE) showed that over 90% of children under five in Vietnam have benefited from EPI from 1993 to 2011, which helped reducing infant mortality remarkably in Vietnam.

The achievement of the ultimate goal of the EPI program in Vietnam remains challenging with constant issues and new emerging problems. Vietnam government has been struggling to maintain the high immunization coverage (especially in hard to reach areas), protect the elimination status of the polio and maternal and neonatal tetanus while at the same time introducing and expanding new and underutilized vaccines (Hib, typhoid, JE vaccines). However, the recent Adverse Events Following Immunizations (AEFI) which occurred have raised concerns on the parent's confidence to vaccinate their children. The lack of transparent, accurate and reliable source of information on the adverse events brought down the trust of parents on the domestic-production vaccines. Their preference then turned to imported vaccines, which have unstable sources of supply resulting in delayed immunization. The expansion of private services has helped boosting the coverage and reducing the burden on the public sector. However, these private services bring along the worries on vaccine management and cold chain as well as their response capacity to AEFI cases.

Despite the great success of the national EPI program, Vietnam has recorded an outbreak of several vaccine-preventable diseases. While measles was projected to be eliminated in 2010, several outbreaks of this disease were recorded in different years. Between October 2008 and January 2010, a total of 7,948 measles cases has been confirmed in 60 out of 63 provinces nationwide. A group of epidemiologists studied these outbreaks and found that the change in routine schedule may influence the elimination plan. Sniadack et al. (2011) figured out that the measles catch-up supplementary immunization activity (SIA), which was introduced by the Vietnamese government in 2002-2003, protected the target age group (children 9 months-10 years of age). However, this strategy failed to follow up the group of persons up to 20 years of age at subnational level in selected provinces during 2007–2008. This failure resulted in the infection initiated amongst the young adults and then transmitted to the small children" (Sniadack et al., 2011). An et al. (2016) offered a new perspective where they used the **timely immunization completion** as an indicator to study the measles outbreak in 2013. They found that the proportion of under-5 children that completed the recommended vaccination schedule was low, especially for the HBV dose 2 and dose 3. The completion is less likely among groups that are disadvantaged in terms of lower household wealth, ethnic minority, hard-to-reach areas, poor education and scarce service availability. The study came up with a recommendation to include the timely immunization completion as an indicator to monitor the national EPI program.

This paper studies the timely immunization completion. The definition of timely immunization corresponds to the case of a child receiving a specific vaccination dose at a time point within the schedule recommended by the WHO. This is important as any delay may potentially lead to serious health consequences (Guerra, 2007). A child can miss the best opportunity in his lifetime to receive protection against the life-threatening diseases with just one injection. Despite the great benefit that timely immunization may bring, the compliance rate is very low in both developed countries and developing countries. In the USA, approximately 26% of children, aged 24 to 35 months from the 2012 National Immunization Survey (NIS), received all doses of six recommended vaccines on time (Kurosky et al., 2016). In the African Region, the median percentages of invalid diphtheria, tetanus, pertussis (DTP1, DTP3) and measles-containing vaccine (MCV) across all countries were 12.1%, 5.7% and 15.5%, respectively (Akmatov et al., 2015). In Vietnam, the compliance to the recommended schedule is relatively high for measles dose 1 vaccines and quite low for hepatitis B dose 1 (An et al., 2016).

This paper expands the study on the timely immunization completion considering the impacts of socio-economic factors as initiated by An et al. (2016) and using a recent data source. We measure these impacts at the micro level and we focus on children, mothers and households in year 2006 and year 2014 separately. These microlevel factors would contribute potentially to children's health WHO (2015), Racine and Joyce (2007). We use a decomposition technique adapted to the logistic regression model. Our contribution to the existing literature on the immunization in Vietnam is the application of this decomposition technique to immunization compliance in order to detect the socio-economic factors that influence this indicator.

We structure the rest of our paper as follows: section 2 shows summary statistics of timely immunization completion among children in Vietnam from 2006 to 2014, using the MICS dataset. Our results and discussion are in section 3. We conclude our research with discussion and policy recommendations.

2 Timely immunization completion among children in Vietnam from 2006 to 2014

2.1 Data

The Multiple Indicator Cluster Survey (MICS) is a survey program at household level to monitor human development with a focus on the situation of women and children. It was first introduced in the mid-90s and has been implemented in over 100 countries. In Vietnam, the UNICEF country office supported the Vietnam General Statistics Office to conduct five rounds of MICS in 1995, 2000, 2006 and 2014. The survey sampled from selected enumeration areas in the Viet Nam Population and Housing Census, using a multi-stage, stratified cluster random sampling approach in the selection of households. The MICS covers a broad range of data on households, women at reproductive age and children-under-5 on various topics including household information, child mortality, child protection, child health, reproductive health, water and sanitation, literacy and education, HIV/AIDS and access to mass media/ICT.

Our dataset is extracted from MICS 2006 and MICS 2014. Our aim is to analyze the progress in the immunization operations in Vietnam in recent years. During this period, the National Health Master Plan (2005 - 2010) has been a springboard to uplift the immunization achievement through which the government allocated resources for the national EPI activities along with the support from the international organization like UNICEF, GAVI (UNICEF, 2009)[1].

The first five outcome variables are the completion rate of five childhood recommended vaccines. These include the BCG (Bacillus Calmette - Guerin), the Hep B (Hepatitis B), the DPT (Diphtheria - Tetanus - Pertussis), the Polio and the MCV (Measles-containing vaccine) vaccines. The sixth outcome variable is the rate of children who completed all the recommended vaccines doses aforementioned. The timely immunization completion of a specific vaccine is a situation where a child

[1]This data set has two different records on weight (factor scores) which correspond to children or women (the mother). In this study, our calculations use the children weights.

receives all the doses as per WHO's recommendation. Table 1 below summarizes the milestones for immunization schedule for children under 1 year old.

First, we perform a descriptive analysis of the timely vaccine completion rate in Vietnam. We only consider the children if they have the immunization card with specific immunization date.[2]. This group accounts for a small fraction of the total sample each year. There is a total of 2680 and 3312 children that completed their immunization schedule in 2006 and 2014 respectively.[3]

We explore **the immunization status of children who have an immunization card but do not have have vaccination information**, for which it is difficult to identify their immunization status - **the "unsure group"**. Statistics show that there is a significant increase in the number of children in urban areas falling into this group with a jump as high as 20% between the two years. The distribution of this group also experienced a huge change in terms of the mother's education. In 2006, the children whose mother completed primary education account for 60.47% whereas this number shifts to 24.97% in 2014. The children whose mother have higher education in this group increases considerably as shown in Table 2.

From table 2 we can see that the fact that a child lives in a rural or urban area affects his status of vaccination compliance. Thus, our analysis will break into two streams of those who live in urban areas and those in rural areas. We will then compare and contrast the results of these two streams to extract the potential socio-economic factors that impact the vaccination compliance rate.

2.2 The vaccination compliance status in urban and rural areas

Figure 1 shows the timely immunization completion of all specific doses and vaccines in 2006 and 2014 in urban and rural sites. We can see an increase between 2006 and 2014 in the number of children who comply with the standard immunization schedule in both urban and rural areas. However, the

[2]MICS data recorded the information from the children's immunization (health) card.

[3]Although MICS's questionnaires involved the vaccines sources, from EPI program and provision of immunization services through hospitals and the private sector, there is no availability of a homogeneous system to record vaccines from EPI program and immunization services.

figure also illustrates an interesting paradox: the increase appears to be larger in rural areas than in urban areas. This fact is against the normal assumption that children who live in cities have a better access to immunization services and their parents are more knowledgeable of child care. The general upward trend is understandable due to the improvement of Vietnam economic condition in recent years with a constant GDP increase. These improvements in rural areas happened thanks to the Decision No. 255/2006/QD-TTg approving the Vietnam national strategy on preventive medicine for 2010 and orientations towards 2020. This decision requires that authorities at all levels engage in preventive medicine. It was also a strong commitment of the government to allocate financial resources from the national budget to the immunization activities.

The amplitude of the change varies across types of vaccines. While the completion of Hep B vaccine as a whole increases significantly in both areas, the breakdown records of Hep B dose 1, dose 2 and dose 3 are different. Hep B dose 1 increases by 45%, dose 2 almost stays the same and there is even a decrease in the completion of dose 3 in urban areas in 2014. The standstill of improvement in the completion of Hep B dose 2 and dose 3 in 2014 results from the death of five children after receiving the Quinvaxem vaccine (including Hep B) in 2013. Following the nine deaths and dozens of cases of severe allergic reactions among local infants due to immunization events within the first half of 2013, the Ministry of Health has suspended the use of this vaccine in the immunization program (Tuoitre, 2013). Because Vietnam consumes 4.5 million doses of Quinvaxem every year since 2010, the suspension has created a severe deficit of Hep B vaccine supply. The scarcity of alternative vaccine resulted in the incompletion of dose 2 and 3 as shown by figures.

The fact that the completion rate in urban areas in 2014 slightly decreases in comparison to what it was in 2006 can also be explained by the communication crisis following the AEFIs incidents in 2013. As the investigations and conclusions on the AEFIs was taking time, the information on the accidents were spreading out widely through informal channels. The delay in response and lack of consistency, transparency, accuracy from the responsible body has reduced the confidence of the parents to the immunization program and hold back their decision to have their children vaccinated. Those parents living in urban areas with more access to communication technology were more influenced than those living in rural areas. This not only explains the decrease in the decline in Hep B dose 3 in urban areas but also more generally the lower completion rate in all vaccine types in urban areas. This also helps explaining the paradox mentioned earlier. Furthermore, the reduced trust in the national EPI's provided vaccines has oriented the parents to the choice of alternatives provided by private services - offering a wider range of equivalent imported prestigious brand vaccines. These services are not recorded in the immunization book but in a separated flyer instead. This explains the children in the "unsure group" which will not be included in the sample. Table 3 shows statistic of independent variables for each specific vaccine in urban and rural sites for the two years.

3 Analytical strategy: decomposition methods

Denote by $T_V^{t,U}$ (resp: $T_V^{t,R}$) the timely immunization rate for vaccines indicated by the letter V standing for BCG, Polio, DPT, Hep B, or MCV in year t, $t = 2006$ or $t = 2014$ and in an urban site (resp: rural). Denote by Y_i the binary variable for each child i which is $= 1$ if the child satisfies timely immunization of vaccine V and $= 0$ otherwise. We first fit a logistic regression model of timely immunization completion for each vaccine and each year to capture the potential impact of these covariates:

$$logit(P\widehat{[Y_i^t = 1]}) = \alpha_0 + \alpha_1 Cage + \alpha_2 Cgender + \alpha_3 Urban + \alpha_4 Ethnic + \tag{1}$$

$$\alpha_5 Wealth + \alpha_6 Education + \alpha_7 Region + \alpha_8 Hsize + \alpha_9 Csize \tag{2}$$

Model (1) replicates the methodology applied by Thang et al. (2007) to capture the immunization inequalities among children in Vietnam. A logistic model overcomes the shortfall of the same study by An et al. (2016) where they used the multilevel analysis regression while MICS data design was not intended for such purpose. Based on the logit regression model (1), we apply the logit decomposition that was introduced by Fairlie (2005). The advantage of this method is that we can measure the portion of each relative contributing factor to a difference in outcome (the probability of timely vaccine completion) between two groups or dates. The result is achieved by separating two different effects: (1) **the composition effect** extracted from the difference in observable covariates across groups (years) and **the structure effect** extracted from the differences in the relationship that links the covariates to the outcome. These terminologies have been used by Devkota and Butler (2016) in caste-ethnic disparity in vaccine use among 0-to 5-year-old children in Nepal. This method has recently been widely used in the health sector, let us quote: inequality in HIV (Helleringer, 2017), determinants of Under-Five Mortality inequality (Bado, 2016), immunization (Devkota and Butler, 2016), diet pattern (Trinh and Michel, 2017), adolescent mental health (Anderson, 2018). In addition to the aforementioned effects, we will push further the decomposition of the composition effect by detailing the contribution of each specific characteristic as in (Rothe, 2015).

For each vaccine V, and each type of area (urban or rural), we decompose the improvement of the timeliness childhood immunization compliance between the two years 2006 and 2014 by applying a logistic decomposition (see Appendix section), i.e we decompose the difference

$$\bar{T}_V^{2014,U} - \bar{T}_V^{2006,U} \tag{3}$$

The same analysis is applied for each vaccine in the rural areas. We summarize the key results of the final logistic decomposition of the timely immunization completion in 2006 and 2014 in Table 4. In this table, we present the results for urban areas and rural areas separately. For each type of area, we first show the result for **the total effect**, **structure effect** and **composition effect** for each vaccine, followed by **the contribution breakdown of each specific characteristic to the total disparity**. As shown in Table 4, the total effects of all vaccines in both areas are positive which indicates that the number of children that comply with the immunization schedule increases from 2006 to 2014. The structure effect accounts for the majority of this change. The net change in the rural areas is higher than in the urban areas, which is in line with our earlier result (see, Figure 1). The highest change in the percentage of completion rate is Hep B (35%) in urban areas and MCV (36%) in rural areas. There is a big difference in the completion rate of MCV vaccine between the two types of areas. While urban areas experience only 4.5% increase with a negative contribution of the structure effect (-4.02%), the corresponding figure in rural areas is 36.07% driven by the significant high structure effect of 39.58%. The measure of the contribution of each specific characteristic to the disparity shows that birth order has a positive impact on the compliance rate in both urban and rural areas. Its effect on HepB vaccine is stronger in urban areas than in rural areas, while its effect on BCG and MCV vaccine in rural areas are much higher than in urban areas.

In rural areas, the mother education level presents the most influential and positive impact for all type of vaccines. Table 3 shows a significant increase in the highest level of education in rural sites (less than Primary level) and an increase in the number of mother that completed upper secondary school (multiplied by four). The shift in the distribution of education level of mothers leads to a positive impact on the improvement of immunization compliance rate among children. In urban sites, although there is a redistribution between mother education categories, this change does not result in a consistent impact across vaccines.

4 Conclusion and Discussion

The Vietnam national EPI program in Vietnam has attained significant achievements since its commencement in 1981. As per records from the World Bank, the under-5 mortality rate per 1000 lives in Vietnam has been reduced from 66 in 1981 to 22 as of 2016. Vietnam achieved the elimination status of polio in 2000 and maternal and neonatal tetanus in 2005 and this status has remained until today. The control over measles has been progressive where only 217 measles cases were recorded in 2004 in comparison to 86,901 in 1980 (UNICEF, 2009). However, the outbreak of several vaccine preventable diseases has slowed down the momentum of the EPI program and imposed a threat on the return of some controlled diseases. The EPI program has been using the coverage percentage as a key indicator to measure the progress of the national vaccination status. This reflects an incomplete picture as it misses out the effectiveness of the immunization. The vaccination is most effective if a child complies with the recommended immunization schedule. Our study shows that there is an increase of timely childhood immunization rate in Vietnam from 2006 to 2014 in both rural and urban areas. The change of this difference in the rural areas is considerably higher than in urban areas. This paradox can be explained by the shift in the behavior of the parents in urban sites where they favor the service-based vaccination over the EPI program. It is widely believed amongst parents that that these services provide imported vaccines of higher quality than the traditional ones under the coverage of EPI and under the pressure of AEFI occurrence in recent years. The fast pace of the growing needs exceeds the supply of these services and results in the out-stock of vaccines. This leads to the delay in complying with the recommended schedule. In another note, in rural areas, most children enroll the program-based services offered freely by commune health centers (CHCs).

Our further analysis based on the decomposition method adapted to the logistic regression reveals that the unmeasured effect (results from the differences in coefficients across models) is the driving force of the change. As shown in table 3, the two most important socio-economic factors are the mother education and birth order. As a norm in Vietnam, the mother is the primary caregiver and takes the lead in child immunization decision. Thus, the perception of the mother about immunization (which is proxied by her education attainment) impacts her child's immunization schedule. However, we note the parabola-effect of the mother education where it has reverse effect if the mother is overloaded with information, especially misleading sources. In the urban areas, the mothers have diverse possibly contradictory information sources and make their own choice based on their own risk parameter.

The birth order of a child matters. The second child of the family complies better with the recommended schedule. This can be explained by the better knowledge of immunization that the mother experiences from her first child. These results are similar in Nairobi-Kenya, a lower-middle income country as Vietnam, where the 2nd-3rd child receives a better immunization (Egondi et al., 2015).

A focus on the timeliness childhood immunization could be an effective strategy to enhance the effectiveness of the immunization program. In a recent movement, the Vietnamese government issued Circular 38/2017/TT-BYT which regulates the enforcement of childhood vaccination of 10 diseases. This circular also mentioned about the timeline of each dose and recommended the compliance to the schedule. This research yields important findings for policy makers to design the next steps with a focus on the compliance to the recommended timeline. The target group that could drive the desired changes is the mother. By understanding the trends of behaviors of mothers in urban and rural areas, the government could design effective strategies tailored to the need of each group. The lesson learned from the immunization crisis in 2013 has been a unique opportunity to understand the impacts of communication on parents' decision. While proper and good communication boosts the compliance rate, the opposite situation demotivates the will to comply with the recommended schedule. The redistribution of the education level of mothers where the higher education category increased has positive impacts on the compliance indicator, especially in rural areas. Thus, the better the knowledge, attitude and perception on immunization are, the more effective the immunization program is - which is reflected by the increased timely childhood immunization compliance. There should be investment on the strategy of Communication for Development activities strategy at UNICEF, with specific design to the urban and rural areas, to raise the awareness amongst parents and equip them with sound knowledge on immunization/the importance of timely immunization. Finally, policymakers should improve the program-based service quality to increase the confidence of the caregivers so that they are comfortable to have their children covered by the EPI program.

Author contribution

The research is conceived and designed by Huong TRINH Thi and Thuy DO Thi Thu. Analyzed the data: Huong TRINH Thi, Christine THOMAS-AGNAN. Wrote the paper: Huong TRINH Thi and

Thuy DO Thi Thu. The paper received technical inputs and consultation from Huy NGUYEN Van and Dung NGUYEN Quang.

Conflicts of Interest

The authors declare no conflict of interest.

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Appendix: Logistic decomposition methodology

The decomposition method was first developed by (Blinder, 1973) and (Oaxaca, 1973). This method has been popular in measuring the contribution of factors that are responsible for equality in labor, capital and welfare. Below, we recall the logistic decomposition that was introduced by Fairlie (2005) which is an extension of Blinder (1973) and Oaxaca (1973) to the case with binary dependent variable.

We first study the timely immunization completion of Bacillus Calmette - Guerin (BCG) vaccine in year t as our outcome variable. We denote by Y_i the binary variable for each child which is $= 1$ if timely immunization of BCG and $= 0$ otherwise. Supposing we have two explanatory variables for each sample: the child gender and the highest level of education of the mother. We denote the two covariates by $X = (X^1, X^2)$. A logistic regression model assumes that

$$logit(P[Y_i = 1]) = log\Big(\frac{P[Y_i = 1]}{1 - P[Y_i = 1]}\Big) = \alpha_0 + \alpha_1 X_i^1 + \alpha_2 X_i^2 \tag{4}$$

Model (4) is estimated by iterative reweighted least squares. We obtain estimated coefficients in year t, from which we estimate the timely immunization completion probability

$$logit(\widehat{P[Y_i^t = 1]}) = \hat{\alpha}_0 + \hat{\alpha}_1 X_i^{1,t} + \hat{\alpha_2} X_i^{2,t} \Rightarrow \hat{Y_i^t} = logit^{-1}(\hat{\alpha}_0 + \hat{\alpha}_1 X_i^{1,t} + \hat{\alpha_2} X_i^{2,t}) \tag{5}$$

$$\widehat{P[Y_i^t = 1]} = \frac{e^{\hat{\alpha}_0 + \hat{\alpha}_1 X_i^{1,t} + \hat{\alpha_2} X_i^{2,t}}}{1 + e^{\hat{\alpha}_0 + \hat{\alpha}_1 X_i^{1,t} 1 + \hat{\alpha_2} X_i^{2,t}}}$$

Assume we have samples of timely immunization completion of BCG vaccine for two periods, year 2006 and year 2014: $(Y_i^{2006}, X^{1,2006}, X^{2,2006})$ and $(Y_i^{2014}, X^{1,2014}, X^{2,2014})$. Our question is: how does the change in the covariates distribution over the years, i.e from $X^{2006} = (X^{1,2006}, X^{2,2006})$ to $X^{2014} = (X^{1,2014}, X^{2,2014})$, contributes to the difference between the estimated timely immunization probabilities $\widehat{P[Y_i^{2014} = 1]} - \widehat{P[Y_i^{2006} = 1]}$?

The decomposition methodology can address this question. From the estimated probabilities, we can compute predicted completion indicators $\hat{Y_i^t}$ using a threshold. Then, the average values of $\hat{Y_i^t}$ in equation (5), which correspond to estimations of timely immunization rates T_V^t can be written in the year 2006 and 2014 as follows:

$$\hat{T_V}^{2006} = \sum_{i=1}^{N^{2006}} \frac{F(X_i^{2006} \hat{\alpha}_i^{2006})}{N^{2006}} \qquad \hat{T_V}^{2014} = \sum_{i=1}^{N^{2014}} \frac{F(X_i^{2014} \hat{\alpha}_i^{2014})}{N^{2014}} \tag{6}$$

where $\hat{\alpha}$ are coefficients estimated from model (4) and $F(u) = \frac{e^u}{1+e^u}$. Then, the difference of timely immunization index between the two years is

$$\hat{T_V}^{2014} - \hat{T_V}^{2006} = \sum_{i=1}^{N^{2014}} \frac{F(X_i^{2014} \hat{\alpha}^{2014})}{N^{2014}} - \sum_{i=1}^{N^{2006}} \frac{F(X_i^{2006} \hat{\alpha}^{2006})}{N^{2006}} \tag{7}$$

$$= \Big[\sum_{i=1}^{N^{2014}} \frac{F(X_i^{2014} \hat{\alpha}^{2014})}{N^{2014}} - \sum_{i=1}^{N^{2006}} \frac{F(X_i^{2006} \hat{\alpha}^{2014})}{N^{2006}}\Big] + \Big[\sum_{i=1}^{N^{2006}} \frac{F(X_i^{2006} \hat{\alpha}^{2014})}{N^{2006}} - \sum_{i=1}^{N^{2006}} \frac{F(X_i^{2006} \hat{\alpha}^{2006})}{N^{2006}}\Big] \tag{8}$$

The first term in brackets in equation (8) represents the progress of the immunization completion indicator between the two years that results from the difference in covariates X^{2006} and X^{2014}, which is called **portion due to differences in the measurable characteristics of groups** or **composition effect**. The second bracket represents the part extracted from the group difference in unmeasurable or unobserved endowments, called **portion due to differences in coefficients across**

models or **structure effect**. In more detail, for this model with two covariates, the **composition effect** explains the contribution of the change in the distribution from $X^{2006} = (X^{1,2006}, X^{2,2006})$ to $X^{2014} = (X^{1,2014})$, i.e the distribution change of the child gender and the education level of their mothers from year 2006 to year 2014.

We further explore the contribution of each covariate $X_j, j = 1, 2$ to the **portion due to the differences in the measurable characteristics of groups**. Fairlie (2005) showed that the contribution of each covariate X_1 and X_2 can be expressed as, respectively (assume $N^{2006} = N^{2014} = N$):

$$\frac{1}{N}\sum_{1}^{N} F(\hat{\alpha^*} + X_i^{1,2014}\hat{\alpha^*}_1 + X_i^{2,2014}\hat{\alpha^*}_2) - F(\hat{\alpha^*} + X_i^{1,2006}\hat{\alpha^*}_1 + X_i^{2,2014}\hat{\alpha^*}_2) \tag{9}$$

and

$$\frac{1}{N}\sum_{1}^{N} F(\hat{\alpha^*} + X_i^{1,2006}\hat{\alpha^*}_1 + X_i^{2,2014}\hat{\alpha^*}_2) - F(\hat{\alpha^*} + X_i^{1,2006}\hat{\alpha^*}_1 + X_i^{2,2006}\hat{\alpha^*}_2) \tag{10}$$

In addition, the sum of above two terms is equal to **the portion due to differences in the measurable characteristics of groups**. It means that we can decompose the composition effects into the direct contribution of each covariate.

In practice, the number of observations for these two years will be usually different. Thus, it is difficult to apply directly equation (8), (9) and (10). For example, in our dataset, the sample size in the year 2014 is larger than the sample size in the year 2006. To obtain the direct contribution of each covariate and their standard error, we devise the following algorithm using 1000 bootstrap samples.

- First, we draw a new sample using the population in the year 2014, namely 2014N, with replacement. The size of the new sample 2014N equals to the population size in the year 2006.
- Second, we apply the logistic decomposition (4) with the 2014N sample and the 2006 sample. We obtain the two predicted samples as noted in the equation (5) for the 2014N sample and the 2006 sample.
- Third, the above two predicted values are separately ranked by their probability and matched by their respective rankings. Then, we use equations (9) and (10) to get the direct contribution of each covariate.

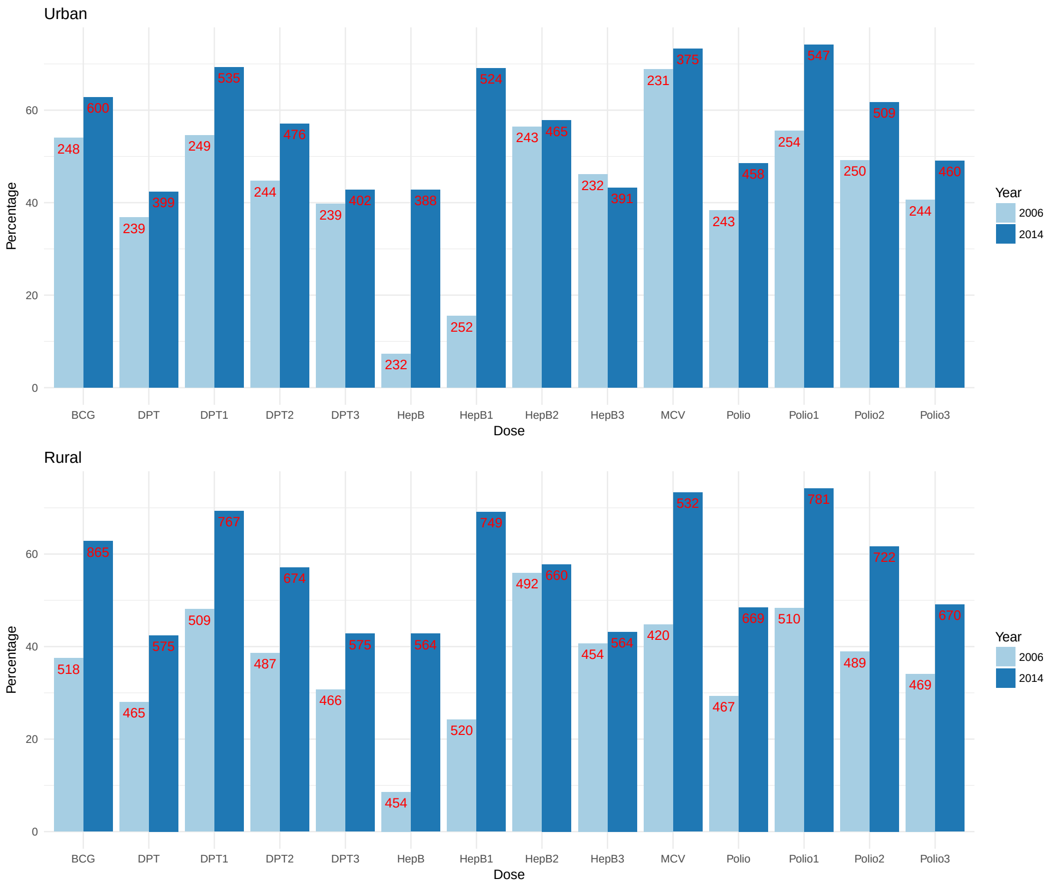
The final result of each contribution is the average of the corresponding 1000 values. The standard error of each contribution can be obtained by calculating the standard error of the corresponding 1000 values.

Table 1: Immunization schedule recommended by WHO for children up to 1 year old

Antigens	Abbreviations	Description	Schedules
HepB-Pediatric	HepB	Hepatitis B pediatric	birth
BCG	BCG	Bacille Calmette-Guerin	birth
DTwPHibHepB	DPT	Diphtheria and Tetanus Pertussis Haemophilus influenzae	2, 3, 4 months
OPV	Polio	Oral polio	2, 3, 4 months
Measles	MCV	Measles	9 months

Source: WHO vaccine-preventable diseases: monitoring system, 2017 global summary - Vietnam

Figure 1: Timely vaccine completion in urban and rural sites, between two year 2006 - 2014 for each specific dose and each vaccine



Red numbers in the bar charts are the number of children with immunization cards used in the survey and with written information indicating that he or she was vaccinated for a specific dose. HepB means the timely completion of the three doses. There is a similar notation for DPT and Polio. All the differences between the two years of each dose are significant.

Table 2: Descriptive of some main explanatory variables for children who have immunization card but had not written information indicating that she or he was vaccinated MCV - similar to the other dose

	2006	2014
Number Obs	2029	2411
Urban	17.05 %	37.66 %
Primary	60.47 %	24.97 %
Lower secondary	25.43 %	35.09 %
Upper secondary	14.1 %	39.94 %

Table 3: Summarize statistic of independent variables for each specific vaccine in Urban and Rural site in the two years

	Urban		Rural	
Year	2006	2014	2006	2014
Number Obs	577	1283	577	1283
Month age of child				
Cage	30 (17)	28.6 (17.4)	29.9 (16.9)	27.6 (17.5)
Ethnic				
Kinh	91.51 %	87.45 %	63.58 %	67.67 %
Minority	8.49 %	12.55 %	36.42 %	32.33 %
Wealth index of mother				
wealth1	3.99 %	7.56 %	36.14 %	36.56 %
wealth2	5.03 %	8.96 %	21.83 %	22.11 %
wealth3	9.53 %	16.29 %	20.21 %	18.92 %
wealth4	19.93 %	25.95 %	16.36 %	15.97 %
wealth5	61.53 %	41.23 %	5.47 %	6.44 %
Education level of mother				
Primary	31.54 %	11.22 %	66.38 %	28.5 %
Lower secondary	26.34 %	27.75 %	24.96 %	39.9 %
Upper secondary	42.11 %	61.03 %	8.65 %	31.6 %
Ecological regions				
Red River Delta	11.79 %	18.47 %	11.75 %	14.1 %
Northern Midlands and Mountain area	11.79 %	14.19 %	27.91 %	24.77 %
North Central and Central Coastal area	23.22 %	15.67 %	21.92 %	13.66 %
Central Highlands	12.65 %	18.86 %	17.78 %	20.74 %
South East	29.46 %	20.65 %	7.89 %	12.58 %
Mekong river Delta	11.09 %	12.16 %	12.74 %	14.15 %
Household size				
Hsize3	9.71 %	8.18 %	9.61 %	7.71 %
Hsize4	32.41 %	28.84 %	25.68 %	25.8 %
Hsize5	24.09 %	21.51 %	22.73 %	25.55 %
Hsize6	14.9 %	18 %	16.5 %	18.82 %
Hsize7	7.97 %	10.91 %	10.22 %	8.94 %
Hsize8	10.92 %	12.55 %	15.26 %	13.17 %
Csize (Number of under five years old)				
Csize1	79.9 %	74.2 %	67.76 %	67.08 %
Csize2	17.68 %	22.37 %	27.72 %	28.7 %
Csize3	2.43 %	3.43 %	4.52 %	4.23 %
Gender of child)				
Male	53.9 %	51.52 %	51.02 %	51.06 %
Female	46.1 %	48.48 %	48.98 %	48.94 %
Birth order)				
First	89.25 %	44.66 %	82.64 %	42.06 %
Others	10.75 %	55.34 %	17.36 %	57.94 %

The independent variable sample also depends on a specific vaccine but the description statistic are similar. This Table is an example of HepB.

Table 4: Non-Linear decomposition of timely immunization completion among children of Vietnam from 2006 to 2014 (Change in %)

	BCG	Polio	DPT	HepB	MCV
Urban					
Total effect	8.8	10.2	5.54	35.46	4.5
Structure effect	11.32	16.86	4.14	36.35	-4.02
Composition effect	-2.52	-6.66	1.4	-0.89	8.53
Contribution of specific characteristics to the total disparity					
Age of child	2.31 (0.14)	1.3 (0.08)	1.81 (0.14)	0.79 (0.07)	-2.19 (0.3)
Gender of child	-0.05 (0.03)	0.41 (0.15)	0.39 (0.13)	0.29 (0.12)	-0.22 (0.1)
Wealth index	**-1.89 (0.25)**	**-1.31 (0.26)**	**-1.29 (0.28)**	0.43 (0.23)	**0.97 (0.17)**
Level education of mother	**0.83 (0.08)**	-0.5 (0.05)	-0.23 (0.08)	2.18 (0.15)	3.63 (0.23)
Region	0.38 (0.75)	-0.57 (0.35)	-0.19 (0.23)	1 (0.31)	-0.64 (0.34)
Ethnic	0.11 (0.05)	-0.01 (0.01)	-0.01 (0.01)	0 (0.01)	-0.07 (0.1)
Household size	0.8 (0.17)	-0.09 (0.35)	0 (0.37)	0.51 (0.27)	0.68 (0.24)
Number of child under five	-0.31 (0.24)	-0.01 (0.16)	-0.01 (0.08)	-0.12 (0.13)	-0.1 (0.14)
Birth order	**1.68 (0.11)**	**2.54 (0.14)**	0.91 (0.05)	**5.6 (0.29)**	0.92 (0.06)
Rural					
Total effect	21.16	14.16	8.56	27.23	36.07
Structure effect	13.79	15.21	6.37	26.7	39.58
Composition effect	7.37	-1.05	2.19	0.52	-3.51
Contribution of specific characteristics to the total disparity					
Age of child	2.26 (0.1)	0.34 (0.01)	0.14 (0.01)	-1.5 (0.09)	-1.25 (0.09)
Gender of child	-0.03 (0.03)	0.02 (0.03)	0.06 (0.05)	0.01 (0.03)	-0.03 (0.04)
Wealth index	-0.24 (0.13)	0.01 (0.05)	0.06 (0.05)	-0.24 (0.12)	0.02 (0.07)
Level education of mothers	**6.77 (0.18)**	**3.64 (0.11)**	**4.51 (0.12)**	**11.54 (0.24)**	**10.87 (0.23)**
Region	0.78 (0.25)	-0.73 (0.11)	-0.79 (0.09)	0.09 (0.05)	-0.02 (0.06)
Ethnic	-0.11 (0.05)	-0.04 (0.02)	0 (0.01)	0.16 (0.04)	0.01 (0.03)
Household size	-0.12 (0.09)	0.19 (0.08)	0.12 (0.04)	0.01 (0.04)	0.3 (0.12)
Number of child under five	-0.1 (0.08)	-0.22 (0.1)	-0.04 (0.04)	-0.04 (0.06)	-0.11 (0.09)
Birth order	**5.11 (0.19)**	**1.92 (0.06)**	0.0 (0.00)	**2.21 (0.07)**	**5.6 (0.18)**

Structure effect - unmeasured effect: Portion due to differences in coefficients across models.
Composition effect: Portion due to differences in the measurable characteristics of groups.
Note: Bootstrapped standard errors, based on 1000 replications, are in parenthesis.