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Interpreting the changing association between caesarean birth and neonatal death: a case study from Ethiopia

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Complete List of Authors:	Yisma, Engida; School of Public Health, The University of Adelaide Mol, Ben; School of Medicine, Monash University, Melbourne, Australia, OB/GYN Lynch, John; School of Public Health, The University of Adelaide Smithers, Lisa; School of Public Health, The University of Adelaide
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3 **1 Interpreting the changing association between caesarean birth and neonatal death:**
4 **2 a case study from Ethiopia**
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10 4 Engida Yisma^{a, b}, Ben W. Mol^{c, d}, John W. Lynch^{a, c, e} and Lisa G. Smithers^{a, c}
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17 6 ^aSchool of Public Health, The University of Adelaide, Adelaide, Australia
18
19

20 7 ^bSchool of Allied Health Sciences, College of Health Sciences, Addis Ababa University, Addis
21 8 Ababa, Ethiopia
22
23

24 9 ^cRobinson Research Institute, School of Medicine, The University of Adelaide, Adelaide,
25 10 Australia
26
27

28
29 11 ^dDepartment of Obstetrics and Gynaecology, Monash University, Melbourne, Australia
30
31

32 12 ^ePopulation Health Sciences, University of Bristol, England, UK
33 13
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38

39 **15 Corresponding Author:**
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42 16 Engida Yisma
43
44

45 17 School of Public Health, The University of Adelaide, Adelaide, Australia
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48 18 Email: engida.derbie@adelaide.edu.au
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1 SUMMARY BOXES

2 What is already known on this topic?

- 3 • Studies that assess the association between caesarean section and neonatal mortality have
4 been conducted periodically, but the results are inconsistent.
- 5 • The majority of the studies are at the aggregate level.
- 6 • Studies based on individual-level data are more likely to report a considerably increased
7 risk of neonatal death associated with caesarean versus vaginally born infants.
- 8 • In developing countries like Ethiopia, contextual factors such as unequal access,
9 infrastructure, and health workforce constraints may play role in the mechanism of
10 association between caesarean birth and neonatal death. However, previous studies lack
11 the interpretation of the association by considering contextual factors with additional
12 supporting evidence.

13 What this study adds

- 14 • This study found that the changing association between caesarean birth and neonatal
15 death within the context of Ethiopia over time may be attributable to changes in pattern
16 of the underlying indications for caesarean intervention which may aggravated by
17 contextual factors such as unequal access, infrastructural, and health workforce
18 constraints.
- 19 • The changing association between caesarean birth and neonatal death may also reflect a
20 maturing of the health system and a shift in the characteristics of Ethiopian women
21 undergoing caesarean section after complicated labour or severe foetal compromise in
22 which caesarean birth may not prevent neonatal deaths because the foetus has already
23 experienced complications that mean neonatal death is difficult to prevent.

1 **ABSTRACT**

2 **Objective**

3 To interpret the changing association between caesarean birth and neonatal death within the
4 context of Ethiopia from 2000 to 2016.

5 **Design**

6 Secondary analysis of Ethiopian Demographic and Health Surveys (DHS).

7 **Setting**

8 All administrative regions of Ethiopia with surveys conducted in 2000, 2005, 2011, and 2016.

9 **Participants**

10 Women aged 15-49 years with a live birth during the five years preceding the survey.

11 **Main outcome measures**

12 We analysed the association between caesarean birth and neonatal death using log-Poisson
13 regression models for each survey adjusted for potential confounders. We then applied the
14 'Three Delays Model' to provide an interpretation of the changing association between caesarean
15 birth and neonatal death in Ethiopia.

16 **Results**

17 The adjusted prevalence ratios (aPR) for neonatal death among neonates born via caesarean
18 section versus vaginal birth increased over time, from 0.95 (95% CI, 0.29, 3.19) in 2000 to 2.81
19 (95% CI, 1.11, 7.13) in 2016. The association between caesarean birth and neonatal death was
20 stronger among rural women (aPR (95% CI) 3.43 (1.22, 9.67)) and among women from the
21 lowest quintile of household wealth (aPR (95% CI) 7.01 (0.92, 53.36) in 2016. However, the
22 aggregate-level analysis revealed that an increase in caesarean section rate is correlated with a
23 decrease in the proportion of neonatal deaths.

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56 2 **Conclusions**
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9 3 The naïve interpretation of the changing association between caesarean birth and neonatal death
10 4 from 2000 to 2016 is that caesarean section is increasingly associated with neonatal death.
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12 5 However, the changing association reflects improvements in health service coverage and a shift
13 6 in the characteristics of Ethiopian women undergoing caesarean section after complicated labour
14 7 or severe foetal compromise.
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19 820 9 **Strengths and limitations of this study**
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- 22
23 10 • This was the first study to examine the changing association between caesarean birth and
24 11 neonatal death within the context of Ethiopia from 2000 to 2016.
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26 12 • A number of analyses were conducted after adjustment for potential confounders helped
27 13 develop the possible scenarios to better understand the interpretation of the changing
28 14 associations.
29
30 15 • We have used additional supporting evidence from Ethiopian DHS data which allowed us
31 16 to interpret the changing association between caesarean birth and neonatal death in view
32 17 of contextual factors in Ethiopia using ‘Three Delays Model’.
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34 18 • We lack data on intrapartum indications for caesarean delivery.
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1 Introduction

2 Globally, 2.6 million neonatal deaths occurred within the first 28 days after birth, which
3 accounted for 46% of all under-five deaths in 2016.¹ The majority of these deaths were from
4 low- and middle-income countries. According to the United Nation Inter-agency Group for Child
5 Mortality Estimation, Southern Asia (39%) and sub-Saharan Africa (38%) comprised the top two
6 regions with the highest proportion of neonatal deaths, while five countries (India, Pakistan,
7 Nigeria, the Democratic Republic of the Congo, and Ethiopia) accounted for 50% of all newborn
8 deaths.¹ Unlike under-five mortality, the proportion of neonatal deaths is increasing.² If the
9 current trend continues, more low-and middle-income countries will fail to achieve the
10 Sustainable Development Goal (SDG) target for neonatal mortality at 12 per 1,000 live births.³

11
12 In contemporary obstetric practice, caesarean section remains an important intervention in
13 preventing neonatal mortality and other adverse birth outcomes.⁴ However, caesarean section
14 may be prone to misuse because of unequal access, social, and cultural factors.⁵⁻⁷ In developing
15 country settings, due to limited medical provisions and/or lack of skilled birth attendants, some
16 women may not benefit from caesarean birth though they are medically eligible, while ineligible
17 women may sometimes have increased access. In the last decades, caesarean section rates have
18 been increasing in low-, middle, and high-income countries.⁸⁻¹⁰ The World Health Organization
19 (WHO) suggests a caesarean section rate of 10–15%.¹¹

20
21 Previous studies conducted using aggregate- and individual-level data have yielded inconsistent
22 results about the association between caesarean birth and neonatal mortality. For instance, two
23 ecological studies^{12,13} conducted using worldwide country-level data have found that caesarean
24 birth was associated with lower neonatal mortality while another two ecological studies^{14,15}
25 showed no association between caesarean birth and neonatal mortality, where caesarean section
26 rates were higher than 10%. Inconsistent results for the association between caesarean birth and
27 neonatal mortality were also reported by different studies conducted in Africa, Latin America,
28 and United States of America based on individual-level data.¹⁶⁻²¹

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30 On the other hand, using both country-and individual-level data collected for nationally

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3 1 representative Demographic and Health Surveys (DHS), Kyu et al. found an increased risk for
4 2 neonatal death associated with caesarean versus vaginal births in countries with low (< 5%) and
5 3 medium (5-15%) caesarean section rates.²² However, factors associated with caesarean section
6 4 that increase risk for neonatal death in countries with low and moderate caesarean section rates
7 5 remain ill-defined. Previous studies are limited by either inconsistent results, which may suggest
8 6 null effects (e.g. at least due to methodological/design limitations), or lack the interpretation of
9 7 findings by considering the contextual factors. It is clear that in addition to the underlying
10 8 indications for caesarean interventions, several contextual factors such as unequal access,
11 9 infrastructural, and health workforce constraints could play a role in the association between
12 10 caesarean section and neonatal death.
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22 12 In low- and middle-income countries, the DHS are the most representative and widely available
23 13 quality data sources for studies related to maternal and child health. We use Ethiopian DHS data
24 14 from 2000, 2005, 2011, and 2016 to examine the association between caesarean birth and
25 15 neonatal death. We then apply ‘Three Delays Model’ developed by Thadeus and Maine²³ to
26 16 provide an interpretation of the changing association between caesarean birth and neonatal death
27 17 in Ethiopia. The ‘Three Delays Model’ is a framework that describe the circumstances of
28 18 pregnancy/labour-related maternal and neonatal mortality due to three delays—delay in deciding
29 19 to seek care (Delay 1); delay in reaching care (Delay 2); and delay in receiving adequate health
30 20 care (Delay 3).²³
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1 **Methods**

2 **Study design and data samples**

3 We used data from the Ethiopian DHS completed in 2000, 2005, 2011, and 2016. The Ethiopian
4 DHS are nationally representative cross-sectional surveys conducted in nine regions (Tigray,
5 Afar, Amhara, Oromia, Somali, Benishangul-Gumuz, SNNPR, Gambela, and Harari), and two
6 city administrations (Addis Ababa and Dire Dawa). Each of the surveys involved a two-stage,
7 stratified, clustered sampling design. The survey datasets are de-identified and made freely
8 available online. Permission to use these data was granted by the MEASURE DHS Program. The
9 details about the methodology and standards for protecting the privacy of study participants in all
10 DHS can be accessed at (<http://www.measuredhs.com/What-We-Do/methodology.cfm>).

12 **Exposure**

13 The DHS questionnaire asks women about pregnancy, antenatal, and delivery care for livebirths
14 they have reported in the past 5 years. The self-reported data collected for caesarean birth are
15 thought to be reliable.²⁴ For this study, the exposure group were children delivered by caesarean
16 section and unexposed group comprised children born vaginally.

18 **Outcome**

19 Neonatal death includes children who were born alive in the 5 years before the survey, but died
20 within the first 28 days of life. The outcome variable, neonatal death, was measured from two
21 variables (whether the child is alive and age at death (in days)).

23 **Confounding**

24 The following potential confounders were identified a priori and included place of delivery
25 (public, private, NGO, home), type of residence (urban/rural), sex of child (male/female), size of
26 baby at birth (very large, larger than average, average, smaller than average, very small, don't
27 know), mother's age at birth (in years), mother's education (no education, primary, secondary,
28 higher), birth order (1, 2-3, 4+), and household wealth quintile (poorest, poorer, middle, richer,
29 richest). Mother's age at birth was calculated as a difference (in years) between infant's date of
30 birth and mother's date of birth. DHS computes the wealth index for each survey based on

1 household assets using principal components analyses²⁵ and categorizes households into wealth
2 quintiles. These asset-based measures represent the wealth distribution relative to other
3 households within the country. They are widely used and are consistent with comparisons to
4 household expenditures and the measurement of inequalities in child mortality, education, and
5 healthcare use in low-and middle-income countries.²⁶

7 **Statistical analysis**

8 All analyses were weighted to be nationally representative. Associations between caesarean birth
9 and neonatal death were analysed using log-Poisson regression using data from Ethiopian DHS
10 in 2000, 2005, 2011, and 2016. We calculated unadjusted and adjusted prevalence ratios (aPR)
11 and their 95% CIs.

12 To explore what happens among different subgroups, we conducted a series of subgroup
13 analyses using the most recent data because the association is more pronounced in 2016 DHS.
14 We first restricted the analysis to participants living in regions with the highest caesarean section
15 rates to examine whether the increased access to caesarean section affected the proportion of
16 neonatal deaths. We then estimated the effect of caesarean birth on neonatal death in rural areas
17 where access to caesarean section is limited, by excluding women living in urban settings (Addis
18 Ababa and Hareri). In addition, we evaluated the association by restricting the analyses to births
19 from the lowest quintile of household wealth, births from the highest quintile of household
20 wealth, births in public health facilities, births to rural, and urban areas separately. This allowed
21 us to examine how contextual factors (e.g. unequal access, infrastructural, and workforce
22 constraints) affected the association between caesarean birth and neonatal death.

23 As women may have had more than one birth within the five-year survey periods, we accounted
24 for both clustering of cesarean deliveries within women as well as the complex survey design
25 during the data analyses using unit of analysis's (children) study number and sample weights.

26 All analyses were conducted using STATA/SE version 15.1 (Stata Corporation, College Station,
27 TX).

28 **Patient involvement**

1 No patients were involved in setting the research question or the outcome measures, nor were
2 they involved in the design and implementation of the study. No patients were asked to advise on
3 interpretation or writing up of results. There are no plans to disseminate the results of the
4 research to study participants or the relevant patient community.

5 **Results**

6 Of the weighted total of 11 023 children in the study (5 725 male and 5 298 female), 213 (1.9%)
7 were born by cesarean section within 5 years preceding Ethiopian DHS 2016. The overall
8 proportion of neonatal death was 2.9% in 2016. **Table 1** shows the characteristics of mothers and
9 children according to mode of delivery. Additional descriptive overview of the data from
10 Ethiopian in DHS 2000, 2005, and 2011 are presented in **Supplementary appendix**. Women
11 who underwent caesarean delivery were more likely to live in urban areas, had a higher level of
12 education, and were from the richest quintile of household wealth. They were also more likely to
13 have male children. Caesarean deliveries were more frequent in women in the age category of
14 20-29 years, and among infants who had either very large or large size at birth. **Figure 1 & 2**
15 shows that the proportion of institutional delivery increased from 5.0% in 2000 to 26.3% in
16 2016, whereas the national caesarean section rate increased from 0.7% in 2000 to 1.9% in 2016.
17 However, the rate of caesarean delivery in Ethiopia varied widely across administrative regions.
18 For instance, Addis Ababa had the highest (21.4%) rate, while Somali region had the lowest
19 (0.4%) in 2016. The overall proportion of neonatal deaths decreased from 4.8% in 2000 to 2.9%
20 in 2016, but the proportion varies among administrative regions (**Figure 1 & 3**). Our analyses
21 based on aggregate-level data showed that an increase in caesarean section rate is correlated with
22 a decrease in the proportion of neonatal deaths (**Supplementary Figure 1**).

23
24 **Table 2** shows that the adjusted prevalence ratio (aPR) for neonatal death associated with
25 caesarean versus vaginal births in 2000 DHS was 0.95 (95%CI, 0.29, 3.19). In 2011, the
26 adjusted prevalence ratio (aPR) for neonatal death associated with caesarean versus vaginal
27 births was 1.15 (95%CI, 0.45, 2.93), while the 2005 Ethiopian DHS found an aPR of 1.53
28 (95%CI, 0.52, 4.50). Likewise, caesarean birth was associated with a 2.81-fold higher risk of
29 neonatal death in 2016 Ethiopian DHS (aPR, 2.81; 95%CI, 1.11, 7.13).

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3 1 **Table 3** summarises the findings of the subgroup analyses based on the 2016 data. When women
4 2 living in urban settings, (Addis Ababa (caesarean section rate (21·4%), and Hareri (9·0%)), were
5 3 excluded from the analyses, the corresponding adjusted PR for neonatal death was increased to
6 4 3·55 (95%CI, 1·31, 8·56). Similarly, when we restricted the analyses to include only rural
7 5 women, the prevalence ratio for neonatal death associated with caesarean versus vaginal births
8 6 was found to be 3·43 (95% CI, 1·22, 9·67). The respective risk of neonatal death increased to
9 7 7·01 (95%CI, 0·92, 53·36) when the analysis was limited to women from the lowest quintile of
10 8 household wealth.
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20 10 Last, when we restricted the analyses to Addis Ababa, the capital of the Ethiopia, the relative risk
21 11 for neonatal death associated with caesarean versus vaginal births was 1·07 (95%CI, 0·20, 5·73).
22 12 Moreover, when the analysis was confined to women from the highest quintile of the household
23 13 wealth, the risk of neonatal death was 2·72 (95% CI, 0·55, 13·38).
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1 **Interpretation**

2 The primary analyses showed that the adjusted prevalence ratios (aPR) for neonatal death
3 associated with caesarean versus vaginal births increased from 0·95 (95% CI, 0·29, 3·19) in
4 2000 to 2·81 (95% CI, 1·11, 7·13) in 2016. These findings suggest that the circumstances for
5 foetuses born in 2000 DHS are different from the foetuses in 2016. Our subgroup analyses using
6 2016 data suggest that the association between caesarean birth and neonatal death was stronger
7 among rural women (aPR (95% CI) 3·43 (1·22, 9·67)) and among women from the lowest
8 quintile of household wealth (aPR (95% CI) 7·01 (0·92, 53·36)), but not for births in areas with
9 wider availability of caesarean such as Addis Ababa (aPR (95% CI) 1·07 (0·20, 5·73)). The
10 changing association between caesarean birth and neonatal death over time, and the stronger
11 association observed among different subgroup analyses may be attributable to changes in the
12 pattern of confounding by indication due to contextual factors such as unequal access, structural
13 health-system deficiencies (insufficient equipment, supplies, and drugs), infrastructural, and
14 health workforce constraints. These situations may have the capacity to make women with labour
15 problems undergo caesarean section after severe complication of labour or severe foetal
16 compromise. Therefore, our interpretation is that caesarean section conducted after severe foetal
17 compromise may not prevent neonatal deaths because they have already experienced such
18 severity of complications that although live born, neonatal death is difficult to prevent.

19
20 There are two possible scenarios leading to caesarean section in Ethiopia. First, when women
21 who have previously had a caesarean section, with breech presentation, or other risk factors such
22 as eclampsia attend specialised health facilities, they are usually allowed to undergo caesarean
23 section. Their caesarean section is commonly classified as “elective or scheduled caesarean
24 section.” Second, when caesarean section is performed for “emergency reasons.” Full term
25 mothers with or without signs of labour will be admitted to health facilities where their progress
26 is monitored and labour-augmenting or inducing medications may be administered. Decisions to
27 perform caesarean section in these facilities or decision to refer the mother to nearby hospitals
28 for caesarean delivery or other action depends on the condition of the mother and foetus during
29 the progress of labour. In primary health facilities (i.e., health posts and health centres), obstetric
30 care providers use a ‘Partograph’, a routine labour monitoring instrument (chart) which helps the
31 health care provider in identifying slow progress in labour and take appropriate action. In

1 hospitals, the decision to perform a caesarean section is reached when the labour is prolonged
2 and/or the second stage of labour is complicated risking the life of mother and foetus.

3
4 Given these pathways to caesarean delivery in mind, our interpretation of the changing
5 association between caesarean birth and neonatal death in Ethiopia may be explained by the
6 ‘Three Delays Model’ developed by Thadeus and Maine.²³ The model comprises *delay in*
7 *decision to seek care* on the part of the mother, family, or both (Delay 1); *delay in reaching care*
8 (Delay 2); and *delay in receiving adequate health care* (Delay 3). First delay—*delay in decision*
9 *to seek care*—occurs when less-educated and poorer women encounter pregnancy or labour
10 complications. Poorer and less-educated women are more likely to select a nearby health facility,
11 especially in rural areas, where there is limited access to caesarean section and the possibility of
12 benefiting from caesarean section is mainly through referral to higher levels of care. Women are
13 more likely to undergo a caesarean section if they present to specialized health facilities.

14 However, the outcome of delivery depends on the severity of the pregnancy complications which
15 is affected by long distance to specialized health facilities and how quick/competent the health
16 care provider is in referring the mother or on intervening. In Ethiopia, only 1.1% of births from
17 the lowest quintile of household wealth are attended by doctors.²⁷ *Delay in reaching care*, the
18 model’s second component, occurs when women with pregnancy complication live further from
19 health facilities, and the availability and cost of transportation is problematic. Like other
20 developing settings, these problems are especially applicable in Ethiopia, where distance to a
21 health facilities limits access to health care for 50% of women.²⁷ The pregnancy complication
22 encountered by mothers will be further worsened by delays in reaching nearby primary health
23 facilities, and compounded by additional delays when mothers are referred to specialised health
24 facility for caesarean section.

25
26 Moreover, the lack of facilities; inadequately trained obstetric care givers (birth attendants); and
27 inadequate and inappropriate referral systems in conjunction with other factors in Ethiopia result
28 in *delay in receiving adequate health care* (Delay 3) among mothers with pregnancy and labour
29 complications in both primary and specialised health facilities. For example, in the 5 years before
30 Ethiopian DHS 2016,²⁷ only 28.0% of births were delivered by ‘skilled providers’ (includes
31 doctor, nurse, midwife, health officer, and health extension worker). The majority of births in

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3 1 Ethiopia are attended by traditional birth attendant (42·0%), nurses or midwives (20·0%)
4 followed by doctors (6·0%), health extension workers (2·0%), and health officers (0·4%).
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9 4 Lastly, delay in caesarean intervention may even happen if mothers with less severe labour
10 complications were referred and presented to specialised health facilities in a timely manner.
11 This is because a trial of labour is usually attempted before a decision to have caesarean section.
12 For instance, some women who are referred from primary health facilities undergo induction and
13 augmentation of labour because these interventions are only provided in health facilities with the
14 capacity to provide caesarean section in Ethiopia. These practices, in turn, will result in delay in
15 receiving caesarean section leading to worsening of the already existing pregnancy complication.
16 Thus, any delays to caesarean intervention have a higher chance of aggravating the already
17 existing complications and increase the risk of neonatal death.
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1 Discussion

2 Our study examined the changing association between caesarean birth and neonatal death within
3 the context of Ethiopia from 2000-2016. The association between caesarean section and neonatal
4 death increased over time and variable among population sub-groups. These changes over time,
5 and variation across population sub-groups may be attributable to changes in the pattern of
6 confounding by indication due to contextual factors such as improvement in health service
7 coverage, unequal access (e.g. due to a range of geographic, social, and economic barriers), and
8 structural, and health workforce constraints.

9
10 In Ethiopia, the proportion of women aged 15-49 who received any antenatal care from a skilled
11 provider has increased from 27% in 2000 to 62% in 2016.²⁷ Health facility-based deliveries have
12 increased from 5% in 2000 to 26% in 2016 (increased from 2% in 2000 to 20% in 2016 for rural
13 women, and increased from 32% in 2000 to 79% in 2016 for urban women).²⁷ The proportion of
14 births in health facilities assisted by a skilled birth attendants increased from 6% in 2000 to 28%
15 in 2016.²⁷ These figures reflect improvement in health service coverage in Ethiopia.

16
17 Moreover, since 2004, with the implementation of the Health Extension Programme—a
18 community-based primary healthcare programme—the Ethiopian government has increased the
19 number of health posts from 4,211 in 2005 to 16,447 in 2015.^{28,29} Likewise, the number of
20 health centres were increased from 600 in 2005 to 3,586 in 2015.^{28,29} However, due to limitations
21 in proper monitoring of labour for making timely decisions, especially on whether or not to
22 initiate a referral from primary health facilities to higher level facilities, and due to poor transport
23 and road networks which are still the common problems in low income countries,³⁰ the
24 underlying medical indications for caesarean intervention will be worsened by these ‘delay
25 factors.’ Delay in receiving adequate and appropriate care is still a common problem in low
26 income countries due to deficiencies in surgical facilities, surgical and anaesthesia personnel and
27 equipment, blood transfusion capacity, and a shortage of skilled birth attendants.³¹⁻³³ These
28 situations often result in poor quality care, and the caesarean section conducted after complicated
29 labour may be associated with increased neonatal mortality due to confounding by indication.

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31 Unlike previous studies, the present study takes into account the interpretation of the changing

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3 1 association between caesarean birth and neonatal death within the context of Ethiopia using DHS
4 data. The change in the strength of effect estimates across DHS waves, and the different
5 2
6 3 subgroup analyses suggest that neonatal mortality can be reduced by increasing timely access to
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8 5 caesarean section and timely decision for caesarean delivery via increasing health service
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10 7 coverage, improving infrastructure, increasing the number of skilled birth attendants, improving
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12 9 quality of care, and increasing awareness about antenatal care and health facility delivery among
13 10
14 11 women. Moreover, provision of training to skilled birth attendants on close monitoring of labour
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16 13 and early detection of complications, equipping the primary health facilities (e.g. health centres)
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18 15 to the level of caesarean capacity, and continuous financial investment in primary health
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20 17 facilities will be an important strategy to reduce neonatal mortality.
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12 It appears that previous studies which used individual-level data are more likely to report an
13 increased risk of neonatal death among infants born by caesarean section than the ecological
14 studies. This may be due to the indications for the caesarean delivery (e.g. the severity of the
15 underlying causes) was involved in causing both caesarean delivery and neonatal death in studies
16 which used individual-level data, suggesting the role of confounding by indication in the
17 association between caesarean birth and neonatal death because an intended effect of caesarean
18 birth is prevention of neonatal death. Therefore, the increased risk for neonatal death associated
19 with caesarean birth, compared with vaginal birth, would appear to be intuitive given the fact
20 that neonatal death rates after emergency caesarean section is strongly dependent upon the
21 underlying indication (e.g. antenatally diagnosed foetal malformation or foetal growth
22 restriction) for caesarean intervention.
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24 In Ethiopia, the national rate of caesarean section increased from 0·7% in 2000 to 1·9% in 2016.
25 On the other hand, neonatal mortality rate declined from 49 deaths per 1,000 live births in 2000
26 to 29 deaths per 1,000 births in 2016.²⁷ Our analyses based on aggregate-level data from
27 Ethiopian DHS showed that an increase in caesarean section rate is correlated with a decrease in
28 the proportion of neonatal deaths. Even though similar context-specific interpretation is
29 applicable to ecological studies, additional explanation may also be necessary to interpret the
30 association. For example, a change in neonatal mortality rate may be attributable to changes
31 acting on the population as a whole (e.g. changes in health coverage indicators, such as an
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3 1 increase in births attended by skilled birth attendants (increased from 6% in 2000 to 28% in
4 2016)).²⁷ The findings of our analyses of DHS data aggregated to different DHS waves and
5 2 administrative regions are presented in **Supplementary appendix**
6 3
7 4

8
9 4 The most important limitation of our study is that we lack data on intrapartum indications for
10 5 caesarean delivery. For example, information on foetal intolerance of labour and arrest of
11 6 labour³⁴ which are thought to affect both caesarean section and neonatal health are not available
12 7 in DHS. However, we believe that our interpretation of the changing association between
13 8 caesarean birth and neonatal death may not be biased even in the presence of confounding by
14 9 indication because emergency caesarean section conducted after complicated labour aggravated
15 10 by any ‘delay factors’ leads to neonatal death. Another limitation is the mother’s recall of the
16 11 child’s size at birth was used as a substitute for the child’s birth weight in this study because the
17 12 data for birth weight was not collected for more than 50% of the neonates in DHS.
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1 **Conclusions**

2 The naïve interpretation of the changing association between caesarean birth and neonatal death
3 from 2000 to 2016 is that caesarean section is increasingly associated with neonatal death.
4 However, the changing association reflects improvements in health service coverage and a shift
5 in the characteristics of Ethiopian women undergoing caesarean section after complicated labour
6 or severe foetal compromise.

7
8 **Contributors:** All authors (EY, BWM, JWL and LGS) contributed to the design of the study
9 and the interpretation of data. EY performed the data analysis and drafted the manuscript. All
10 other authors critically revised the draft manuscript. All authors read and approved the final
11 manuscript. EY is the guarantor of the paper.

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21
22 **Ethical approval:** Not required.

23 **Data sharing:** Datasets used for this study are freely available online at <http://dhsprogram.com/>.

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3 1 **Transparency declaration:** The corresponding author (EY) affirms that this manuscript is an
4
5 2 honest, accurate, and transparent account of the study being reported; that no important aspects
6
7 3 of the study have been omitted; and that any discrepancies from the study as planned have been
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9 4 explained.

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1 **References**

- 2 1. United Nations Inter-agency Group for Child Mortality Estimation (UN IGME). Levels
3 and Trends in Child Mortality: Report 2017, Estimates Developed by the UN Inter-agency Group
4 for Child Mortality Estimation. New York: United Nations Children's Fund, 2017.
- 5 2. Lawn JE, Cousens S, Zupan J. 4 million neonatal deaths: When? Where? Why? *The*
6 *Lancet* 2005; **365**(9462): 891-900.
- 7 3. UN Development Program. Sustainable Development Goals. Geneva: United Nations;
8 2015.
- 9 4. Costello A, Osrin D. Epidemiological transition, medicalisation of childbirth, and
10 neonatal mortality: three Brazilian birth-cohorts. *The Lancet* 2005; **365**(9462): 825-6.
- 11 5. Gibbons L, Belizan JM, Lauer JA, Betran AP, Merialdi M, Althabe F. Inequities in the
12 use of cesarean section deliveries in the world. *Am J Obstet Gynecol* 2012; **206**(4): 331 e1-19.
- 13 6. Leone T, Padmadas SS, Matthews Z. Community factors affecting rising caesarean
14 section rates in developing countries: An analysis of six countries. *Social Science & Medicine*
15 2008; **67**(8): 1236-46.
- 16 7. de Mello e Souza C. C-sections as ideal births: the cultural constructions of beneficence
17 and patients' rights in Brazil. *Camb Q Healthc Ethics* 1994; **3**(3): 358-66.
- 18 8. Dumont A, de Bernis L, Bouvier-Colle MH, Breart G. Caesarean section rate for
19 maternal indication in sub-Saharan Africa: a systematic review. *Lancet* 2001; **358**(9290): 1328-
20 33.
- 21 9. Vogel JP, Betrán AP, Vindevoghel N, Souza JP, Torloni MR, Zhang J. Use of the
22 Robson classification to assess caesarean section trends in 21 countries: a secondary analysis of
23 two WHO multicountry surveys. *The Lancet Global health* 2015; **3**.
- 24 10. Ye J, Betran AP, Guerrero Vela M, Souza JP, Zhang J. Searching for the optimal rate of
25 medically necessary cesarean delivery. *Birth* 2014; **41**(3): 237-44.
- 26 11. World Health Organisation. Appropriate technology for birth. *Lancet* 1985; **2**(8452): 436-
27 7.
- 28 12. Betran AP, Merialdi M, Lauer JA, et al. Rates of caesarean section: analysis of global,
29 regional and national estimates. *Paediatr Perinat Epidemiol* 2007; **21**(2): 98-113.

- 1 13. Molina G, Weiser TG, Lipsitz SR, et al. Relationship between cesarean delivery rate and
2 maternal and neonatal mortality. *JAMA* 2015; **314**(21): 2263-70.
- 3 14. Ye J, Zhang J, Mikolajczyk R, Torloni MR, Gulmezoglu AM, Betran AP. Association
4 between rates of caesarean section and maternal and neonatal mortality in the 21st century: a
5 worldwide population-based ecological study with longitudinal data. *BJOG : an international
6 journal of obstetrics and gynaecology* 2016; **123**(5): 745-53.
- 7 15. Althabe F, Sosa C, Belizan JM, Gibbons L, Jacquerioz F, Bergel E. Cesarean section
8 rates and maternal and neonatal mortality in low-, medium-, and high-income countries: an
9 ecological study. *Birth* 2006; **33**(4): 270-7.
- 10 16. Lumbiganon P, Laopaiboon M, Gulmezoglu AM, et al. Method of delivery and
11 pregnancy outcomes in Asia: the WHO global survey on maternal and perinatal health 2007-08.
12 *Lancet* 2010; **375**(9713): 490-9.
- 13 17. Villar J, Carroli G, Zavaleta N, et al. Maternal and neonatal individual risks and benefits
14 associated with caesarean delivery: multicentre prospective study. *BMJ* 2007; **335**(7628): 1025.
- 15 18. MacDorman MF, Declercq E, Menacker F, Malloy MH. Infant and neonatal mortality for
16 primary cesarean and vaginal births to women with "no indicated risk," United States, 1998-2001
17 birth cohorts. *Birth* 2006; **33**(3): 175-82.
- 18 19. MacDorman MF, Declercq E, Menacker F, Malloy MH. Neonatal mortality for primary
19 cesarean and vaginal births to low-risk women: application of an "intention-to-treat" model.
20 *Birth* 2008; **35**(1): 3-8.
- 21 20. Kallen K, Olausson PO. Neonatal mortality for low-risk women by method of delivery.
22 *Birth* 2007; **34**(1): 99-100; author reply 1-2.
- 23 21. Shah A, Fawole B, M'Imunya J M, et al. Cesarean delivery outcomes from the WHO
24 global survey on maternal and perinatal health in Africa. *International Journal of Gynecology
25 and Obstetrics* 2009; **107**(3).
- 26 22. Kyu HH, Shannon HS, Georgiades K, Boyle MH. Cesarean delivery and neonatal
27 mortality rates in 46 low- and middle-income countries: a propensity-score matching and meta-
28 analysis of Demographic and Health Survey data. *International journal of epidemiology* 2013;
29 **42**(3): 781-91.
- 30 23. Thaddeus S, Maine D. Too far to walk: maternal mortality in context. *Social science &
31 medicine (1982)* 1994; **38**(8): 1091-110.

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3 1 24. Stanton CK, Dubourg D, De Brouwere V, Pujades M, Ronsmans C. Reliability of data on
4 2 caesarean sections in developing countries. *Bull World Health Organ* 2005; **83**(6): 449-55.
5 3 25. Filmer D, Pritchett LH. Estimating Wealth Effects without Expenditure Data—or Tears:
6 4 An Application to Educational Enrollments in States of India. *Demography* 2001; **38**(1): 115-32.
7 5 26. Filmer D, Scott K. Assessing Asset Indices. *Demography* 2012; **49**(1): 359-92.
8 6 27. Central Statistical Agency - CSA/Ethiopia, ICF. Ethiopia Demographic and Health
9 7 Sruvey 2016. Addis Ababa, Ethiopia: CSA and ICF, 2017.
10 8 28. Federal Ministry of Health. Health and health related indicators 1997 E.C. (2004/05
11 9 G.C.). Addis Ababa, Ethiopia: Federal Ministry of Health; 2005.
12 10 29. Federal Ministry of Health. Health and health related indicators 2007 E.C. (2014/15
13 11 G.C.). Addis Ababa, Ethiopia: Federal Ministry of Health; 2015.
14 12 30. Atuoye KN, Dixon J, Rishworth A, Galaa SZ, Boamah SA, Luginaah I. Can she make it?
15 13 Transportation barriers to accessing maternal and child health care services in rural Ghana. *BMC*
16 14 *Health Services Research* 2015; **15**(1): 333.
17 15 31. Bergström S. Training non-physician mid-level providers of care (associate clinicians) to
18 16 perform caesarean sections in low-income countries. *Best practice & research Clinical obstetrics*
19 17 *& gynaecology* 2015; **29**(8): 1092-101.
20 18 32. Orji EO, Ojofeitimi EO, Esimai AO, Adejuyigbe E, Adeyemi AB, Owolabi OO.
21 19 Assessment of delays in receiving delivery care at a tertiary healthcare delivery centre in Nigeria.
22 20 *Journal of Obstetrics and Gynaecology* 2006; **26**(7): 643-4.
23 21 33. Miller S, Abalos E, Chamillard M, et al. Beyond too little, too late and too much, too
24 22 soon: a pathway towards evidence-based, respectful maternity care worldwide. *The Lancet* 2016;
25 23 **388**(10056): 2176-92.
26 24 34. Barber EL, Lundsberg LS, Belanger K, Pettker CM, Funai EF, Illuzzi JL. Indications
27 25 contributing to the increasing cesarean delivery rate. *Obstet Gynecol* 2011; **118**(1): 29-38.
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1 **Supplementary Figure 2.** The relationship between caesarean section rate and neonatal death by
2 survey years.

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1 **Table 1.** Characteristics of the study participants according to mode of delivery, Ethiopia DHS
 2 2016

	Mode of delivery	
	Caesarean (n=213) %	Vaginal (n= 10,810) %
Neonatal death		
Yes	8·28	2·74
No	91·72	97·26
Types of residence		
Urban	60·43	10·06
Rural	39·57	89·94
Region		
Tigray	6·81	6·49
Afar	0·37	1·05
Amhara	22·10	18·74
Oromia	21·22	44·46
Somali	1·02	4·68
Benishangul-Gumuz	0·56	1·11
SNNP	20·98	20·83
Gambela	0·17	0·25
Harari	1·09	0·22
Addis Ababa	24·53	1·77
Dire Dawa	1·16	0·41
Mother's age at birth		
<20	6·42	9·99
20-29	58·43	54·64
30-39	31·74	30·88
40-49	3·40	4·50
Mother's education		
No education	22·80	66·93
Primary	35·14	26·60
Secondary	15·31	4·45
Higher	26·76	2·01
Place of delivery		
Public	83·95	23·64
Private	13·69	0·90
NGO	2·36	0·24
Home	0·00	75·22
Birth order		
1	41·36	18·23
2-3	43·76	30·21
4+	14·88	51·56
Sex of child		
Male	53·97	51·90
Female	46·03	48·10
Size of baby at birth*		
Very large	26·53	17·58
Larger than average	16·00	13·82

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	Average	36·12	41·66
	Smaller than average	7·02	10·09
	Very small	12·65	16·04
	Don't know	1·68	0·82
	Wealth quantile		
	Poorest	7·23	24·25
	Poorer	12·25	23·07
	Middle	10·81	20·88
	Richer	9·27	18·31
	Richest	60·44	13·50

1 NB: *n*=weighted; * mother's estimate of baby's size at birth

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Table 2. Crude and multivariable-adjusted prevalence ratios for neonatal death associated with caesarean vs vaginal delivery, Ethiopia DHS, 2016, 2011, 2005 and 2000

	Prevalence Ratio (95% CI) for neonatal death
Ethiopia DHS 2016	
Vaginal delivery	1 [Ref.]
Caesarean delivery, crude (n= 10,641)	3·02 (1·37, 6·66)
Caesarean delivery, model 1 ^a (n=10,641)	2·81 (1·11, 7·13)
Ethiopia DHS 2011	
Vaginal delivery	1 [Ref.]
Caesarean delivery, crude (n=11,654)	1·49 (0·62, 3·61)
Caesarean delivery, model 1 ^a (n= 11,654)	1·15 (0·45, 2·93)
Ethiopia DHS 2005	
Vaginal delivery	1 [Ref.]
Caesarean delivery, crude (n= 9,861)	1·74 (0·67, 4·51)
Caesarean delivery, model 1 ^a (n= 9, 861)	1·53 (0·52, 4·50)
Ethiopia DHS 2000	
Vaginal delivery	1 [Ref.]
Caesarean delivery, crude (n= 10,873)	0·93 (0·38, 2·30)
Caesarean delivery, model 1 ^a (n= 10,853)	0·95 (0·29, 3·19)

^aAdjusted for place of delivery, type of residence (urban/rural), sex of child, size of baby at birth, Mother's age at birth, Mother's education, Birth order, Household wealth.

Table 3. Crude and multivariable-adjusted prevalence ratios for neonatal death associated with caesarean vs vaginal delivery, Ethiopia DHS 2016

	Prevalence Ratio (95% CI) for neonatal death
Main analysis	
Vaginal delivery	1 [Ref.]
Caesarean delivery, crude (n= 10,641)	3·02 (1·37, 6·66)
Caesarean delivery, model 1 ^a (n=10,641)	2·81 (1·11, 7·13)
Sensitivity analyses	
Restricted to Addis Ababa region ^a (n=461)	1·07 (0·20, 5·73)
Excluded Addis Ababa and Hareri regions ^a (n= 9,575)	3·35 (1·31, 8·56)
Restricted to births in public facility ^a (n=3,023)	2·78 (1·16, 6·63)
Restricted to rural mothers ^a (n= 8,636)	3·43 (1·22, 9·67)
Restricted to women from lowest quintile of household wealth (n=3958)	7·01 (0·92, 53·36)
Restricted to women from highest quintile of household wealth (n=2092)	2·72 (0·55, 13·38)

^aAdjusted for place of delivery, type of residence (urban/rural), sex of child, size of baby at birth, Mother's age at birth, Mother's education, Birth order, Household wealth.

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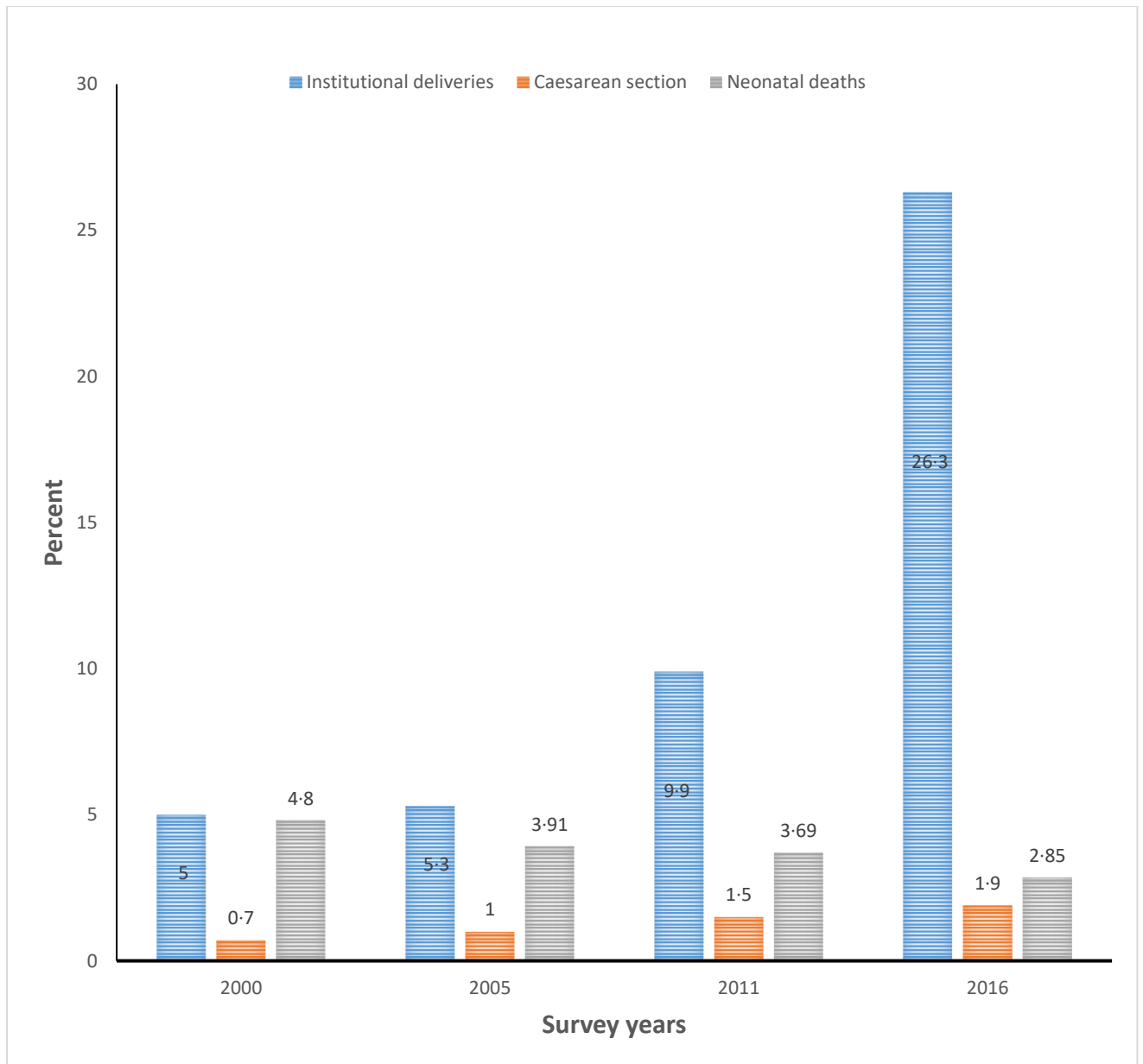


Figure 1. Trends in proportion of institutional deliveries, caesarean section and neonatal deaths in the 5 years before each of the surveys, Ethiopia DHS 2000, 2005, 2011 and 2016.

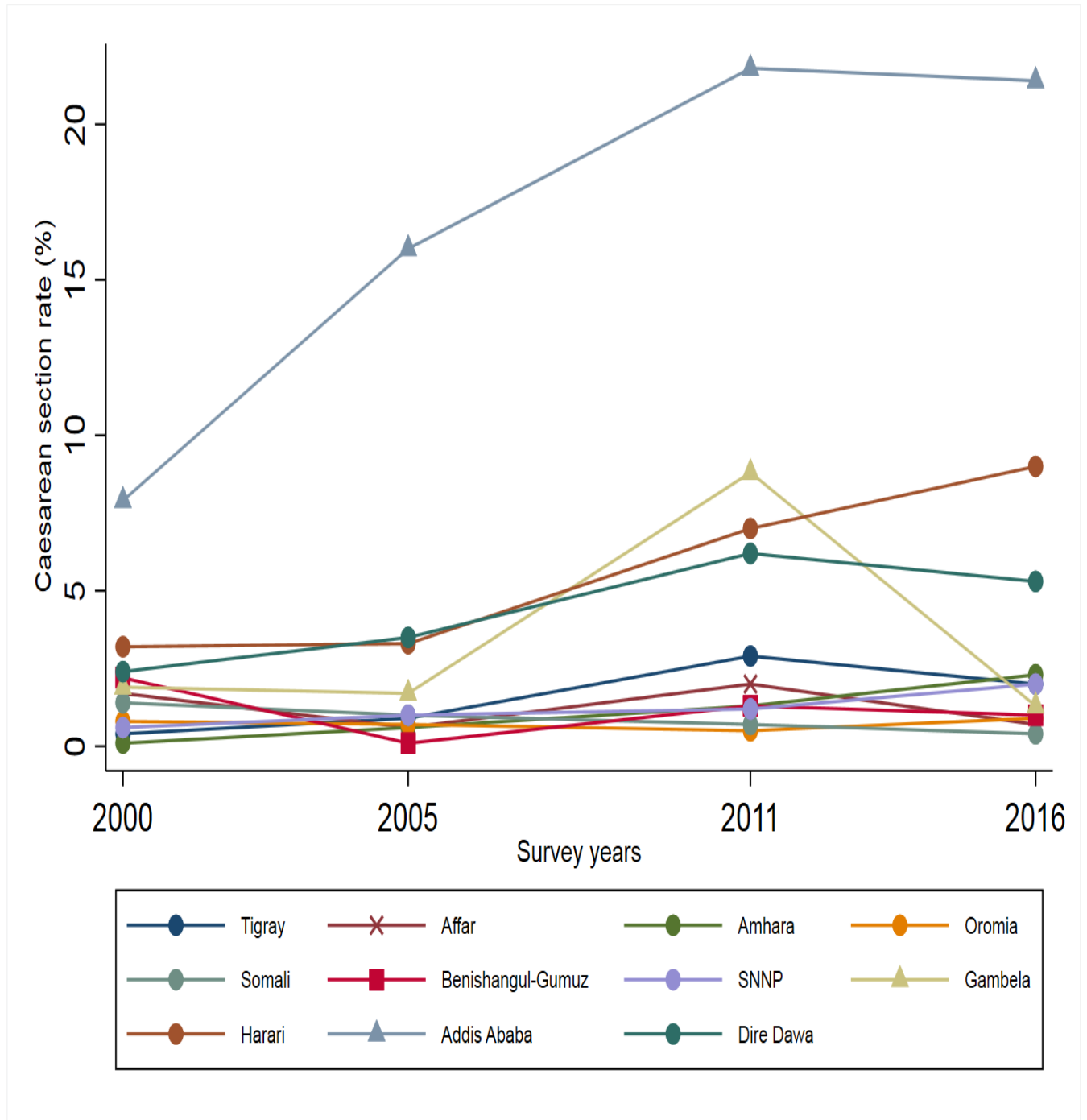


Figure 2. Trends in caesarean section rates in the 5 years before each of the surveys by region of residence, Ethiopia DHS 2000, 2005, 2011 and 2016.

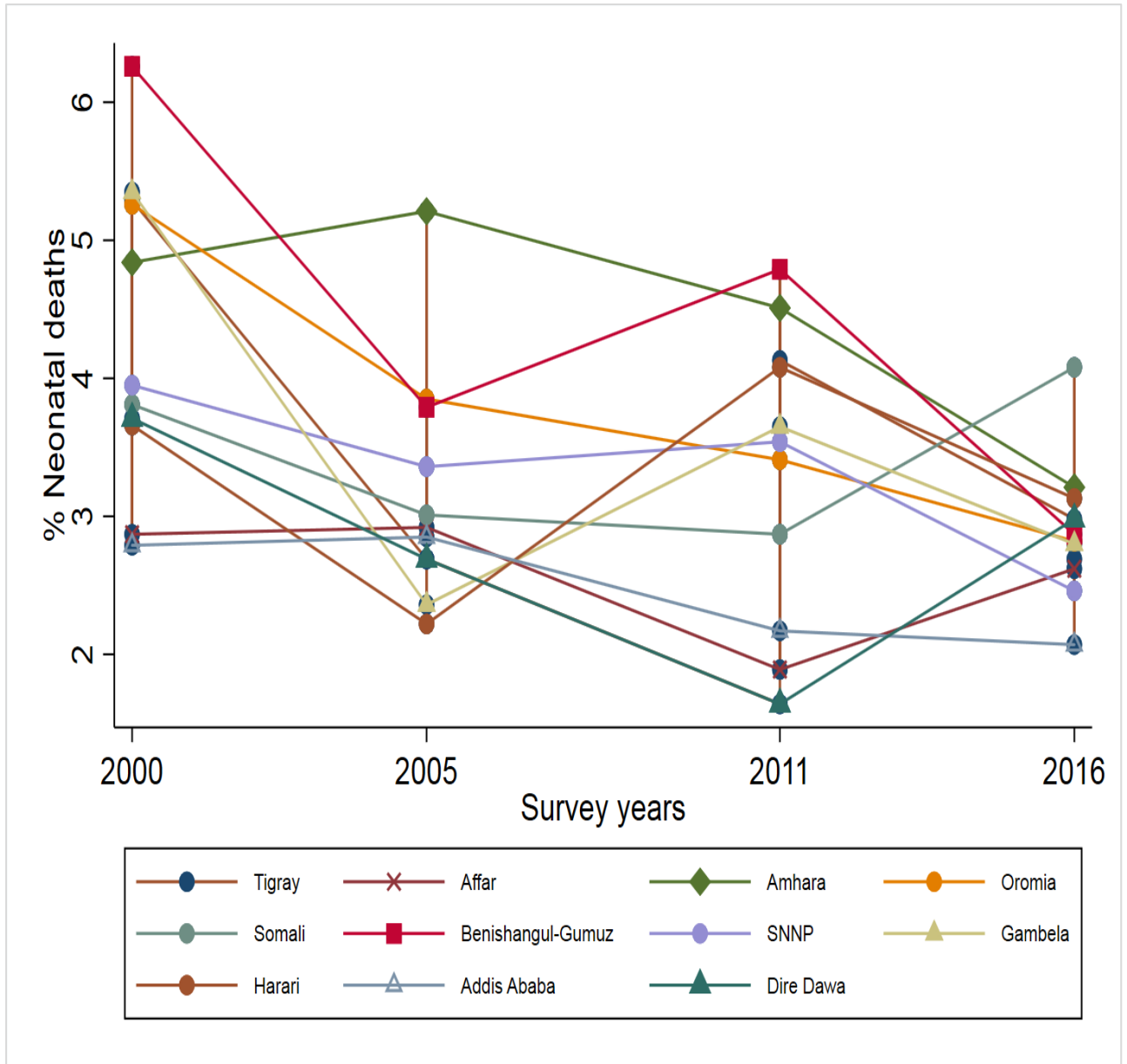


Figure 3. Trends in proportion of neonatal deaths in the 5 years before each of the surveys by region of residence, Ethiopia DHS 2000, 2005, 2011 and 2016.

Supplementary Table 1. Characteristics of the study participants according to mode of delivery, Ethiopia DHS 2000.

	Mode of delivery	
	Caesarean (n=86) %	Vaginal (n=12,174) %
Neonatal death		
Yes	4.48	4.80
No	95.52	95.20
Types of residence		
Urban	76.16	9.95
Rural	23.84	90.05
Region		
Tigray	3.98	6.44
Afar	2.46	1.02
Amhara	3.71	26.27
Oromia	46.31	40.74
Somali	2.29	1.15
Benishangul-Gumuz	3.15	0.99
SNNP	18.55	21.24
Gambela	0.63	0.23
Harari	0.95	0.20
Addis Ababa	16.87	1.38
Dire Dawa	1.11	0.32
Mother's age at birth		
<20	19.37	12.02
20-29	70.83	51.27
30-39	9.81	30.05
40-49	0.00	6.66
Mother's education		
No education	15.66	82.54
Primary	21.76	12.96
Secondary	56.41	4.31
Higher	6.17	0.19
Place of delivery		
Public	96.31	4.04
Private	1.29	0.13
NGO	2.40	0.18
Home	0.00	95.65
Birth order		
1	75.47	18.64
2-3	19.76	30.18
4+	4.77	51.18
Sex of child		
Male	61.80	51.21
Female	38.20	48.79
Size of baby at birth*		
Very large	9.76	5.26
Larger than average	31.96	25.44
Average	34.62	35.73
Smaller than average	19.73	27.56
Very small	3.75	5.86
Don't know	0.19	0.15
Wealth quantile		
Poorest	1.86	21.06
Poorer	4.93	20.98
Middle	4.09	21.96

Richer	6·13	20·54
Richest	82·98	15·46

NB: *n*=weighted; * mother's estimate of baby's size at birth

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Supplementary Table 2. Characteristics of the study participants according to mode of delivery, Ethiopia DHS 2005.

	Mode of delivery	
	Caesarean (n=111) %	Vaginal (n= 11,052) %
Neonatal death		
Yes	6.74	3.89
No	93.26	96.11
Types of residence		
Urban	68.84	6.68
Rural	31.16	93.32
Region		
Tigray	5.38	6.26
Afar	0.58	0.97
Amhara	15.21	23.56
Oromia	28.45	39.62
Somali	4.23	4.28
Benishangul-Gumuz	0.14	0.95
SNNP	21.61	22.40
Gambela	0.46	0.28
Harari	0.66	0.20
Addis Ababa	22.09	1.17
Dire Dawa	1.17	0.33
Mother's age at birth		
<20	13.27	13.39
20-29	59.76	51.18
30-39	24.07	29.28
40-49	2.90	6.16
Mother's education		
No education	30.09	79.67
Primary	14.48	16.64
Secondary	46.54	3.40
Higher	8.88	0.30
Place of delivery		
Public	90.23	3.92
Private	5.93	0.27
NGO	3.84	0.13
Home	0.00	95.67
Birth order		
1	53.19	16.95
2-3	31.69	30.00
4+	15.12	53.04
Sex of child		
Male	51.29	51.27
Female	48.71	48.73
Size of baby at birth*		
Very large	30.74	22.31
Larger than average	11.45	9.45
Average	37.81	39.99
Smaller than average	9.41	7.25
Very small	9.54	20.57
Don't know	1.05	0.42
Wealth quantile		
Poorest	0.58	22.07
Poorer	5.87	21.25
Middle	3.94	22.45

Richer	9.74	20.00
Richest	79.87	14.22

NB: *n*=weighted; * mother's estimate of baby's size at birth

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Supplementary Table 3. Characteristics of the study participants according to mode of delivery, Ethiopia DHS 2011.

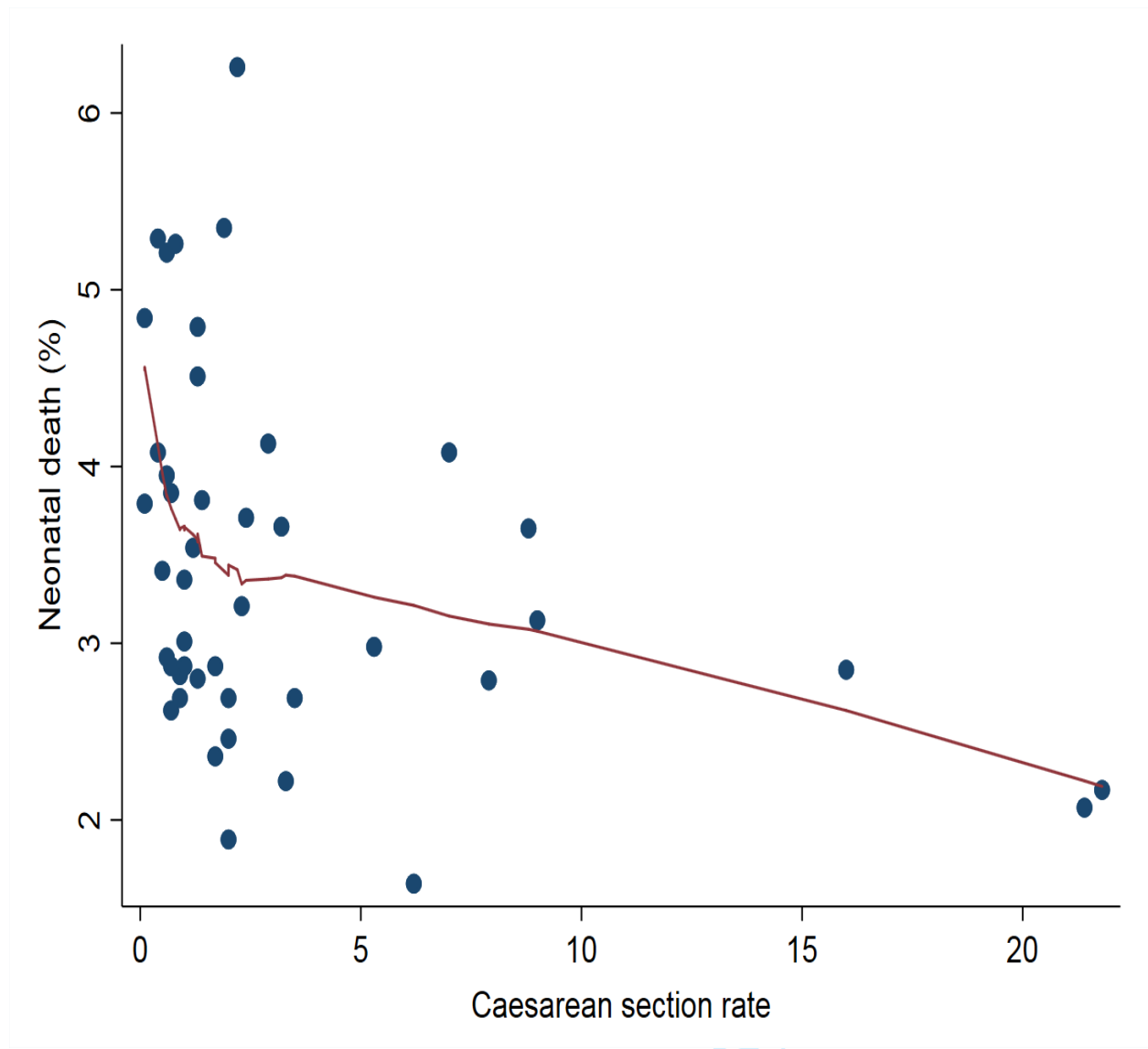
	Mode of delivery	
	Caesarean (n=175) %	Vaginal (n= 11,697) %
Neonatal death		
Yes	5.47	3.66
No	94.53	96.34
Types of residence		
Urban	70.92	12.00
Rural	29.08	88.00
Region		
Tigray	12.52	6.25
Afar	1.41	1.02
Amhara	19.38	22.42
Oromia	14.63	42.64
Somali	1.44	3.09
Benishangul-Gumuz	1.04	1.18
SNNP	17.45	21.06
Gambela	2.01	0.32
Harari	1.15	0.23
Addis Ababa	27.57	1.48
Dire Dawa	1.38	0.31
Mother's age at birth		
<20	10.49	10.86
20-29	62.84	55.69
30-39	23.66	28.71
40-49	3.00	4.74
Mother's education		
No education	19.92	70.04
Primary	44.73	26.78
Secondary	22.17	1.94
Higher	13.18	1.24
Place of delivery		
Public	83.49	7.61
Private	13.55	0.81
NGO	2.96	0.18
Home	0.00	91.41
Birth order		
1	53.54	18.53
2-3	27.37	31.17
4+	19.09	50.29
Sex of child		
Male	57.24	51.87
Female	42.76	48.13
Size of baby at birth*		
Very large	25.82	19.22
Larger than average	11.66	12.75
Average	42.31	38.25
Smaller than average	4.86	8.74
Very small	14.78	20.61
Don't know	0.58	0.42
Wealth quantile		
Poorest	2.05	23.13
Poorer	8.37	22.60
Middle	8.99	20.70

Richer	6·51	19·32
Richest	74·09	14·24

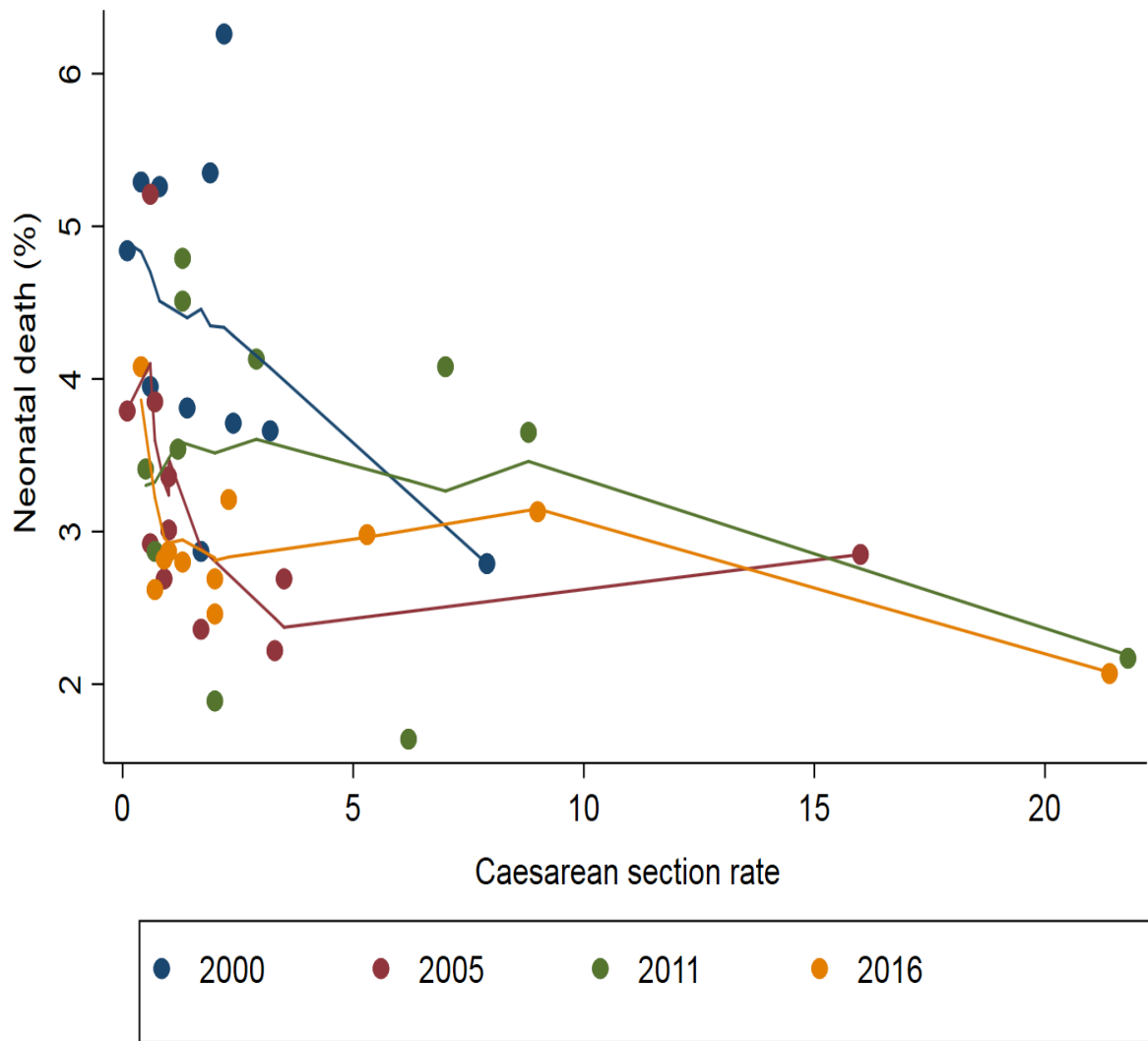
NB: *n*=weighted; * mother's estimate of baby's size at birth

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Supplementary Figure 1. The relationship between caesarean section rate and neonatal death.



Supplementary Figure 2. The relationship between caesarean section rate and neonatal death by survey years.

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The changing temporal association between caesarean birth and neonatal death in Ethiopia: secondary analysis of nationally representative surveys

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Manuscripts

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3 **1 The changing temporal association between caesarean birth and neonatal death**
4 **in Ethiopia: secondary analysis of nationally representative surveys**
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10 4 Engida Yisma^{a, b}, Ben W. Mol^{c, d}, John W. Lynch^{a, c, e} and Lisa G. Smithers^{a, c}
11
12
13
14 5
15
16

17 6 ^aSchool of Public Health, The University of Adelaide, Adelaide, Australia
18
19

20 7 ^bSchool of Allied Health Sciences, College of Health Sciences, Addis Ababa University,
21 Addis Ababa, Ethiopia
22
23

24 9 ^cRobinson Research Institute, School of Medicine, The University of Adelaide, Adelaide,
25 Australia
26 10

27
28
29 11 ^dDepartment of Obstetrics and Gynaecology, Monash University, Melbourne, Australia
30
31

32 12 ^ePopulation Health Sciences, University of Bristol, England, UK
33
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36
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38

39 **15 Corresponding Author:**
40
41

42 16 Engida Yisma
43
44

45 17 School of Public Health, The University of Adelaide, Adelaide, Australia
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47

48 18 Email: engida.derbie@adelaide.edu.au
49

50 19 Tel: +61434860775
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1 **ABSTRACT**

2 **Objective**

3 To interpret the changing temporal association between caesarean birth and neonatal death
4 within the context of Ethiopia from 2000 to 2016.

5 **Design**

6 Secondary analysis of Ethiopian Demographic and Health Surveys (DHS).

7 **Setting**

8 All administrative regions of Ethiopia with surveys conducted in 2000, 2005, 2011, and 2016.

9 **Participants**

10 Women aged 15-49 years with a live birth during the five years preceding the survey.

11 **Main outcome measures**

12 We analysed the association between caesarean birth and neonatal death using log-Poisson
13 regression models for each survey adjusted for potential confounders. We then applied the
14 'Three Delays Model' to provide an interpretation of the changing association between
15 caesarean birth and neonatal death in Ethiopia.

16 **Results**

17 The adjusted prevalence ratios (aPR) for neonatal death among neonates born via caesarean
18 section versus vaginal birth increased over time, from 0.95 (95% CI, 0.29, 3.19) in 2000 to
19 2.81 (95% CI, 1.11, 7.13) in 2016. The association between caesarean birth and neonatal
20 death was stronger among rural women (aPR (95% CI) 3.43 (1.22, 9.67)) and among women
21 from the lowest quintile of household wealth (aPR (95% CI) 7.01 (0.92, 53.36)) in 2016.
22 Aggregate-level analysis revealed that an increased caesarean section rates were correlated
23 with decreased proportion of neonatal deaths.

24

1 **Conclusions**

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6 2 A naïve interpretation of the changing temporal association between caesarean birth and
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8 3 neonatal death from 2000 to 2016 is that caesarean section is increasingly associated with
9
10 4 neonatal death. However, the changing temporal association reflects improvements in health
11
12 5 service coverage and secular shifts in the characteristics of Ethiopian women undergoing
13
14 6 caesarean section after complicated labour or severe foetal compromise.
15

7 8 **Strengths and limitations of this study**

- 9
- 10 • This was the first study to examine the temporal association between caesarean birth
11 and neonatal death within the context of Ethiopia from 2000 to 2016.
 - 12 • A number of analyses were conducted after adjustment for potential confounders
13 helped develop the possible scenarios to better understand the interpretation of the
14 changing associations.
 - 15 • We have used additional supporting evidence from Ethiopian DHS data which
16 allowed us to interpret the changing association between caesarean birth and neonatal
17 death in view of contextual factors in Ethiopia using the ‘Three Delays Model’.
 - 18 • Given the very low base rates of caesarean delivery in Ethiopia, the interpretation of
19 our findings may not reflect the context of other low-and middle-income countries.
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1 Introduction

2 Globally, 2.6 million neonatal deaths occurred within the first 28 days after birth, which
3 accounted for 46% of all under-five deaths in 2016.¹ The majority of these deaths were from
4 low- and middle-income countries. According to the United Nations Inter-agency Group for
5 Child Mortality Estimation, Southern Asia (39%) and sub-Saharan Africa (38%) comprised
6 the top two regions with the highest proportion of neonatal deaths, while five countries
7 (India, Pakistan, Nigeria, the Democratic Republic of the Congo, and Ethiopia) accounted for
8 50% of all newborn deaths.¹ Unlike under-five mortality, the proportion of neonatal deaths is
9 increasing.² If the current trend continues, more low-and middle-income countries will fail to
10 achieve the Sustainable Development Goal (SDG) target for neonatal mortality at 12 per
11 1,000 live births.³

12
13 In contemporary obstetric practice, caesarean section remains an important intervention in
14 preventing neonatal mortality and other adverse birth outcomes.⁴ However, caesarean section
15 may be prone to misuse because of unequal access, social, and cultural factors.⁵⁻⁷ In
16 developing country settings, due to limited medical provisions and/or lack of skilled birth
17 attendants, some women may not benefit from caesarean birth though they are medically
18 eligible, while ineligible women may sometimes have increased access. In the last decades,
19 caesarean section rates have been increasing in low-, middle, and high-income countries.⁸⁻¹⁰
20 The World Health Organization (WHO) suggests, “every effort should be made to provide
21 caesarean sections to women in need, rather than striving to achieve a specific rate.”¹¹

22
23 Previous studies conducted using aggregate- and individual-level data have yielded
24 inconsistent results about the association between caesarean birth and neonatal mortality. For
25 instance, two ecological studies^{12,13} conducted using worldwide country-level data have
26 found that caesarean birth was associated with lower neonatal mortality while another two
27 ecological studies^{14,15} showed no association between caesarean birth and neonatal mortality,
28 where caesarean section rates were higher than 10%. Inconsistent results for the association
29 between caesarean birth and neonatal mortality were also reported by different studies
30 conducted in Africa, Latin America, Asia, and United States of America based on individual-
31 level data.¹⁶⁻²¹ For example, a large study conducted by Villar et al. in 410 health facilities in
32 24 areas in eight Latin American countries found that, with cephalic presentation, both
33 intrapartum and elective caesarean was associated with 1.66 (95% Confidence Interval (CI):

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3 1 1.26, 2.20) and 1.99 (95%CI: 1.51, 2.63) times higher odds of neonatal mortality up to
4 hospital discharge, respectively.¹⁷ However, another study based on WHO global survey
5 completed in nine countries in Asia found that both pre-labour (Adjusted Odds Ratio (aOR)
6 0.2, (95% CI: 0.1, 0.3)) and intrapartum caesarean sections (aOR 0.3, 95% CI: 0.2, 0.4) were
7 associated with improved perinatal outcomes following breech presentation¹⁶.
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13
14 7 On the other hand, using both country-and individual-level data collected for nationally
15 representative Demographic and Health Surveys (DHS), Kyu et al. found an increased risk
16 for neonatal death associated with caesarean versus vaginal births in countries with low (<
17 5%) and medium (5-15%) caesarean section rates.²² However, factors associated with
18 caesarean section that increase risk for neonatal death in countries with low and moderate
19 caesarean section rates remain ill-defined. Previous studies are limited by either inconsistent
20 results or lack the interpretation of findings by considering the contextual factors.¹²⁻²² In
21 addition to the underlying indications for caesarean interventions like ‘fetal distress’, ‘cord
22 prolapse’, ‘prolonged and obstructed labour’, ‘fetal mal-presentation’, ‘major antepartum
23 haemorrhage’, and ‘placenta praevia’;^{23,24} several contextual factors such as unequal access,
24 infrastructural, and health workforce constraints could play a role in the association between
25 caesarean section and neonatal death.
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36 20 In low- and middle-income countries, the DHS are the most representative and widely
37 available quality data sources for studies related to maternal and child health. In a recent
38 study using DHS data in Ethiopia, it was shown that the proportion of institutional deliveries
39 and caesarean section rates are still low, especially for rural births though increases from
40 2000 to 2016 surveys are notable.²⁵ We use Ethiopian DHS data from 2000, 2005, 2011, and
41 2016 to examine the association between caesarean birth and neonatal death. We then apply
42 the ‘Three Delays Model’ developed by Thadeus and Maine²⁶ to provide an interpretation of
43 the changing association between caesarean birth and neonatal death in Ethiopia.
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1 **Methods**

2 **Study design and data samples**

3 We used data from the Ethiopian DHS completed in 2000, 2005, 2011, and 2016. The
4 Ethiopian DHS are nationally representative cross-sectional surveys conducted in nine
5 regions (Tigray, Afar, Amhara, Oromia, Somali, Benishangul-Gumuz, SNNPR, Gambela,
6 and Harari), and two city administrations (Addis Ababa and Dire Dawa). Each of the surveys
7 involved a two-stage, stratified, clustered sampling design. The survey datasets are de-
8 identified and made freely available online. Permission to use these data was granted by the
9 MEASURE DHS Program. The details about the methodology and standards for protecting
10 the privacy of study participants in all DHS can be accessed at
11 (<http://www.measuredhs.com/What-We-Do/methodology.cfm>).

13 **Exposure**

14 The DHS questionnaire asks women about pregnancy, antenatal, and delivery care for
15 livebirths they have reported in the past 5 years. The self-reported data on caesarean section
16 rates collected for DHS, compared with facility-based records of caesarean sections, are
17 found to be reliable in developing countries.²⁷ For this study, the exposure group were
18 children delivered by caesarean section and unexposed group comprised children born
19 vaginally.

21 **Outcome**

22 Neonatal death includes children who were born alive in the 5 years before the survey, but
23 died within the first 28 days of life. The outcome variable, neonatal death, was measured
24 from two variables (whether the child is alive and age at death (in days)).

26 **Confounding**

27 The following potential confounders were identified based on a priori subject-matter and
28 expert knowledge. They included place of delivery (public, private, NGO, home), type of
29 residence (urban/rural), sex of child (male/female), size of baby at birth (very large, larger
30 than average, average, smaller than average, very small, don't know), mother's age at birth
31 (in years), mother's education (no education, primary, secondary, higher), birth order (1, 2-3,
32 4+), and household wealth quintile (poorest, poorer, middle, richer, richest). Mother's age at

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3 1 birth was calculated as a difference (in years) between infant's date of birth and mother's date
4 of birth. DHS computes the wealth index for each survey based on household assets using
5 2 principal components analyses²⁸ and categorizes households into wealth quintiles. These
6 3 asset-based measures represent the wealth distribution relative to other households within the
7 4 country. They are widely used and are consistent with comparisons to household
8 5 expenditures and the measurement of inequalities in child mortality, education, and
9 6 healthcare use in low-and middle-income countries.²⁹
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17 9 **Statistical analysis**

10 All analyses were weighted to be nationally representative. As women may have had more
11 than one birth within the five-year survey periods, we also accounted for both clustering of
12 cesarean deliveries within women as well as the complex survey design during the data
13 analyses using the unit of analysis (children) study number and sample weights. We then
14 conducted both individual- and aggregate-levels analyses. Our analysis was also
15 supplemented by an application of the 'Three Delays Model' to interpret the changing
16 association between caesarean birth and neonatal death both empirically and theoretically.
17 All analyses were conducted using STATA/SE version 15.1 (Stata Corporation, College
18 Station, TX).
19

20 **Individual-level analysis**

21 Associations between caesarean birth and neonatal death at the individual level were analysed
22 using log-Poisson regression using data from Ethiopian DHS in 2000, 2005, 2011, and 2016.
23 We calculated unadjusted and adjusted prevalence ratios (aPR) and their 95% Confidence
24 Intervals (CIs) for each survey. We have then compared the strength of association between
25 caesarean birth and neonatal death across all surveys analysed.
26

27 After noting the increasing association between caesarean birth and neonatal death over time,
28 we conducted a series of analyses to explore what was during the change. We used the 2016
29 data because the association was more pronounced. We first restricted the analysis to
30 participants living in regions with the highest caesarean section rates to examine whether the
31 increased access to caesarean section affected the proportion of neonatal deaths. We then
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3 1 estimated the effect of caesarean birth on neonatal death in regions with low caesarean
4 2 section rate (ranged: 0.4-5.3%) or where access to caesarean section is limited, by excluding
5 3 births in relatively high caesarean section rate regions—Addis Ababa (21.4%) and Hareri
6 4 (9.0%).²⁵ Both low-and high-level of caesarean use has risks exceeding the risks of
7 5 spontaneous vaginal deliveries.^{16,30} It was demonstrated that low levels of caesarean are
8 6 related to lack of access and can contribute to maternal and newborn deaths.^{22,31}
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42 8 Given the very large rural-urban differences in caesarean section in Ethiopia,^{25,32} we also
43 9 conducted similar analyses separately for rural women. In addition, we evaluated the
44 10 association by restricting the analyses to births from the lowest quintile of household wealth,
45 11 births from the highest quintile of household wealth, and births in public health facilities
46 12 separately. These alternative analyses were exploratory in nature and helped us to understand
47 13 contextual factors leading to inequalities in caesarean use that may occur not only due to
48 14 inadequate access among the poorest women, but also overuse of caesarean section among
49 15 the richest population subgroups.^{33,34} However, as the caesarean section rate in Ethiopia is
50 16 low (about 2%), the number of neonatal deaths following caesarean birth is low and resulted
51 17 in wide confidence intervals for the estimates. The subgroup analyses allowed us to explain
52 18 how contextual factors such as unequal access, infrastructural, and workforce constraints
53 19 could play role in the association between caesarean section and neonatal death because these
54 20 factors will result in delay in accessing emergency caesarean section, which is usually
55 21 accessible at specialized health facilities.

56 22 The 2016 DHS data included an additional question regarding ‘timing of decision to conduct
57 23 caesarean section (i.e., whether it was before or after the onset of labour pains).’ We used this
58 24 variable as a proxy to type of caesarean birth (indicative of intrapartum or pre-labour
59 25 caesarean section) and conducted analysis to examine the association between types of
60 26 caesarean section and neonatal death. As this is confined only to 2016 data, we have provided
61 27 the results in the **Supplementary Table A1**.

62 28 **Aggregate-level analysis**

63 29 Data on the caesarean section rate and proportion of neonatal deaths were disaggregated by
64 30 urban-rural areas for each of the nine regions and two city administrations in Ethiopia for
65 31 each of DHS surveys in 2000, 2005, 2011, and 2016. However, the urban-rural stratification
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3 1 for Addis Ababa is only available for the 2005 survey. These results in a total of 85 data
4 points (observations). In order to assess the correlation between caesarean section and
5 2 neonatal death at aggregate-level, we conducted simple linear regression for overall surveys
6 3 together and for individual surveys separately.
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13 6 **The ‘Three Delays Model’**

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16 7 The ‘Three Delays Model’ is a conceptual framework developed by Thadeus and Maine to
17 8 examine factors contributing to maternal mortality with specific focus on those that affect the
18 9 “interval between the onset of obstetric complication and its outcome.”²⁶ The ‘Three Delays
19 10 Model’ summarises the various factors that affect this interval into three phases of delay—
20 11 delay in deciding to seek care (*Phase I delay*); delay in identifying and reaching medical
21 12 facility (*Phase II delay*); and delay in receiving adequate and appropriate treatment (*Phase III*
22 13 *delay*). Some of the key factors that shape the model include: the status of women; distance
23 14 from the health facility; availability and cost of transportation; condition of roads; distribution
24 15 of health facilities; shortage of supplies, equipment, and skilled birth attendants; and
25 16 adequacy of referral system.²⁶ The pictorial presentation of the ‘Three Delays Model’ is
26 17 provided in the **Supplementary Figure A1-A4**.
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38 19 As maternal and neonatal mortality share many risk factors, we adopted the ‘Three Delays
39 20 Model’ as a framework to help interpret the changing association between caesarean birth
40 21 and neonatal mortality within the context of Ethiopia because factors contributing to the
41 22 ‘three delays’ aggravate the underlying medical indications for caesarean intervention that
42 23 make neonatal death difficult to prevent. Previous studies conducted in India,³⁵ Tanzania³⁶
43 24 and Uganda³⁷ have applied the ‘Three Delays Model’ to their analyses of perinatal deaths.

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47 25 We have identified some contributing factors underlying the ‘Three Delays Model’ from the
48 26 2016 survey. For example, information regarding problems faced by women of reproductive
49 27 age (15-49 years) in accessing health care to obtain medical advice or treatment for
50 28 themselves when they are sick were gathered. It consisted of four questions: distance to
51 29 health facility (big problem/not big problem); getting money for treatment (big problem/not
52 30 big problem); getting permission to go for treatment (big problem/not big problem); and not
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3 1 wanting to go alone (big problem/not big problem). Furthermore, data on attendance by
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5 2 skilled birth attendants during delivery and women's socioeconomic and demographic status
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7 3 are also available in the DHS. This information can particularly be important to understand
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9 4 and address the barriers that women face in seeking care during pregnancy and delivery.³²
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11 5 We have, therefore, analysed the DHS data to describe these factors empirically in the
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13 6 context of Ethiopia.

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16 17 8 **Patient involvement**

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19 9 No patients were involved in setting the research question or the outcome measures, nor were
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21 10 they involved in the design and implementation of the study. No patients were asked to
22
23 11 advise on interpretation or writing up of results. There are no plans to disseminate the results
24
25 12 of the research to study participants or the relevant patient community.

1 Results

2 **Table 1** shows the characteristics of mothers and children according to mode of delivery for
3 each of the surveys conducted in 2000, 2005, 2011, and 2016. Across the four DHS survey
4 waves, women who underwent caesarean delivery were more likely to live in urban areas,
5 had a higher level of education, and were from the richest quintile of household wealth. They
6 were also more likely to have male children. Caesarean deliveries were more frequent in
7 women in the age category of 20-29 years, and among infants who had either very large or
8 large size at birth. **Figure 1** shows that the proportion of institutional deliveries increased
9 from 5.0% in 2000 to 26.3% in 2016, whereas the national caesarean section rate increased
10 from 0.7% in 2000 to 1.9% in 2016. However, the rate of caesarean delivery in Ethiopia
11 varied widely across administrative regions (**Figure 2**). For instance, Addis Ababa had the
12 highest (21.4%) rate, while Somali region had the lowest (0.4%) in 2016. The national
13 proportion of neonatal deaths decreased from 4.8% in 2000 to 2.9% in 2016, but the
14 proportion varies among administrative regions (**Figure 1 & Supplementary Table A2**).

15
16 **Table 2** shows that the adjusted prevalence ratio (aPR) for neonatal death associated with
17 caesarean versus vaginal births in 2000 DHS was 0.95 (95%CI, 0.29, 3.19), in 2005 it was
18 1.53 (95%CI, 0.52, 4.50). In 2011, the adjusted prevalence ratio (aPR) for neonatal death
19 associated with caesarean versus vaginal births was 1.15 (95%CI, 0.45, 2.93), while in 2016
20 it was 2.81-fold higher risk of neonatal death (aPR, 2.81; 95%CI, 1.11, 7.13).

21
22 **Table 3** summarises the findings of the subgroup analyses based on the 2016 data. When
23 women living in urban settings, (Addis Ababa (caesarean section rate (21.4%), and Hareri
24 (9.0%)), were excluded from the analyses, the corresponding adjusted PR for neonatal death
25 was increased to 3.55 (95%CI, 1.31, 8.56). Similarly, when we restricted the analyses to
26 include only rural women, the prevalence ratio for neonatal death associated with caesarean
27 versus vaginal births was found to be 3.43 (95% CI, 1.22, 9.67). The respective risk of
28 neonatal death increased to 7.01 (95%CI, 0.92, 53.36) when the analysis was limited to
29 women from the lowest quintile of household wealth.

30
31 When we restricted the analyses to Addis Ababa, the capital of Ethiopia, the relative risk for
32 neonatal death associated with caesarean versus vaginal births was 1.07 (95%CI, 0.20, 5.73).

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3 1 Moreover, when the analysis was confined to women from the highest quintile of the
4 2 household wealth, the risk of neonatal death was 2.72 (95% CI, 0.55, 13.38).

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9 4 Lastly, **Figure 3** shows that an increase in caesarean section rate is weakly correlated with a
10 5 decrease in the proportion of neonatal deaths (correlation coefficient (r) = -0.1839) when
11 6 aggregate-level data for all surveys together was analyzed. However, the relationship
12 7 between caesarean birth and neonatal death is variable when the analysis is restricted to each
13 8 survey year separately (see **Figure 4**).

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1 Interpretation

2 The primary individual level analyses showed that the adjusted prevalence ratios (aPR) for
3 neonatal death associated with caesarean versus vaginal births increased from 0.95 (95% CI,
4 0.29, 3.19) in 2000 to 2.81 (95% CI, 1.11, 7.13) in 2016. These findings suggest that the
5 circumstances for foetuses born in 2000 DHS are different from the foetuses in 2016. Our
6 subgroup analyses using 2016 data suggest that the association between caesarean birth and
7 neonatal death was stronger among rural women (aPR (95% CI) 3.43 (1.22, 9.67)) and among
8 women from the lowest quintile of household wealth (aPR (95% CI) 7.01 (0.92, 53.36)), but
9 not for births in areas with wider availability of caesarean such as Addis Ababa (aPR (95%
10 CI) 1.07 (0.20, 5.73)). The changing association between caesarean birth and neonatal death
11 over time, and the stronger association observed among different subgroup analyses may be
12 attributable to changes in the pattern of confounding by indication due to contextual factors
13 such as unequal access, structural health-system deficiencies (insufficient equipment,
14 supplies, and drugs), infrastructural, and health workforce constraints.

15
16 The national caesarean section and institutional delivery rates in Ethiopia are still low though
17 increases in the past decade are notable. There is also substantial disparity in caesarean
18 section rates, with very low rates in rural areas and among the poorest women,²⁵ suggesting
19 unequal access which may be as a consequence of a range of geographic, social, and
20 economic barriers. The low caesarean rates may also be due to lack of skilled birth
21 attendants, and poor health infrastructure (e.g., shortage of medical care institutions,
22 deficiencies in surgical facilities, surgical and anaesthesia personnel and equipment, and
23 blood transfusion capacity).³⁸⁻⁴⁰ In Ethiopia, there are only 820 Obstetricians, 10,846 General
24 practitioners, 996 Emergency obstetric surgeons, 6,345 Health officers, 41,009 Nurses, 8,635
25 Midwives, 233 Anaesthesiologists, and 33,320 Health extension workers for the population
26 of over 90 million in 2015.⁴¹ Similarly, there are only 3,547 functional Health centres, 16,
27 447 functional Health posts, and 189 functional Hospitals in 2015.⁴²

28
29 We know from previous research that inadequate access to timely caesarean section may
30 result in perinatal asphyxia, uterine rupture, obstructed labour, and these can contribute to
31 maternal and newborn deaths.⁴³ Conversely, it was demonstrated that maternal and neonatal
32 mortality due to obstetric complications can be prevented with timely access to caesarean
33 section.^{43,44} Delay, therefore, emerges as relevant factor in worsening the underlying medical

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3 1 indications for caesarean intervention thereby contributing to neonatal death. Context specific
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5 2 factors that delay access to caesarean section may have the capacity to make women with
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7 3 labour problems undergo caesarean section after severe complication of labour or severe
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9 4 foetal compromise. Therefore, our interpretation is that caesarean section conducted after
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11 5 severe foetal compromise may not prevent neonatal deaths because they have already
12
13 6 experienced such severity of complications that although live born, neonatal death is difficult
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15 7 to prevent.
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17 8
18 9 There are two possible scenarios leading to caesarean section in Ethiopia. First, when women
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20 10 who have previously had a caesarean section, with breech presentation, or other risk factors
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22 11 such as eclampsia attend specialised health facilities, they are usually allowed to undergo
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24 12 caesarean section. Their caesarean section is commonly classified as “elective or scheduled
25
26 13 caesarean section.” Second, when caesarean section is performed for “emergency reasons.”
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28 14 Full term mothers with or without signs of labour will be admitted to health facilities where
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30 15 their progress is monitored and labour-augmenting or inducing medications may be
31
32 16 administered. Decisions to perform caesarean section in these facilities or decision to refer
33
34 17 the mother to nearby hospitals for caesarean delivery or other action depends on the condition
35
36 18 of the mother and foetus during the progress of labour. In primary health facilities (i.e., health
37
38 19 posts and health centres), obstetric care providers use a ‘Partograph’,^{45,46} a routine labour
39
40 20 monitoring instrument (chart) which helps the health care provider in identifying slow
41
42 21 progress in labour and take appropriate action. In hospitals, the decision to perform a
43
44 22 caesarean section is reached when the labour is prolonged and/or the second stage of labour is
45
46 23 complicated risking the life of mother and foetus.
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48 24
49 25 Given these pathways to caesarean delivery in mind, our interpretation of the changing
50
51 26 association between caesarean birth and neonatal death in Ethiopia may be shaped by
52
53 27 examining factors contributing to delays in the ‘Three Delays Model.’ This is because delays
54
55 28 to caesarean section aggravate the underlying medical indications for caesarean intervention.
56
57 29 **Table 4** shows factors affecting the lengths of delays in the ‘Three Delays Model’, according
58
59 30 to sociodemographic characteristics in Ethiopia.
60

31 32 **Phase I delay: deciding to seek care**

33 In Ethiopia, poorer and less-educated women are more likely to select a nearby health

1 facility, especially in rural areas, where there is limited access to caesarean section and the
2 possibility of benefiting from caesarean section is mainly through referral to higher levels of
3 care. Women are more likely to undergo a caesarean section if they present to specialized
4 health facilities. However, the outcome of delivery depends on how quick/competent the
5 health care provider is in referring the mother or on intervening, and the severity of the
6 underlying medical complication for caesarean intervention which may be affected by the
7 delay in women's or family's decision to seek care. Poor health decision-making depends on
8 numerous factors such as educational status, distance to health facility, economic status,
9 sociocultural factors (e.g., unsupportive spouse, and lack of autonomy), and quality of
10 care.^{26,47,48}

11
12 **Table 4** shows that 'distance to health facility' was a big problem in accessing health care for
13 about 60% of rural and 17% of urban women in Ethiopia. Similarly, 'getting money for
14 treatment' is a big problem to access health care and was reported by 61% of rural and 35%
15 of urban women in 2016 DHS. On the other hand, the status of women in a given society
16 affects the decision to seek care. For instance, efforts to seek timely care is influenced by
17 women's limited mobility because they need permission to travel from spouse and/or mother-
18 in-law.²⁶ In Ethiopia, about 37% of rural and 15% of urban women reported 'getting
19 permission to go for treatment' is a big problem to access health care.

22 **Phase II delay: identifying and reaching a medical facility**

23 Delay in reaching health care may occur when women who encounter obstetric complication
24 live further from health facilities, where the availability and cost of transportation is
25 problematic. In one study conducted in rural India, Kumar *et al.*⁴⁷ found that health facility
26 births occur less likely among women living farther away from the health facilities,
27 suggesting distance as an important barrier to in-facility births for rural women. In addition to
28 the travel distance, the scarcity of transportation which may be accompanied by poor roads is
29 also another obstacle for women with labour complications to timely reach even the closest
30 health facility. As a result of this, women who arrive at the nearby facility following labour
31 complications probably will travel further to specialised hospital due to emergency referral. It
32 is clear that the obstetric complications encountered by mothers reaching nearby primary
33 health facilities will be compounded by additional delays when they are referred for

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2
3 1 caesarean section. These scenarios highlight the likelihood of adverse delivery outcome
4 followed by aggravated obstetric complications due to delays in reaching medical facility as
5 2 high.
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10 5 In Ethiopia, about 50% of women of reproductive age (15-49 years) reported ‘distance to
11 6 health facility’ as a big problem to access health care (see **Table 4**). Moreover, access to
12 7 caesarean situation in Ethiopia is worse than in most other settings.
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15 9 **Phase III delay: receiving adequate and appropriate treatment**

16 10 Phase III delays occur within any health facilities and are indicators of inadequate care due to
17 11 lack of facilities; inadequately trained obstetric care givers (skilled birth attendants); and
18 12 deficiencies in surgical facilities, surgical and anaesthesia personnel and equipment, and
19 13 blood transfusion as well as inadequate and inappropriate referral systems. These
20 14 deficiencies will limit women’s access to lifesaving procedures such as caesarean section. In
21 15 Ethiopia, only 28.0% of all births were delivered by ‘skilled providers’ (includes doctor,
22 16 nurse, midwife, health officer, and health extension worker) in 2016 DHS. **Table 4** also
23 17 shows that there are disparities in the proportion of births attended by skilled birth attendants
24 18 by urban-rural place of residence, region, level of mother’s education, and household wealth.
25 19 It is clear that an insufficient number of skilled birth attendants at any health facility will lead
26 20 to delay in receiving appropriate treatment among women with obstetric complications.

27 21 Although health posts and health centres (primary health care unit) are the most accessible to
28 22 the general population in Ethiopia, they are not fully equipped to deal with obstetric
29 23 complications.^{41,42} As a result of this, women with complications will have to travel on to
30 24 better equipped institution (secondary and tertiary level health care) with caesarean section
31 25 capacity (e.g. general hospitals and specialized hospitals) through referral. By the time the
32 26 women reach these well-equipped health facility, the delays will have further aggravated the
33 27 obstetric complication on the way. A schematic representation of Ethiopian health system
34 28 structure is provided in **Supplementary Figure A5**.
35 29

36 30 On the other hand, delay in caesarean intervention may even happen if mothers with less
37 31 severe labour complications were referred and presented to specialised health facilities in a
38 32 timely manner. This is because a trial of labour is usually attempted before a decision to have
39 33 caesarean section. For instance, some women who are referred from primary health facilities
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3 1 undergo induction and augmentation of labour because these interventions are only provided
4 in health facilities with the capacity to provide caesarean section in Ethiopia. These practices,
5 2 in turn, will result in delay in receiving caesarean section leading to worsening of the already
6 3 existing obstetric complications. Thus, any delays to caesarean intervention have a higher
7 4 chance of aggravating the already existing complications and increase the risk of neonatal
8 5 death.
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1 Discussion

2 Our study examined the changing temporal association between caesarean birth and neonatal
3 death within the context of Ethiopia from 2000 to 2016. The association between caesarean
4 section and neonatal death increased over time and was variable among population
5 subgroups. These changes over time, and variation across population sub-groups may be
6 attributable to changes in the pattern of confounding by indication due to contextual factors
7 such as improvement in health service coverage, unequal access (e.g. due to a range of
8 geographic, social, and economic barriers), and structural, and health workforce constraints.

9
10 In Ethiopia, the proportion of women aged 15-49 who received any antenatal care from a
11 skilled provider has increased from 27% in 2000 to 62% in 2016.³² Health facility-based
12 deliveries have increased from 5% in 2000 to 26% in 2016 (increased from 2% in 2000 to
13 20% in 2016 for rural women, and increased from 32% in 2000 to 79% in 2016 for urban
14 women).³² The proportion of births in health facilities assisted by a skilled birth attendants
15 increased from 6% in 2000 to 28% in 2016.³² These figures reflect improvement in health
16 service coverage in Ethiopia.

17
18 Moreover, since 2004, with the implementation of the Health Extension Programme—a
19 community-based primary healthcare programme—the Ethiopian government has increased
20 the number of health posts from 4,211 in 2005 to 16,447 in 2015.^{42,49} Likewise, the number
21 of health centres were increased from 600 in 2005 to 3,586 in 2015.^{42,49} However, due to
22 limitations in proper monitoring of labour for making timely decisions, especially on whether
23 or not to initiate a referral from primary health facilities to higher level facilities, and due to
24 poor transport and road networks which are still the common problems in low income
25 countries,⁵⁰ the underlying medical indications for caesarean intervention will be worsened
26 by factors contributing to ‘delays.’ Delay in receiving adequate and appropriate care is still a
27 common problem in low income countries due to deficiencies in surgical facilities, surgical
28 and anaesthesia personnel and equipment, blood transfusion capacity, and a shortage of
29 skilled birth attendants.⁵¹⁻⁵³ There is also an inequitable distribution of the health workforce
30 across urban and rural areas. For example, the majority of specialist doctors in Ethiopia serve
31 in urban areas, where the total population distribution is only 19.4%.^{41,42} These situations
32 often result in poor quality care to rural women, and the caesarean section conducted after a
33 complicated labour may be associated with increased neonatal mortality due to confounding

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7 3 Unlike previous studies, the present study takes into account the interpretation of the
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9 4 changing association between caesarean birth and neonatal death within the context of
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11 5 Ethiopia using DHS data. The change in the strength of effect estimates across DHS waves,
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13 6 and the different subgroup analyses suggest that neonatal mortality can be reduced by
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15 7 increasing timely access to caesarean section and timely decision for caesarean delivery via
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17 8 increasing health service coverage, improving infrastructure (e.g. increasing number of health
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19 9 facilities), increasing the number of skilled birth attendants, improving quality of care, and
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21 10 increasing awareness about antenatal care and health facility delivery among women.
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23 11 Moreover, provision of training to skilled birth attendants on close monitoring of labour and
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25 12 early detection of complications, equipping the primary health facilities (e.g. health centres)
26
27 13 to the level of caesarean capacity, and continuous financial investment in primary health
28
29 14 facilities will be an important strategy to reduce neonatal mortality.
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32
33 16 It appears that previous studies which used individual-level data are more likely to report an
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35 17 increased risk of neonatal death among infants born by caesarean section than the ecological
36
37 18 studies. This may be due to the indications for the caesarean delivery (e.g. the severity of the
38
39 19 underlying causes) was involved in causing both caesarean delivery and neonatal death in
40
41 20 studies which used individual-level data, suggesting the role of confounding by indication in
42
43 21 the association between caesarean birth and neonatal death because an intended effect of
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45 22 caesarean birth is prevention of neonatal death. Therefore, the increased risk for neonatal
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47 23 death associated with caesarean birth, compared with vaginal birth, would appear to be
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49 24 intuitive given the fact that neonatal death rates after emergency caesarean section is strongly
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51 25 dependent upon the underlying medical indication (e.g. antenatally diagnosed foetal
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53 26 malformation or foetal growth restriction) for caesarean intervention.
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57 28 In Ethiopia, the national rate of caesarean section increased from 0.7% in 2000 to 1.9% in
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59 29 2016. On the other hand, neonatal mortality rate declined from 49 deaths per 1,000 live births
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30 in 2000 to 29 deaths per 1,000 births in 2016.³² Similarly, the pregnancy-related mortality
31
32 ratio decreased from 871 pregnancy-related deaths per 100,000 live births in 2000 to 412
33
34 pregnancy-related deaths per 100,000 live birth in 2016 DHS.³² Our analyses based on
35
36 aggregate-level data from Ethiopian DHS showed that an increase in caesarean section rate is

1 correlated with a decrease in the proportion of neonatal deaths. Even though similar context-
2 specific interpretation is applicable to ecological studies, additional explanation may also be
3 necessary to interpret the association. For example, a change in neonatal mortality rate may
4 be attributable to changes acting on the population as a whole—e.g. changes in health
5 coverage indicators, such as an increase in births attended by skilled birth attendants
6 (increased from 6% in 2000 to 28% in 2016)³² and immunization coverage (was 86.4% in
7 2015).⁴²

8 We acknowledge the following limitations of this study. Firstly, as both the proportion of
9 institutional deliveries and caesarean section rate is low in Ethiopia, especially rural area, the
10 number of neonatal deaths following caesarean section may be low. However, since our
11 analyses are weighted, we believe that the weight improves the representativeness of the data
12 in terms of size, distribution and characteristics of the Ethiopian population. The weight may
13 also ensure that our estimates are unbiased though the confidence interval for some subgroup
14 analyses are somewhat wide. Secondly, the interpretation of our study is specific to the
15 context of Ethiopia and may not be generalizable to other developing countries in Africa or
16 elsewhere. Another limitation is the mother's recall of the child's size at birth was used as a
17 substitute for the child's birth weight in this study because the data for birth weight was not
18 collected for more than 50% of the neonates in DHS.

1 **Conclusions**

2 A naïve interpretation of the changing association between caesarean birth and neonatal death
3 from 2000 to 2016 is that caesarean section is increasingly associated with neonatal death.
4 However, the changing temporal association likely reflects improvements in health service
5 coverage and a shift in the characteristics of Ethiopian women undergoing caesarean section
6 after complicated labour or severe foetal compromise.

7
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13 and the interpretation of data. EY performed the data analysis and drafted the manuscript. All
14 other authors critically revised the draft manuscript. All authors read and approved the final
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19 **Competing interests:** None declared.

20 **Patient consent for publication:** Not required.

21 **Ethical approval:** Not required.

22 **Data sharing:** Datasets used for this study are freely available online at
23 <http://dhsprogram.com/>.

24 **Transparency declaration:** The corresponding author (EY) affirms that this manuscript is an
25 honest, accurate, and transparent account of the study being reported; that no important
26 aspects of the study have been omitted; and that any discrepancies from the study as planned

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1 1 **References**

- 2 1. United Nations Inter-agency Group for Child Mortality Estimation (UN IGME).
3 Levels and Trends in Child Mortality: Report 2017, Estimates Developed by the UN Inter-
4 agency Group for Child Mortality Estimation. New York: United Nations Children's Fund,
5 2017.
- 6 2. Lawn JE, Cousens S, Zupan J. 4 million neonatal deaths: When? Where? Why? *The*
7 *Lancet* 2005; **365**(9462): 891-900.
- 8 3. UN Development Program. Sustainable Development Goals. Geneva: United Nations;
9 2015.
- 10 4. Costello A, Osrin D. Epidemiological transition, medicalisation of childbirth, and
11 neonatal mortality: three Brazilian birth-cohorts. *The Lancet* 2005; **365**(9462): 825-6.
- 12 5. Gibbons L, Belizan JM, Lauer JA, Betran AP, Merialdi M, Althabe F. Inequities in
13 the use of cesarean section deliveries in the world. *Am J Obstet Gynecol* 2012; **206**(4): 331
14 e1-19.
- 15 6. Leone T, Padmadas SS, Matthews Z. Community factors affecting rising caesarean
16 section rates in developing countries: An analysis of six countries. *Social Science & Medicine*
17 2008; **67**(8): 1236-46.
- 18 7. de Mello e Souza C. C-sections as ideal births: the cultural constructions of
19 beneficence and patients' rights in Brazil. *Camb Q Healthc Ethics* 1994; **3**(3): 358-66.
- 20 8. Dumont A, de Bernis L, Bouvier-Colle MH, Breart G. Caesarean section rate for
21 maternal indication in sub-Saharan Africa: a systematic review. *Lancet* 2001; **358**(9290):
22 1328-33.
- 23 9. Vogel JP, Betrán AP, Vindevoghel N, Souza JP, Torloni MR, Zhang J. Use of the
24 Robson classification to assess caesarean section trends in 21 countries: a secondary analysis
25 of two WHO multicountry surveys. *The Lancet Global health* 2015; **3**.
- 26 10. Ye J, Betran AP, Guerrero Vela M, Souza JP, Zhang J. Searching for the optimal rate
27 of medically necessary cesarean delivery. *Birth* 2014; **41**(3): 237-44.
- 28 11. World Health Organization. WHO Statement on Caesarean Section Rates. Geneva:
29 World Health Organization, 2015.
- 30 12. Betran AP, Merialdi M, Lauer JA, et al. Rates of caesarean section: analysis of global,
31 regional and national estimates. *Paediatr Perinat Epidemiol* 2007; **21**(2): 98-113.
- 32 13. Molina G, Weiser TG, Lipsitz SR, et al. Relationship between cesarean delivery rate
33 and maternal and neonatal mortality. *JAMA* 2015; **314**(21): 2263-70.

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57
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59
60
14. Ye J, Zhang J, Mikolajczyk R, Torloni MR, Gulmezoglu AM, Betran AP. Association between rates of caesarean section and maternal and neonatal mortality in the 21st century: a worldwide population-based ecological study with longitudinal data. *BJOG : an international journal of obstetrics and gynaecology* 2016; **123**(5): 745-53.
 15. Althabe F, Sosa C, Belizan JM, Gibbons L, Jacquerioz F, Bergel E. Cesarean section rates and maternal and neonatal mortality in low-, medium-, and high-income countries: an ecological study. *Birth* 2006; **33**(4): 270-7.
 16. Lumbiganon P, Laopaiboon M, Gulmezoglu AM, et al. Method of delivery and pregnancy outcomes in Asia: the WHO global survey on maternal and perinatal health 2007-08. *Lancet* 2010; **375**(9713): 490-9.
 17. Villar J, Carroli G, Zavaleta N, et al. Maternal and neonatal individual risks and benefits associated with caesarean delivery: multicentre prospective study. *BMJ* 2007; **335**(7628): 1025.
 18. MacDorman MF, Declercq E, Menacker F, Malloy MH. Infant and neonatal mortality for primary cesarean and vaginal births to women with "no indicated risk," United States, 1998-2001 birth cohorts. *Birth* 2006; **33**(3): 175-82.
 19. MacDorman MF, Declercq E, Menacker F, Malloy MH. Neonatal mortality for primary cesarean and vaginal births to low-risk women: application of an "intention-to-treat" model. *Birth* 2008; **35**(1): 3-8.
 20. Kallen K, Olausson PO. Neonatal mortality for low-risk women by method of delivery. *Birth* 2007; **34**(1): 99-100.
 21. Shah A, Fawole B, M'Imunya J M, et al. Cesarean delivery outcomes from the WHO global survey on maternal and perinatal health in Africa. *International Journal of Gynecology and Obstetrics* 2009; **107**(3).
 22. Kyu HH, Shannon HS, Georgiades K, Boyle MH. Cesarean delivery and neonatal mortality rates in 46 low- and middle-income countries: a propensity-score matching and meta-analysis of Demographic and Health Survey data. *International journal of epidemiology* 2013; **42**(3): 781-91.
 23. Begum T, Rahman A, Nababan H, et al. Indications and determinants of caesarean section delivery: Evidence from a population-based study in Matlab, Bangladesh. *PloS one* 2017; **12**(11): e0188074-e.

- 1
2
3 1 24. Belizan JM, Minckas N, McClure EM, et al. An approach to identify a minimum and
4 2 rational proportion of caesarean sections in resource-poor settings: a global network study.
5 3 *The Lancet Global health* 2018; **6**(8): e894-e901.
6 4
7 25. Yisma E, Smithers LG, Lynch JW, Mol BW. Cesarean section in Ethiopia: prevalence
8 5 and sociodemographic characteristics. *The Journal of Maternal-Fetal & Neonatal Medicine*
9 6 2019; **32**(7): 1130-5.
10 7
11 26. Thaddeus S, Maine D. Too far to walk: maternal mortality in context. *Social science*
12 8 & *medicine* 1994; **38**(8): 1091-110.
13 9
14 27. Stanton CK, Dubourg D, De Brouwere V, Pujades M, Ronsmans C. Reliability of data
15 10 on caesarean sections in developing countries. *Bull World Health Organ* 2005; **83**(6): 449-55.
16 11
17 28. Filmer D, Pritchett LH. Estimating Wealth Effects without Expenditure Data—or
18 12 Tears: An Application to Educational Enrollments in States of India. *Demography* 2001;
19 13 **38**(1): 115-32.
20 14
21 29. Filmer D, Scott K. Assessing Asset Indices. *Demography* 2012; **49**(1): 359-92.
22 15
23 30. Souza JP, Gulmezoglu A, Lumbiganon P, et al. Cesarean section without medical
24 16 indications is associated with an increased risk of adverse short-term maternal outcomes: the
25 17 2004-2008 WHO Global Survey on Maternal and Perinatal Health. *BMC Med* 2010; **8**: 71.
26 18
27 31. Ronsmans C, Etard JF, Walraven G, et al. Maternal mortality and access to obstetric
28 19 services in West Africa. *Trop Med Int Health* 2003; **8**(10): 940-8.
29 20
30 32. Central Statistical Agency - CSA/Ethiopia, ICF. Ethiopia Demographic and Health
31 21 Survey 2016. Addis Ababa, Ethiopia: CSA and ICF, 2017.
32 22
33 33. Boerma T, Ronsmans C, Melesse DY, et al. Global epidemiology of use of and
34 23 disparities in caesarean sections. *Lancet* 2018; **392**(10155): 1341-8.
35 24
36 34. Boatman AA, Schlottheuber A, Betran AP, et al. Within country inequalities in caesarean
37 25 section rates: observational study of 72 low and middle income countries. *BMJ* 2018; **360**:
38 26 k55.
39 27
40 35. Upadhyay RP, Rai SK, Krishnan A. Using Three Delays Model to Understand the
41 28 Social Factors Responsible for Neonatal Deaths in Rural Haryana, India. *Journal of Tropical*
42 29 *Pediatrics* 2012; **59**(2): 100-5.
43 30
44 36. Mbaruku G, van Roosmalen J, Kimondo I, Bilango F, Bergstrom S. Perinatal audit
45 31 using the 3-delays model in western Tanzania. *Int J Gynaecol Obstet* 2009; **106**(1): 85-8.
46
47
48
49
50
51
52
53
54
55
56
57
58
59
60

- 1
2
3 1 37. Waiswa P, Kallander K, Peterson S, Tomson G, Pariyo GW. Using the three delays
4 2 model to understand why newborn babies die in eastern Uganda. *Trop Med Int Health* 2010;
5 3 **15**(8): 964-72.
6
7 8
8 4 38. Holmer H, Lantz A, Kunjumen T, et al. Global distribution of surgeons,
9 5 anaesthesiologists, and obstetricians. *The Lancet Global health* 2015; **3 Suppl 2**: S9-11.
10 6
11 39. Ologunde R, Vogel JP, Cherian MN, Sbaiti M, Merialdi M, Yeats J. Assessment of
12 7 cesarean delivery availability in 26 low- and middle-income countries: a cross-sectional
13 8 study. *Am J Obstet Gynecol* 2014; **211**(5): 504 e1- e12.
14 9
15 40. Say L, Raine R. A systematic review of inequalities in the use of maternal health care
16 10 in developing countries: examining the scale of the problem and the importance of context.
17 11 *Bull World Health Organ* 2007; **85**(10): 812-9.
18 12
19 41. WHO. Primary health care systems (PRIMASYS): case study from Ethiopia, abridged
20 13 version. Geneva: World Health Organization; 2017. Licence: CC BY-NC-SA 3.0 IGO.
21 14
22 42. Federal Ministry of Health. Health and health related indicators 2007 E.C. (2014/15
23 15 G.C.). Addis Ababa, Ethiopia: Federal Ministry of Health; 2015.
24 16
25 43. Betran AP, Torloni MR, Zhang JJ, Gulmezoglu AM. WHO Statement on Caesarean
26 17 Section Rates. *BJOG : an international journal of obstetrics and gynaecology* 2016; **123**(5):
27 18 667-70.
28 19
29 44. Thomas S, Meadows J, McQueen KA. Access to Cesarean Section Will Reduce
30 20 Maternal Mortality in Low-Income Countries: A Mathematical Model. *World J Surg* 2016;
31 21 **40**(7): 1537-41.
32 22
33 45. Yisma E, Dessalegn B, Astatkie A, Fesseha N. Knowledge and utilization of
34 23 partograph among obstetric care givers in public health institutions of Addis Ababa, Ethiopia.
35 24 *BMC Pregnancy and Childbirth* 2013; **13**(1): 17.
36 25
37 46. Yisma E, Dessalegn B, Astatkie A, Fesseha N. Completion of the modified World
38 26 Health Organization (WHO) partograph during labour in public health institutions of Addis
39 27 Ababa, Ethiopia. *Reproductive Health* 2013; **10**(1): 23.
40 28
41 47. Kumar S, Dansereau EA, Murray CJL. Does distance matter for institutional delivery
42 29 in rural India? *Applied Economics* 2014; **46**(33): 4091-103.
43 30
44 48. Anselmi L, Lagarde M, Hanson K. Health service availability and health seeking
45 31 behaviour in resource poor settings: evidence from Mozambique. *Health economics review*
46 32 2015; **5**(1).

- 1
2
3 1 49. Federal Ministry of Health. Health and health related indicators 1997 E.C. (2004/05
4 2 G.C.). Addis Ababa, Ethiopia: Federal Ministry of Health; 2005.
5 3
6 3 50. Atuoye KN, Dixon J, Rishworth A, Galaa SZ, Boamah SA, Luginaah I. Can she make
7 4 it? Transportation barriers to accessing maternal and child health care services in rural Ghana.
8 5 *BMC Health Services Research* 2015; **15**(1): 333.
9 6
10 6 51. Bergström S. Training non-physician mid-level providers of care (associate clinicians)
11 7 to perform caesarean sections in low-income countries. *Best practice & research Clinical*
12 8 *obstetrics & gynaecology* 2015; **29**(8): 1092-101.
13 9
14 9 52. Orji EO, Ojofeitimi EO, Esimai AO, Adejuyigbe E, Adeyemi AB, Owolabi OO.
15 10 Assessment of delays in receiving delivery care at a tertiary healthcare delivery centre in
16 11 Nigeria. *Journal of Obstetrics and Gynaecology* 2006; **26**(7): 643-4.
17 12
18 12 53. Miller S, Abalos E, Chamillard M, et al. Beyond too little, too late and too much, too
19 13 soon: a pathway towards evidence-based, respectful maternity care worldwide. *The Lancet*
20 14 2016; **388**(10056): 2176-92.
21 15
22 16
23 17
24 18
25 19
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3 **1 LIST OF TABLES AND FIGURES**
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5
6 **2 Table 1.** Characteristics of the study participants according to mode of delivery, Ethiopia
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8 **3** DHS 2000, 2005, 2011 and 2016
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10 **4 Table 2.** Crude and multivariable-adjusted prevalence ratios for neonatal death associated
11 with caesarean vs vaginal delivery, Ethiopia DHS **2000, 2005, 2011, and 2016**
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13 **6**
14 **7 Table 3.** Crude and multivariable-adjusted prevalence ratios for neonatal death associated
15 with caesarean vs vaginal delivery, Ethiopia **DHS 2016**
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17 **10 Table 4.** Factors contributing to the ‘Three Delays Model’, according to sociodemographic
18 characteristics, Ethiopia DHS 2016
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23 **13 Figure 1.** Trends in proportion of institutional deliveries, caesarean section and neonatal
24 death in the 5 years before each of the surveys, Ethiopia DHS 2000, 2005, 2011 and 2016.
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27 **16 Figure 2.** Trends in caesarean section rates in the 5 years before each of the surveys by
28 region of residence, Ethiopia DHS 2000, 2005, 2011 and 2016.
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32 **19 Figure 3.** The relationship between caesarean section rate and neonatal death in Ethiopia
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34 **21 Figure 4.** The relationship between caesarean section rate and neonatal death by survey years
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1 **Table 1.** Characteristics of the study participants according to mode of delivery, Ethiopia DHS 2000, 2005, 2011 and 2016

	Mode of delivery							
	DHS 2000		DHS 2005		DHS 2011		DHS 2016	
	Caesarean (n=86) %	Vaginal (n=12,174) %	Caesarean (n=111) %	Vaginal (n= 11,052) %	Caesarean (n=175) %	Vaginal (n= 11,697) %	Caesarean (n=213) %	Vaginal (n= 10,810) %
Neonatal death								
Yes	4.5	4.8	6.7	3.9	5.5	3.7	8.3	2.7
No	95.5	95.2	93.3	96.1	94.5	96.3	91.7	97.3
Types of residence								
Urban	76.2	9.9	68.8	6.7	70.9	12.0	60.4	10.1
Rural	23.8	90.1	31.2	93.3	29.1	88.0	39.6	89.9
Region								
Tigray	4.0	6.4	5.4	6.3	12.5	6.2	6.8	6.5
Afar	2.5	1.0	0.6	1.0	1.4	1.0	0.4	1.0
Amhara	3.7	26.3	15.2	23.6	19.4	22.4	22.1	18.7
Oromia	46.3	40.7	28.5	39.6	14.6	42.6	21.2	44.5
Somali	2.3	1.2	4.2	4.3	1.4	3.1	1.0	4.7
Benishangul-Gumuz	3.1	1.0	0.1	0.9	1.0	1.2	0.6	1.1
SNNP	18.5	21.2	21.6	22.4	17.4	21.1	21.0	20.8
Gambela	0.6	0.2	0.5	0.3	2.0	0.3	0.2	0.2
Harari	0.9	0.2	0.7	0.2	1.2	0.2	1.1	0.2
Addis Ababa	16.9	1.4	22.1	1.2	27.6	1.5	24.5	1.8
Dire Dawa	1.1	0.3	1.2	0.3	1.4	0.3	1.2	0.4
Mother's age at birth								
<20	19.4	12.0	13.3	13.4	10.5	10.9	6.4	10.0
20-29	70.8	51.3	59.8	51.2	62.8	55.7	58.4	54.6
30-39	9.8	30.0	24.1	29.3	23.7	28.7	31.7	30.9
40-49	0.0	6.7	2.9	6.2	3.3	4.7	3.4	4.5
Mother's education								
No education	15.7	82.5	30.1	79.7	19.9	70.0	22.8	66.9
Primary	21.8	13.0	14.5	16.6	44.7	26.8	35.1	26.6

Secondary	56.4	4.3	46.5	3.4	22.2	1.9	15.3	4.5
Higher	6.2	0.2	8.9	0.3	13.2	1.2	26.8	2.0
Place of delivery[§]								
Public	96.3	4.0	90.2	3.9	83.5	7.6	84.0	23.6
Private	1.3	0.1	5.9	0.3	13.6	0.8	13.7	0.9
NGO	2.4	0.2	3.8	0.1	3.0	0.2	2.4	0.2
Home	0.0	95.6	0.0	95.7	0.00	91.4	0.00	75.2
Birth order								
1	75.5	18.6	53.2	17.0	53.5	18.5	41.4	18.2
2	17.5	16.5	26.0	15.5	17.0	17.0	25.6	16.0
3	2.2	13.7	5.7	14.5	10.3	14.2	18.2	14.2
4	1.0	11.3	1.5	12.9	6.0	12.6	3.3	12.5
5	0.6	10.4	2.2	10.8	8.4	10.5	5.3	11.4
6+	3.2	29.5	11.4	29.4	4.7	27.2	6.3	27.6
Sex of child								
Male	61.8	51.2	51.3	51.3	57.2	51.9	54.0	51.9
Female	38.2	48.8	48.7	48.7	42.8	48.1	46.0	48.1
Size of baby at birth*								
Very large	9.8	5.3	30.7	22.3	25.8	19.2	26.5	17.6
Larger than average	32.0	25.4	11.4	9.5	11.7	12.7	16.0	13.8
Average	34.6	35.7	37.4	40.0	42.3	38.2	36.1	41.7
Smaller than average	19.7	27.5	9.4	7.3	4.9	8.7	7.0	10.1
Very small	3.7	5.9	9.5	20.6	14.8	20.6	12.7	16.0
Don't know	0.2	0.2	1.1	0.4	0.6	0.4	1.7	0.8
Wealth quantile								
Poorest	1.9	21.1	0.6	22.1	2.0	23.1	7.2	24.2
Poorer	4.9	21.0	5.9	21.3	8.4	22.6	12.2	23.1
Middle	4.1	22.0	3.9	22.5	9.0	20.7	10.8	20.9
Richer	6.1	20.5	9.7	20.0	6.5	19.3	9.3	18.3
Richest	83.0	15.5	79.9	14.2	74.1	14.2	60.4	13.5

1 NB: *n*=weighted; [§]Missing for 2000 (n = 9); * mother's estimate of baby's size at birth; **DHS**, Demographic and Health Survey

Table 2. Crude and multivariable-adjusted prevalence ratios for neonatal death associated with caesarean versus vaginal delivery, Ethiopia DHS 2000, 2005, 2011, and 2016

	Prevalence Ratio (95% CI) for neonatal death
Ethiopia DHS 2000	
Vaginal delivery	1 [Ref.]
Caesarean delivery, crude (n= 10,873)	0.93 (0.38, 2.30)
Caesarean delivery, model 1 ^a (n=10,853)	0.95 (0.29, 3.19)
Ethiopia DHS 2005	
Vaginal delivery	1 [Ref.]
Caesarean delivery, crude (n= 9,861)	1.74 (0.67, 4.51)
Caesarean delivery, model 1 ^a (n= 9,861)	1.53 (0.52, 4.50)
Ethiopia DHS 2011	
Vaginal delivery	1 [Ref.]
Caesarean delivery, crude (n=11,654)	1.49 (0.62, 3.61)
Caesarean delivery, model 1 ^a (n= 11,654)	1.15 (0.45, 2.93)
Ethiopia DHS 2016	
Vaginal delivery	1 [Ref.]
Caesarean delivery, crude (n= 10,641)	3.02 (1.37, 6.66)
Caesarean delivery, model 1 ^a (n= 10,641)	2.81 (1.11, 7.13)

^aAdjusted for place of delivery, type of residence (urban/rural), sex of child, size of baby at birth, Mother's age at birth, Mother's education, Birth order, Household wealth.

Table 3. Crude and multivariable-adjusted prevalence ratios for neonatal death associated with caesarean versus vaginal delivery, Ethiopia DHS 2016

	Prevalence Ratio (95% CI) for neonatal death
Main analysis	
Vaginal delivery	1 [Ref.]
Caesarean delivery, crude (n= 10,641)	3.02 (1.37, 6.66)
Caesarean delivery, model 1 ^a (n=10,641)	2.81 (1.11, 7.13)
Subgroup analyses	
Restricted to Addis Ababa ^b (n=461)	1.07 (0.20, 5.73)
Excluded Addis Ababa and Hareri region ^a (n= 9,575)	3.35 (1.31, 8.56)
Restricted to births in public facility ^a (n=3,023)	2.78 (1.16, 6.63)
Restricted to rural mothers ^b (n= 8,636)	3.43 (1.22, 9.67)
Restricted to women from lowest quintile of household wealth ^c (n=3,958)	7.01 (0.92, 53.36)
Restricted to women from highest quintile of household wealth ^c (n=2,092)	2.72 (0.55, 13.38)

^aAdjusted for place of delivery, type of residence (urban/rural), sex of child, size of baby at birth, Mother's age at birth, Mother's education, Birth order, Household wealth.

^bAdjusted for place of delivery, sex of child, size of baby at birth, Mother's age at birth, Mother's education, Birth order, Household wealth.

^cAdjusted for place of delivery, sex of child, size of baby at birth, Mother's age at birth, Mother's education, Birth order.

Table 4. Factors contributing to the ‘Three Delays Model’, according to sociodemographic characteristics, Ethiopia DHS 2016

	Delivery by skilled provider [§]	Number of births	Problems in accessing health care by women aged 15-49 years*					Number of women
			Distance to health facility	Getting money for treatment	Getting permission to go for treatment	Not wanting to go alone	At least one problem accessing health care	
Types of residence								
Urban	80.1	1216	17.0	34.7	15.1	21.4	45.6	3476
Rural	21.2	9807	59.8	60.5	37.0	47.9	76.9	12207
Region								
Tigray	59.3	716	37.4	46.1	15.3	24.6	60.7	1129
Afar	16.4	114	54.3	51.7	28.2	41.8	66.6	128
Amhara	27.7	2072	33.7	35.3	15.4	34.6	55.7	3714
Oromia	19.7	4851	68.9	70.1	58.3	57.0	82.9	5701
Somali	20.0	508	47.3	63.0	25.7	32.2	72.6	459
Benishangul-Gumuz	28.6	122	57.4	62.4	36.5	43.8	76.8	160
SNNPR	28.6	2296	52.7	59.1	18.4	39.5	75.4	3288
Gambela	46.9	27	41.0	44.3	24.3	33.7	61.2	44
Harari	51.2	26	18.1	28.2	16.3	13.8	30.8	38
Addis Ababa	96.8	244	10.8	29.2	8.7	14.5	40.0	930
Dire Dawa	56.7	47	57.4	64.5	58.7	55.2	71.4	90
Mother's education								
No education	17.2	7284	59.2	62.9	37.6	47.1	78.0	7498
Primary	38.6	2951	50.3	55.7	31.9	43.2	71.1	5490
Secondary	78.4	514	27.8	33.2	18.2	27.8	48.1	1817
More than secondary	93.2	274	20.6	23.8	15.9	20.4	39.8	877
Wealth quintile								
Poorest	11.0	2636	67.7	70.9	40.0	54.5	85.3	2633

Poorer	20.8	2520	66.8	67.0	42.1	52.7	82.9	2809
Middle	24.2	2280	59.4	61.0	35.2	47.6	77.3	2978
Richer	28.5	1999	49.8	50.2	33.8	41.2	68.2	3100
Richest	70.3	1588	22.1	35.2	17.0	23.4	47.7	4163
Total	27.7	11023	50.3	54.8	32.1	42.0	70.0	15683

§Percentage delivered by a skilled provider (includes doctor, nurse, midwife, health officer, and health extension worker)

*Percentage of women age 15-49 who reported that they have serious problems in accessing health care for themselves when they are sick, by type of problem, according to sociodemographic characteristics, Ethiopia DHS 2016

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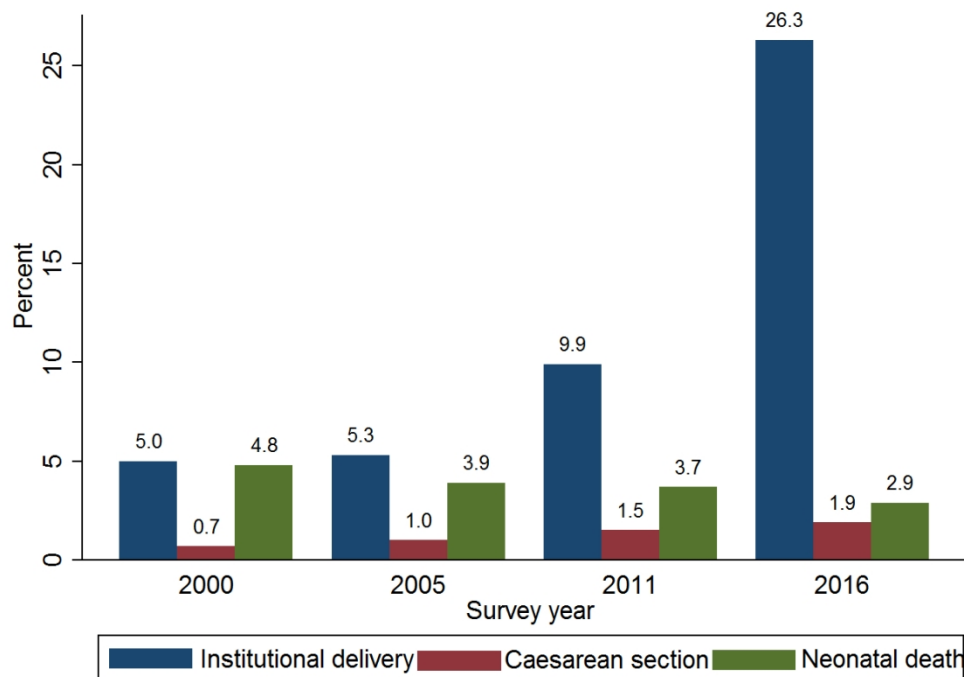


Figure 1. Trends in proportion of institutional deliveries, caesarean section and neonatal death in the 5 years before each of the surveys, Ethiopia DHS 2000, 2005, 2011 and 2016

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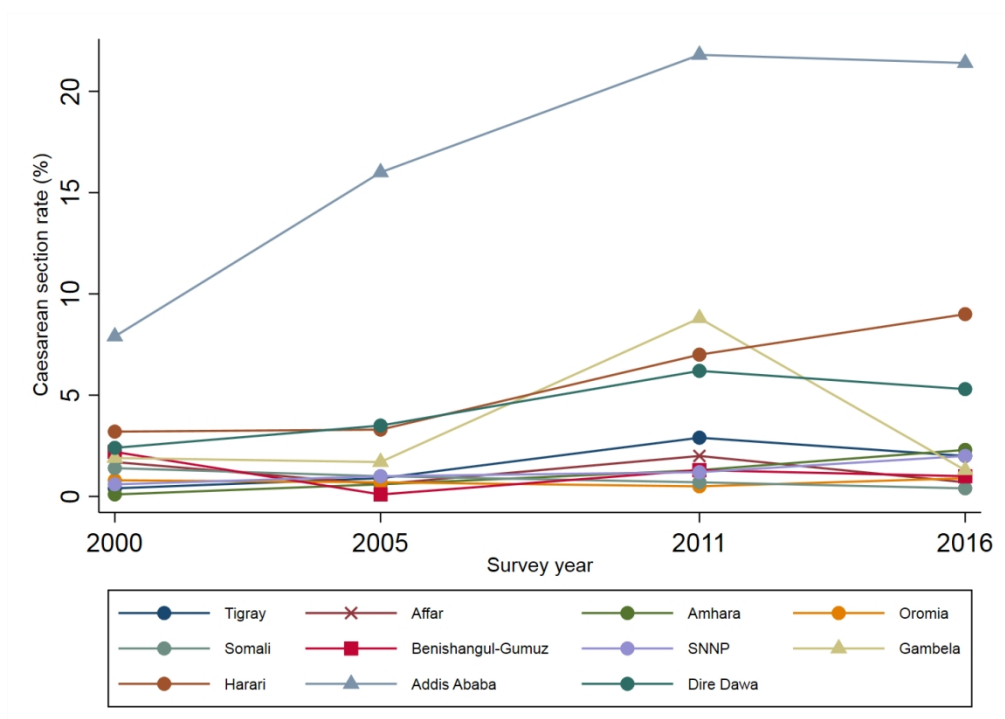


Figure 2. Trends in caesarean section rates in the 5 years before each of the surveys by region of residence, Ethiopia DHS 2000, 2005, 2011 and 2016

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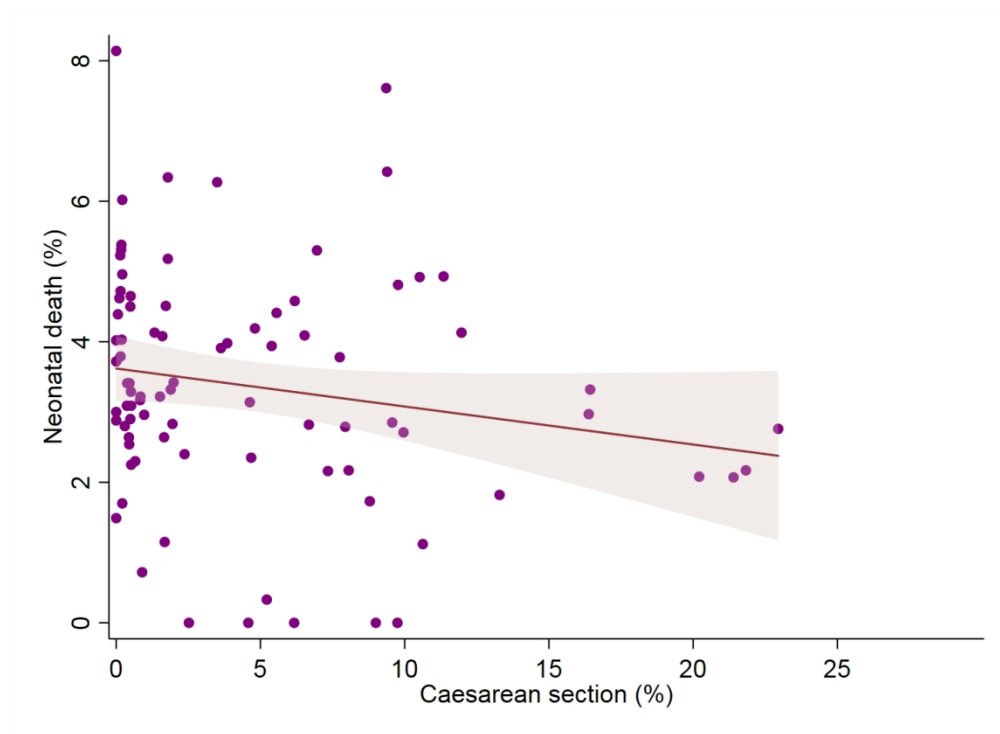


Figure 3. The relationship between caesarean section rate and neonatal death in Ethiopia

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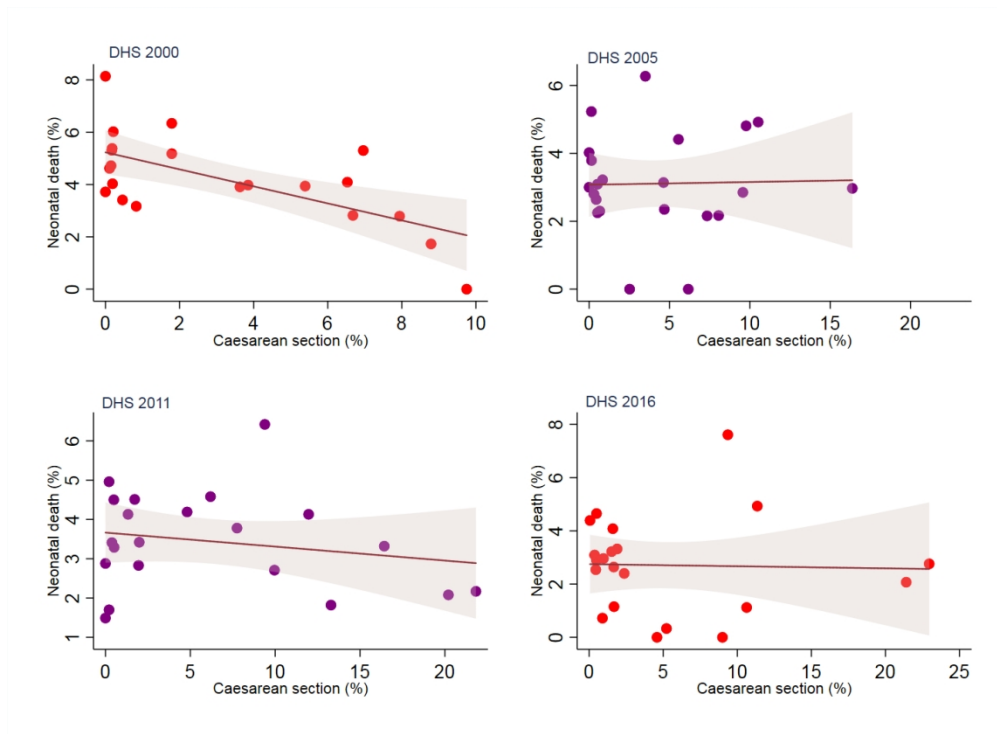


Figure 4. The relationship between caesarean section rate and neonatal death by survey years

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SUPPLEMENTARY MATERIAL

This file includes supplementary analyses that complement the main findings and pictures that describe the ‘Three Delays Model’ and the Ethiopian health system structure cited in the full text of the article.

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Table A1. Crude and multivariable-adjusted prevalence ratios for neonatal death associated with ‘timing of decision to conduct caesarean section’ versus vaginal delivery, Ethiopian DHS, 2016

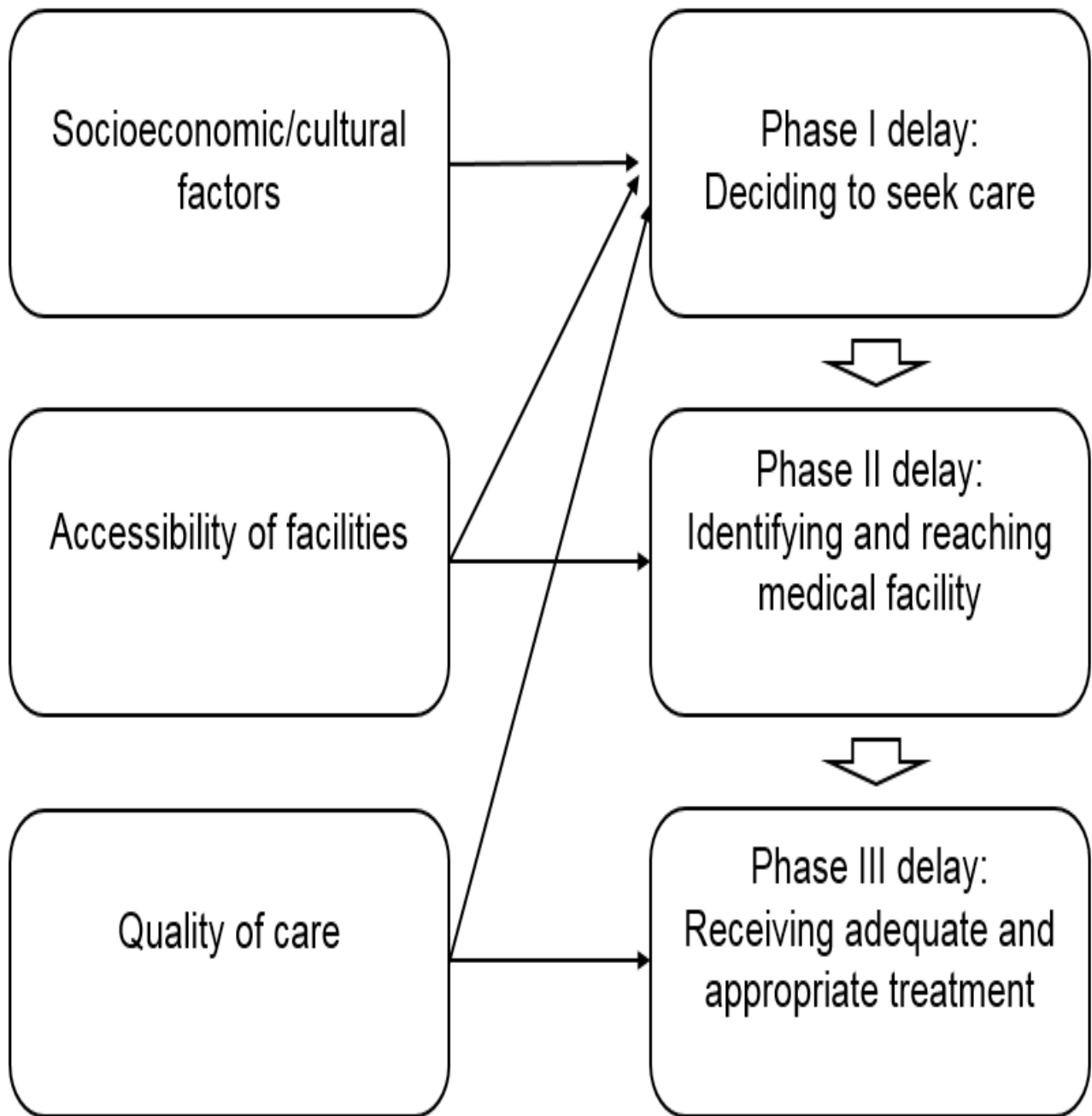
	Prevalence Ratio (95%CI) for neonatal death
Unadjusted (n= 10 641)	
Vaginal delivery	1 [<i>Ref.</i>]
Caesarean section decided before onset of labour	4.21 (1.34, 13.19)
Caesarean section decided after onset of labour	2.31 (0.84, 6.41)
Adjusted^a (n=10 641)	
Vaginal delivery	1 [<i>Ref.</i>]
Caesarean section decided before onset of labour	3.79 (1.03, 13.93)
Caesarean section decided after onset of labour	2.26 (0.75, 6.82)

^aAdjusted for place of delivery, type of residence (urban/rural), sex of child, size of baby at birth, Mother’s age at birth, Mother’s education, Birth order, Household wealth

NB: ‘Timing of decision to conduct caesarean section’—caesarean section that was planned before the onset of labor pains and caesarean section that was decided after the onset of labor pains—was used as a proxy to pre-labour caesarean section and emergency caesarean section.

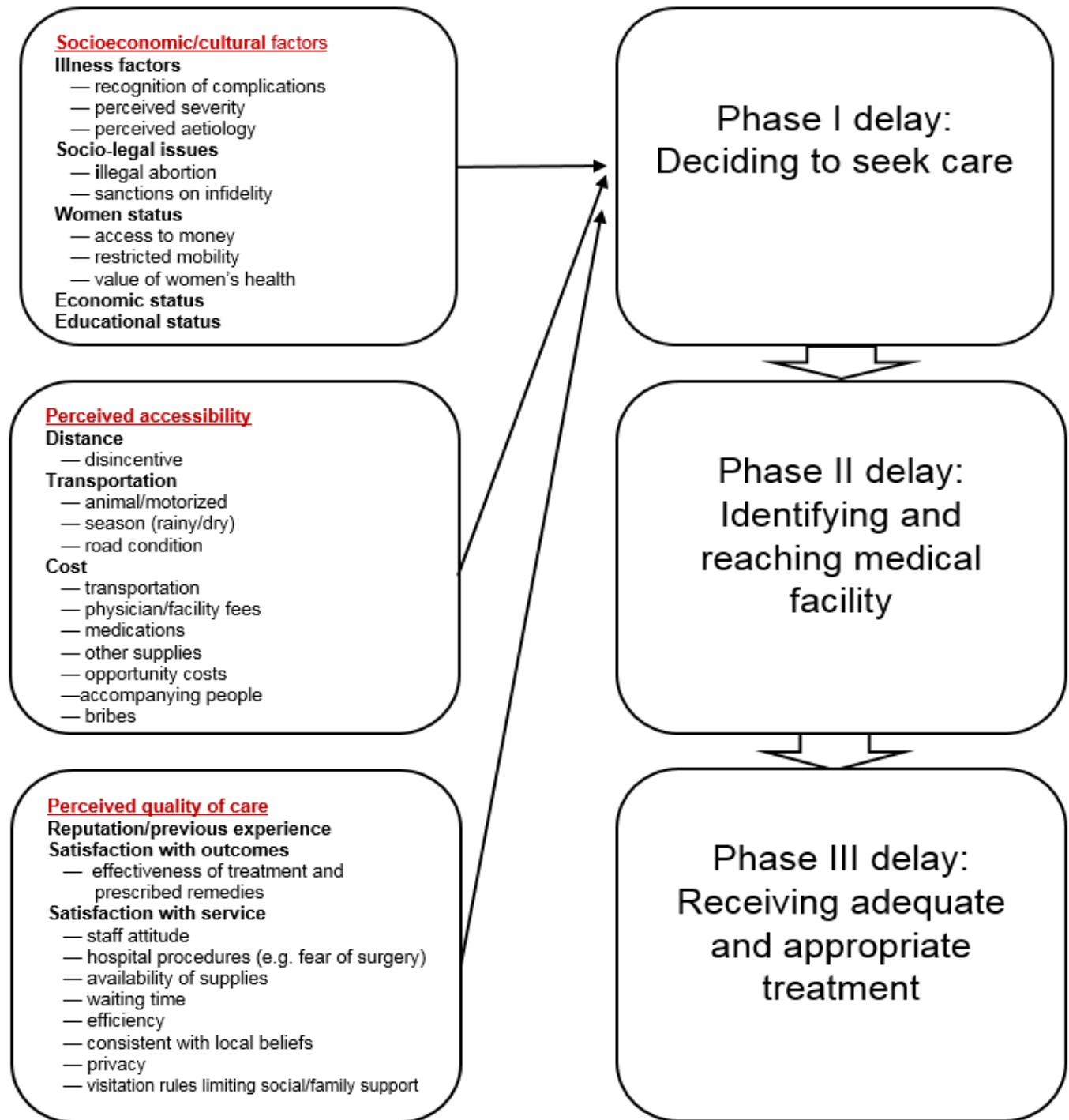
Table A2. Trends in proportion of neonatal deaths in the 5 years before each of the surveys by region of residence, Ethiopia DHS 2000, 2005, 2011 and 2016

	Survey year								
	2000 %	Number of births	2005 %	Number of births	2011 %	Number of births	2016 %	Number of births	Absolute change %
Types of residence									
Urban	4.4	1277	4.4	815	3.9	1528	3.4	1216	-1.0
Rural	4.8	10983	3.9	10348	3.7	10344	2.8	9807	-2.0
Region									
Tigray	5.3	788	2.7	698	4.1	753	2.7	716	-2.6
Afar	2.9	126	2.9	107	1.9	121	2.6	114	-0.3
Amhara	4.8	3202	5.2	2621	4.5	2656	3.2	2072	-1.6
Oromia	5.3	4999	3.8	4411	3.4	5014	2.8	4851	-2.5
Somali	3.8	142	3.0	477	2.9	364	4.1	508	+0.3
Benishangul- Gumuz	6.3	124	3.8	105	4.8	140	2.9	122	-3.4
SNNP	4.0	2602	3.4	2500	3.5	2494	2.5	2296	-1.5
Gambela	5.3	29	2.4	31	3.6	40	2.8	27	-2.5
Harari	3.7	25	2.2	22	4.1	29	3.1	26	-0.6
Addis Ababa	2.8	182	2.9	153	2.2	222	2.1	244	-0.7
Dire Dawa	3.7	40	2.7	37	1.6	39	3.0	47	-0.7
Total	4.8	12260	3.9	11163	3.7	11872	2.9	11023	-2.0



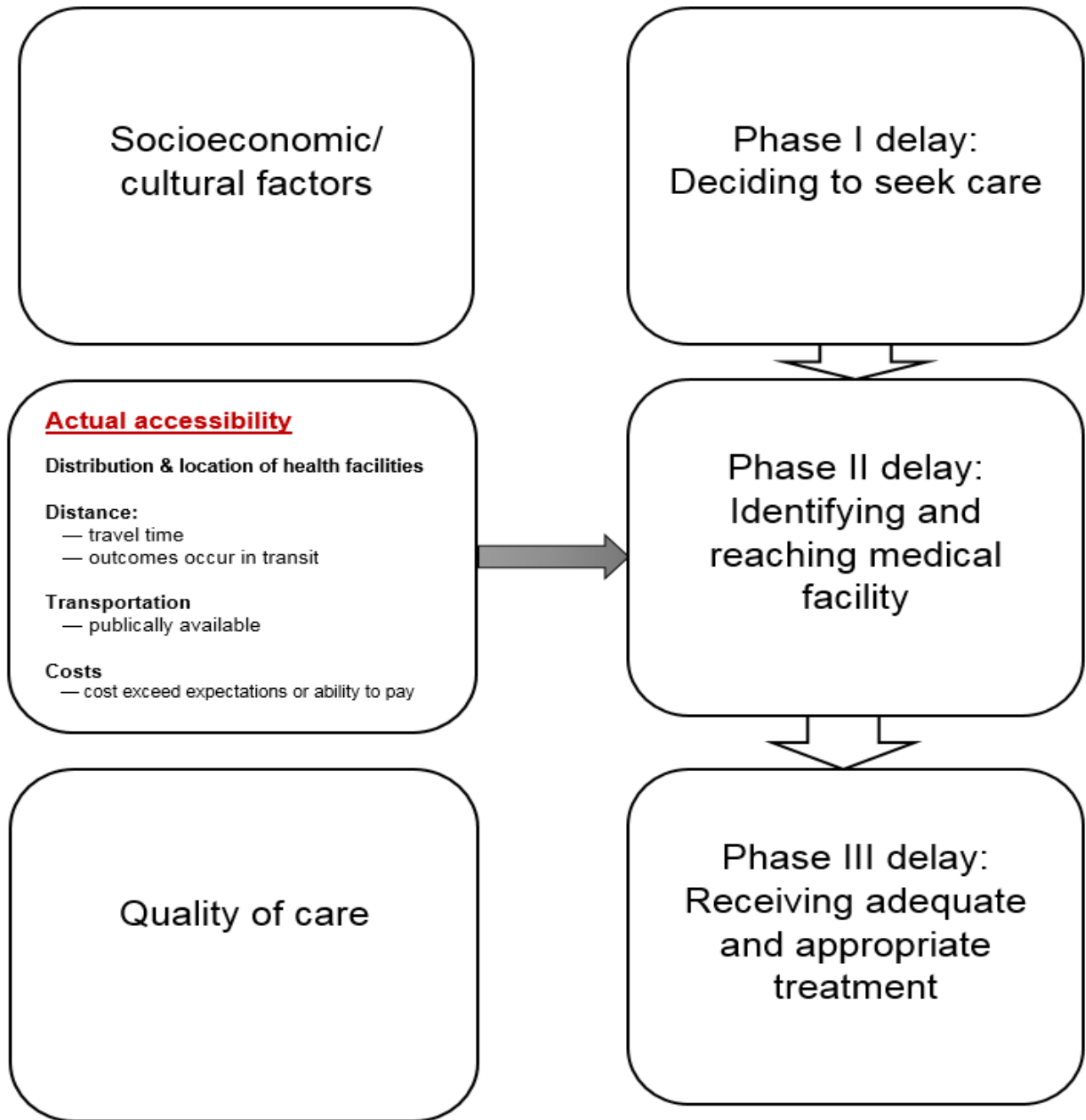
Source: Social science & medicine, 1994; 38(8): 1091-110.¹

Figure A1. The 'Three Delays Model'



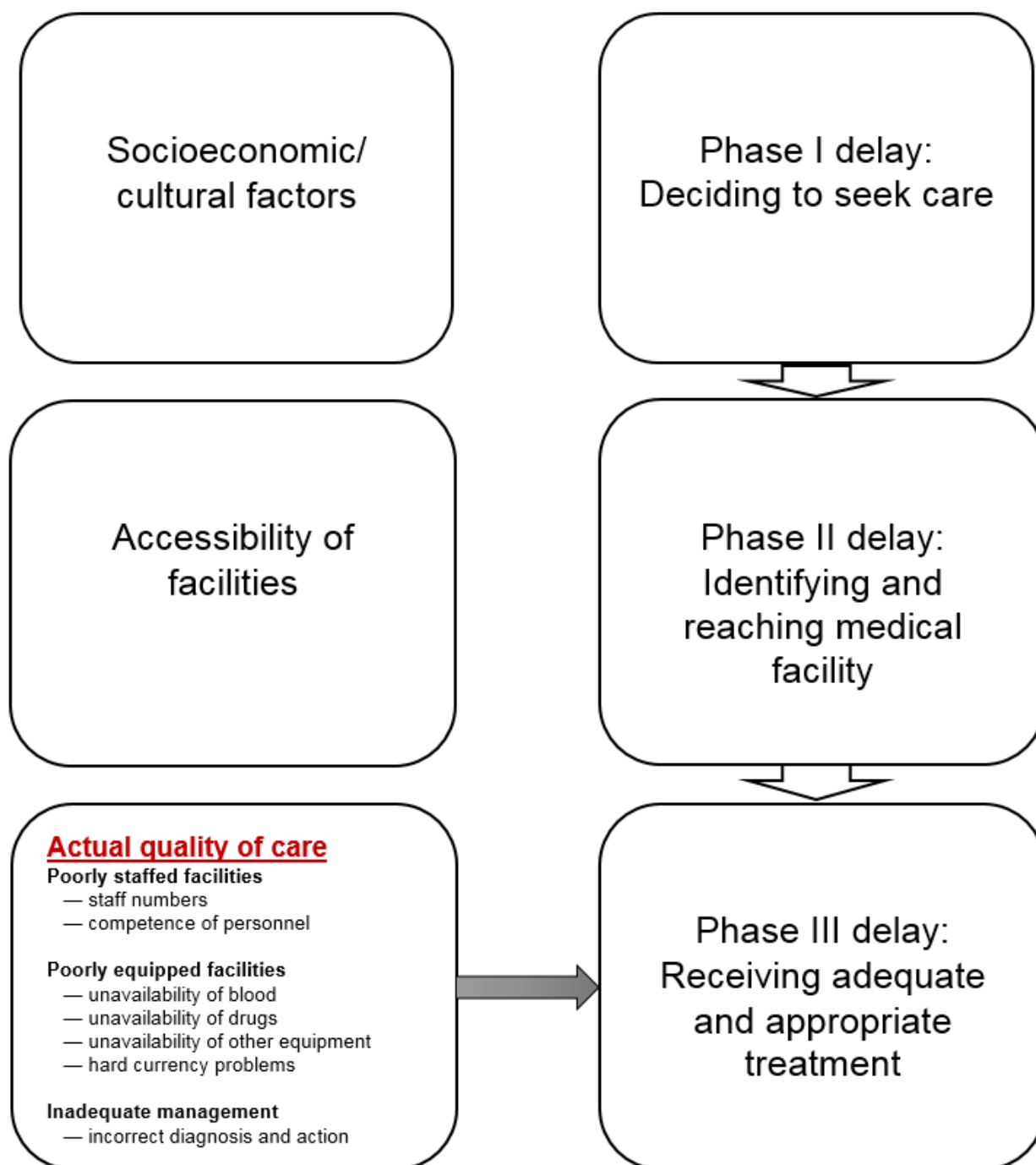
Source: Social science & medicine, 1994; 38(8): 1091-110.¹

Figure A2. Phase I delay, detail



46 *Source:* Social science & medicine, 1994; **38**(8): 1091-110.¹

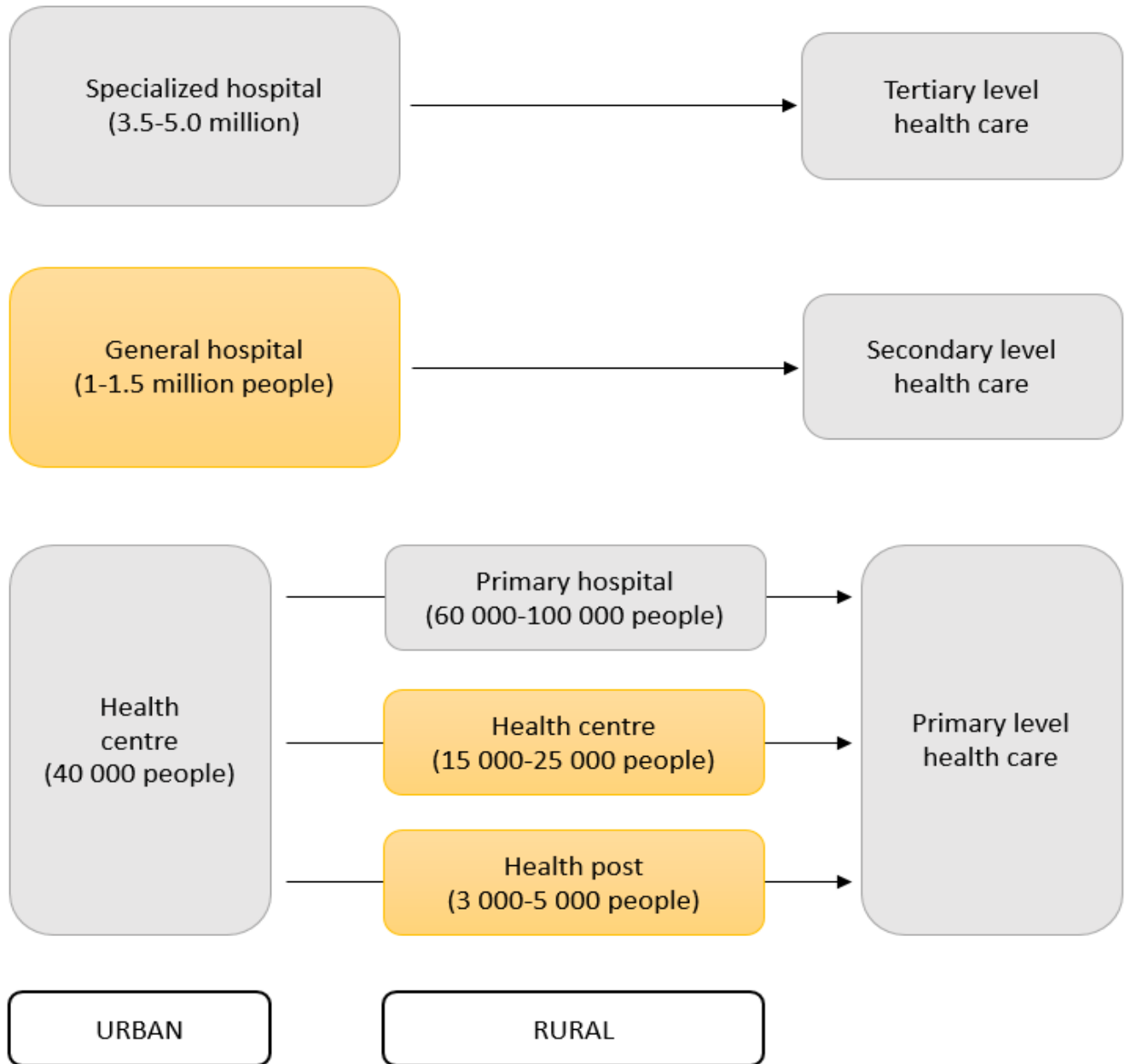
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49 **Figure A3.** Phase II delay, detail



47 *Source:* Social science & medicine, 1994; **38**(8): 1091-110.¹

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50 **Figure A4.** Phase III delay, detail

Ethiopian health tier system



Source: Ethiopian Health Sector Transformation Plan, 2015,² and World Health Organization, 2017.³

Figure A5. Ethiopian health system structure

References

1. Thaddeus S, Maine D. Too far to walk: maternal mortality in context. *Social science & medicine* 1994; **38**(8): 1091-110.
2. Ministry of Health. Health Sector Transformation Plan. Addis Ababa: Federal Democratic Republic of Ethiopia; 2015.
3. WHO. Primary health care systems (PRIMASYS): case study from Ethiopia, abridged version. Geneva: World Health Organization; 2017. Licence: CC BY-NC-SA 3.0 IGO.

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STROBE Statement—Checklist of items that should be included in reports of *cross-sectional studies*

	Item No	Recommendation	Page No.	Relevant text from manuscript
Title and abstract	1	(a) Indicate the study’s design with a commonly used term in the title or the abstract	Page 1-3	(See Title and Abstract): “The changing temporal association between caesarean birth and neonatal death in Ethiopia: secondary analysis of nationally representative surveys”
		(b) Provide in the abstract an informative and balanced summary of what was done and what was found	Page 2	(see Abstract: Main outcome measures; Results)
Introduction				
Background/rationale	2	Explain the scientific background and rationale for the investigation being reported	Page 4-5	(see Introduction)
Objectives	3	State specific objectives, including any prespecified hypotheses	Page 5	“We use Ethiopian DHS data from 2000, 2005, 2011, and 2016 to examine the association between caesarean birth and neonatal death. We then apply the ‘Three Delays Model’ developed by Thadeus and Maine ²⁶ to provide an interpretation of the changing association between caesarean birth and neonatal death in Ethiopia.”
Methods				
Study design	4	Present key elements of study design early in the paper	Page 6	(see Methods—Study design and data samples)
Setting	5	Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection	Page 6	(see Methods—Study design and data samples)
Participants	6	(a) Give the eligibility criteria, and the sources and methods of selection of participants	Page 6	“The DHS questionnaire asks women about pregnancy, antenatal,

1				
2				and delivery care for livebirths they
3				have reported in the past 5 years.
4				For this study, the exposure group
5				were children delivered by
6				caesarean section and unexposed
7				group comprised children born
8				vaginally.”
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12	Variables	7	Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable	Page 6-9 (see Methods—Exposure, Outcome and Confounding)
13				
14	Data sources/ measurement	8*	For each variable of interest, give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group	Page 6 “Exposure
15				The DHS questionnaire asks
16				women about pregnancy, antenatal,
17				and delivery care for livebirths they
18				have reported in the past 5 years.
19				The self-reported data on caesarean
20				section rates collected for DHS,
21				compared with facility-based
22				records of caesarean sections, are
23				found to be reliable in developing
24				countries. ²⁷ For this study, the
25				exposure group were children
26				delivered by caesarean section and
27				unexposed group comprised
28				children born vaginally.
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35				Outcome
36				Neonatal death includes children
37				who were born alive in the 5 years
38				before the survey, but died within
39				the first 28 days of life. The
40				outcome variable, neonatal death,
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was measured from two variables (whether the child is alive and age at death (in days)).”

Bias	9	Describe any efforts to address potential sources of bias	Page 7-10	(see Methods—Statistical analysis)
Study size	10	Explain how the study size was arrived at	Page 6	(see Methods—Study design and data samples): “We used data from the Ethiopian DHS completed in 2000, 2005, 2011, and 2016. The Ethiopian DHS are nationally representative cross-sectional surveys conducted in nine regions (Tigray, Afar, Amhara, Oromia, Somali, Benishangul-Gumuz, SNNPR, Gambela, and Harari), and two city administrations (Addis Ababa and Dire Dawa).”
Quantitative variables	11	Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen and why	Page 6-9	(see Methods— Confounding)
Statistical methods	12	(a) Describe all statistical methods, including those used to control for confounding	Page 7-10	(see Methods—Statistical analysis)
		(b) Describe any methods used to examine subgroups and interactions	Page 7-9	(see Methods—Statistical analysis)
		(c) Explain how missing data were addressed		Not applicable
		(d) If applicable, describe analytical methods taking account of sampling strategy	Page 7	“All analyses were weighted to be nationally representative. As women may have had more than one birth within the five-year survey periods, we also accounted for both clustering of cesarean deliveries within women as well as the complex survey design during the data analyses using the unit of

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				analysis (children) study number and sample weights.”
		(e) Describe any sensitivity analyses		Not applicable
Results				
Participants	13*	(a) Report numbers of individuals at each stage of study—eg numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analysed	Page 11	(see Results): “Table 1”
		(b) Give reasons for non-participation at each stage		Not applicable
		(c) Consider use of a flow diagram		Not applicable
Descriptive data	14*	(a) Give characteristics of study participants (eg demographic, clinical, social) and information on exposures and potential confounders	Page 11	(see Results)
		(b) Indicate number of participants with missing data for each variable of interest		Not applicable
Outcome data	15*	Report numbers of outcome events or summary measures	Page 11-12	(see Results)
Main results	16	(a) Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (eg, 95% confidence interval). Make clear which confounders were adjusted for and why they were included	page 11-12	(see Results)
		(b) Report category boundaries when continuous variables were categorized	Page 11-12	(see Results)
		(c) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period		Not applicable
Other analyses	17	Report other analyses done—eg analyses of subgroups and interactions, and sensitivity analyses	Page 11-12	(see Results)
Discussion				
Key results	18	Summarise key results with reference to study objectives	Page 13 & page 18	(See Interpretation and Discussion sections)
Limitations	19	Discuss limitations of the study, taking into account sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias	Page 20	(See Discussion: “We acknowledge the following limitations of this study. Firstly, as both the proportion of institutional deliveries and caesarean section rate is low in Ethiopia, especially rural area, the number of neonatal deaths

following caesarean section may be low. However, since our analyses are weighted, we believe that the weight improves the representativeness of the data in terms of size, distribution and characteristics of the Ethiopian population. The weight may also ensure that our estimates are unbiased though the confidence interval for some subgroup analyses are somewhat wide. Secondly, the interpretation of our study is specific to the context of Ethiopia and may not be generalizable to other developing countries in Africa or elsewhere. Another limitation is the mother’s recall of the child’s size at birth was used as a substitute for the child’s birth weight in this study because the data for birth weight was not collected for more than 50% of the neonates in DHS”)

Interpretation	20	Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence	Page 13-20	(See Interpretation and Discussion sections)
Generalisability	21	Discuss the generalisability (external validity) of the study results	Page 20	(See Discussion)
Other information				
Funding	22	Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based	Page 21	(See Funding—The first author is fully supported by an Australian Government Research Training Programme (RTP) Scholarship. The

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funder does not have role in the
design of the study.)

*Give information separately for exposed and unexposed groups.

Note: An Explanation and Elaboration article discusses each checklist item and gives methodological background and published examples of transparent reporting. The STROBE checklist is best used in conjunction with this article (freely available on the Web sites of PLoS Medicine at <http://www.plosmedicine.org/>, Annals of Internal Medicine at <http://www.annals.org/>, and Epidemiology at <http://www.epidem.com/>). Information on the STROBE Initiative is available at www.strobe-statement.org.

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The changing temporal association between caesarean birth and neonatal death in Ethiopia: secondary analysis of nationally representative surveys

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Manuscripts

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3 **1 The changing temporal association between caesarean birth and neonatal death**
4 **in Ethiopia: secondary analysis of nationally representative surveys**
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10 4 Engida Yisma^{a, b}, Ben W. Mol^{c, d}, John W. Lynch^{a, c, e} and Lisa G. Smithers^{a, c}
11
12
13
14 5
15
16

17 6 ^aSchool of Public Health, The University of Adelaide, Adelaide, Australia
18
19

20 7 ^bSchool of Allied Health Sciences, College of Health Sciences, Addis Ababa University,
21 Addis Ababa, Ethiopia
22
23

24 9 ^cRobinson Research Institute, School of Medicine, The University of Adelaide, Adelaide,
25 Australia
26 10
27

28
29 11 ^dDepartment of Obstetrics and Gynaecology, Monash University, Melbourne, Australia
30
31

32 12 ^ePopulation Health Sciences, University of Bristol, England, UK
33
34
35 14
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38

39 **15 Corresponding Author:**
40
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42 16 Engida Yisma
43
44

45 17 School of Public Health, The University of Adelaide, Adelaide, Australia
46
47

48 18 Email: engida.derbie@adelaide.edu.au
49
50

51 19 Tel: +61434860775
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1 **ABSTRACT**

2 **Objective**

3 To examine the changing temporal association between caesarean birth and neonatal death
4 within the context of Ethiopia from 2000 to 2016.

5 **Design**

6 Secondary analysis of Ethiopian Demographic and Health Surveys (DHS).

7 **Setting**

8 All administrative regions of Ethiopia with surveys conducted in 2000, 2005, 2011, and 2016.

9 **Participants**

10 Women aged 15-49 years with a live birth during the five years preceding the survey.

11 **Main outcome measures**

12 We analysed the association between caesarean birth and neonatal death using log-Poisson
13 regression models for each survey adjusted for potential confounders. We then applied the
14 'Three Delays Model' to 2016 survey to provide an interpretation of the association between
15 caesarean birth and neonatal death in Ethiopia.

16 **Results**

17 The adjusted prevalence ratios (aPR) for neonatal death among neonates born via caesarean
18 section versus vaginal birth increased over time, from 0.95 (95% CI, 0.29, 3.19) in 2000 to
19 2.81 (95% CI, 1.11, 7.13) in 2016. The association between caesarean birth and neonatal
20 death was stronger among rural women (aPR (95% CI) 3.43 (1.22, 9.67)) and among women
21 from the lowest quintile of household wealth (aPR (95% CI) 7.01 (0.92, 53.36)) in 2016.
22 Aggregate-level analysis revealed that an increased caesarean section rates were correlated
23 with a decreased proportion of neonatal deaths.

24

1 **Conclusions**

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6 2 A naïve interpretation of the changing temporal association between caesarean birth and
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8 3 neonatal death from 2000 to 2016 is that caesarean section is increasingly associated with
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10 4 neonatal death. However, the changing temporal association reflects improvements in health
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12 5 service coverage and secular shifts in the characteristics of Ethiopian women undergoing
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14 6 caesarean section after complicated labour or severe foetal compromise.
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17 **Strengths and limitations of this study**

- 18 8
- 19 9 • This was the first study to examine the temporal association between caesarean birth
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21 and neonatal death within the context of Ethiopia from 2000 to 2016.
 - 22 10
23 11 • A number of analyses conducted after adjustment for potential confounders helped
24
25 12 develop the possible scenarios to better understand the interpretation of the changing
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27 13 associations.
 - 28 14
29 14 • We have used additional supporting evidence from the 2016 Ethiopian Demographic
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31 15 and Health Survey data which allowed us interpret the association between caesarean
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33 16 birth and neonatal death in view of contextual factors in Ethiopia using the ‘Three
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35 17 Delays Model’.
 - 36 18 • Given the very low base rates of caesarean delivery in Ethiopia, the interpretation of
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38 19 our findings may not reflect the context of other low-and middle-income countries.
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1 Introduction

2 Globally, 2.6 million neonatal deaths occurred within the first 28 days after birth, which
3 accounted for 46% of all under-five deaths in 2016.¹ The majority of these deaths were from
4 low- and middle-income countries. According to the United Nations Inter-agency Group for
5 Child Mortality Estimation, Southern Asia (39%) and sub-Saharan Africa (38%) comprised
6 the top two regions with the highest proportion of newborn deaths, while five countries
7 (India, Pakistan, Nigeria, the Democratic Republic of the Congo, and Ethiopia) accounted for
8 50% of all newborn deaths.¹ Evidence show that, compared to mortality among children aged
9 1-59 months, neonatal mortality is decreasing more slowly.¹ If the current trend continues,
10 more low-and middle-income countries will fail to achieve the Sustainable Development
11 Goal (SDG) target for neonatal mortality at least as low as 12 per 1,000 live births.²

12
13 In contemporary obstetric practice, caesarean section remains an important intervention in
14 preventing neonatal mortality and other adverse birth outcomes.³ However, caesarean section
15 may be prone to misuse because of unequal access, social, and cultural factors.⁴⁻⁶ In
16 developing country settings, due to limited medical provisions and/or lack of skilled birth
17 attendants, some women may not benefit from caesarean birth though they are medically
18 eligible, while ineligible women may sometimes have increased access. In the last decades,
19 caesarean section rates have been increasing in low-, middle, and high-income countries.⁷⁻⁹
20 The World Health Organization (WHO) suggests, “every effort should be made to provide
21 caesarean sections to women in need, rather than striving to achieve a specific rate.”¹⁰

22
23 Previous studies conducted using aggregate- and individual-level data have yielded
24 inconsistent results about the association between caesarean birth and neonatal mortality. For
25 instance, two ecological studies^{11,12} conducted using worldwide country-level data have
26 found that caesarean birth was associated with lower neonatal mortality while another two
27 ecological studies^{13,14} showed no association between caesarean birth and neonatal mortality,
28 where caesarean section rates were higher than 10%. Inconsistent results for the association
29 between caesarean birth and neonatal mortality were also reported by different studies based
30 on individual-level data conducted in Africa, Latin America, Asia, and United States of
31 America.¹⁵⁻²⁰ For example, a large study conducted by Villar *et al.* in 410 health facilities in
32 24 areas in eight Latin American countries found that, with cephalic presentation, both
33 intrapartum and elective caesarean was associated with 1.66 (95% Confidence Interval (CI):

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3 1 1.26, 2.20) and 1.99 (95%CI: 1.51, 2.63) times higher odds of neonatal mortality up to
4 hospital discharge, respectively.¹⁶ However, another study based on WHO global survey
5 2 completed in nine countries in Asia found that both pre-labour (Adjusted Odds Ratio (aOR)
6 3 0.2, (95% CI: 0.1, 0.3)) and intrapartum caesarean sections (aOR 0.3, 95% CI: 0.2, 0.4) were
7 4 associated with improved perinatal outcomes following breech presentation.¹⁵
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10 7 On the other hand, using both country-and individual-level data collected for nationally
11 8 representative Demographic and Health Surveys (DHS), Kyu *et al.* found an increased risk
12 9 for neonatal death associated with caesarean versus vaginal births in countries with low (<
13 10 5%) and medium (5-15%) caesarean section rates.²¹ However, factors associated with
14 11 caesarean section that increase risk for neonatal death in countries with low and moderate
15 12 caesarean section rates remain ill-defined. Previous studies are limited by either inconsistent
16 13 results or lack the interpretation of findings by considering the contextual factors.¹¹⁻²¹ In
17 14 addition to the underlying indications for caesarean interventions like ‘fetal distress’, ‘cord
18 15 prolapse’, ‘prolonged and obstructed labour’, ‘fetal mal-presentation’, ‘major antepartum
19 16 haemorrhage’, and ‘placenta praevia’,^{22,23} several contextual factors such as unequal access,
20 17 infrastructural, and health workforce constraints could play a role in the association between
21 18 caesarean section and neonatal death.
22 19

23 20 In low- and middle-income countries, the DHS are the most representative and widely
24 21 available high quality data sources for studies related to maternal and child health. We use
25 22 Ethiopian DHS data from 2000, 2005, 2011, and 2016 to examine the changing temporal
26 23 association between caesarean birth and neonatal death. We then apply the ‘Three Delays
27 24 Model’ developed by Thadeus and Maine²⁴ to facilitate the interpretation of the association
28 25 between caesarean birth and neonatal death in Ethiopia using the 2016 data.
29 26

1 **Methods**

2 **Study design and data samples**

3 We used data from the Ethiopian DHS completed in 2000, 2005, 2011, and 2016. The
4 Ethiopian DHS are nationally representative cross-sectional surveys conducted in nine
5 regions (Tigray, Afar, Amhara, Oromia, Somali, Benishangul-Gumuz, SNNPR, Gambela,
6 and Harari), and two city administrations (Addis Ababa and Dire Dawa). Each of the surveys
7 involved a two-stage, stratified, clustered sampling design. The survey datasets are de-
8 identified and made freely available online. Permission to use these data was granted by the
9 MEASURE DHS Program. The details about the methodology and standards for protecting
10 the privacy of study participants in all DHS can be accessed at
11 (<http://www.measuredhs.com/What-We-Do/methodology.cfm>).

13 **Exposure**

14 The DHS questionnaire asks women about pregnancy, antenatal, and delivery care for
15 livebirths they have reported in the past 5 years. The data on caesarean section and other
16 variables in the DHS was collected based on mothers' self-report. For example, the self-
17 reported data on caesarean section was collected by asking mothers a question that reads,
18 "Was (NAME) delivered by caesarean section, that is, did they cut your belly open to take the
19 baby out?" Stanton and colleagues²⁵ in their study demonstrated that the DHS caesarean
20 section rates, compared with facility-based records of caesarean section rates, are reliable for
21 national and global monitoring in developing countries. For this study, the exposure group
22 were children delivered by caesarean section and unexposed group comprised children born
23 vaginally.

25 **Outcome**

26 Neonatal death includes children who were born alive in the 5 years before the survey, but
27 died within the first 28 days of life. The outcome variable, neonatal death, was measured
28 from two variables (whether the child is alive and age at death (in days)).

30 **Confounding**

31 The following potential confounders were identified based on a priori subject-matter and
32 expert knowledge. They included place of delivery (public, private, NGO, home), type of

1 residence (urban/rural), sex of child (male/female), size of baby at birth (very large, larger
2 than average, average, smaller than average, very small, don't know), mother's age at birth
3 (in years), mother's education (no education, primary, secondary, higher), birth order (1, 2-3,
4 4+), and household wealth quintile (poorest, poorer, middle, richer, richest). The size of baby
5 at birth was assessed based on mother's perception (estimate) of baby size at birth. It has
6 previously been shown that in the absence of complete enumeration of birth weight, mother's
7 perception of baby size at birth can be used as a proxy to birth weight in nationally
8 representative surveys.²⁶ Mother's age at birth was calculated as a difference (in years)
9 between infant's date of birth and mother's date of birth. DHS computes the wealth index for
10 each survey based on household assets using principal components analyses²⁷ and categorizes
11 households into wealth quintiles. These asset-based measures represent the wealth
12 distribution relative to other households within the country. They are widely used and are
13 consistent with comparisons to household expenditures and the measurement of inequalities
14 in child mortality, education, and healthcare use in low-and middle-income countries.²⁸

16 **Statistical analysis**

17 Missing information is uncommon in DHS because the data is collected by a trained
18 interviewers at a face-to-face interview. All analyses (i.e., Ethiopian DHS 2000, 2005, 2011
19 and 2016) were weighted to be nationally representative. As women may have had more than
20 one births within the five-year survey periods, we also accounted for both clustering of
21 caesarean deliveries within women as well as the complex survey design during the data
22 analyses using the unit of analysis (i.e., children) study number and sample weights. We then
23 conducted both individual- and aggregate-levels analyses. Our 2016 data analysis was also
24 supplemented by an application of the 'Three Delays Model' to interpret the association
25 between caesarean birth and neonatal death both empirically and theoretically. All analyses
26 were conducted using STATA/SE version 15.1 (Stata Corporation, College Station, TX).

28 **Individual-level analysis**

29 Associations between caesarean birth and neonatal death at individual-level were analysed
30 using log-Poisson regression models using data from Ethiopian DHS conducted in 2000,
31 2005, 2011, and 2016. We calculated unadjusted and adjusted prevalence ratios (aPR) and

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3 1 their 95% Confidence Intervals (CIs) for each survey. We have then compared the strength of
4 2 association between caesarean birth and neonatal death across all surveys analysed.
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10 4 After noting the increasing association between caesarean birth and neonatal death over time,
11 5 we conducted a series of analyses to explore what was during the change. We used the 2016
12 6 data because the association was more pronounced. We first restricted the analysis to
13 7 participants living in regions with the highest caesarean section rates to examine whether the
14 8 increased access to caesarean section affected the proportion of neonatal deaths. We then
15 9 estimated the effect of caesarean birth on neonatal death in regions with low caesarean
16 10 section rate (ranged: 0.4-5.3%) or where access to caesarean section is limited, by excluding
17 11 births in relatively high caesarean section rate regions—Addis Ababa (21.4%) and Harari
18 12 (9.0%).²⁹ Both low-and high-level of caesarean use has risks exceeding the risks of
19 13 spontaneous vaginal deliveries.^{15,30} It was demonstrated that low levels of caesarean are
20 14 related to lack of access and can contribute to maternal and newborn deaths.^{21,31}
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16 16 Given the very large rural-urban differences in caesarean section in Ethiopia,^{29,32} we also
17 17 conducted similar analyses separately for rural women. In addition, we evaluated the
18 18 association by restricting the analyses to births from the lowest quintile of household wealth,
19 19 births from the highest quintile of household wealth, and births in public health facilities
20 20 separately. These alternative analyses were exploratory in nature and helped us understand
21 21 contextual factors leading to inequalities in caesarean use that may occur not only due to
22 22 inadequate access among the poorest women, but also due to overuse among the richest
23 23 population subgroups.^{33,34} However, as the caesarean section rate in Ethiopia is low (about
24 24 2%), the number of neonatal deaths following caesarean birth is low and resulted in wide
25 25 confidence intervals for the estimates. The subgroup analyses allowed us to explain how
26 26 contextual factors such as unequal access, infrastructural, and workforce constraints could
27 27 play role in the association between caesarean section and neonatal death because these
28 28 factors will result in delay in accessing emergency caesarean section, which is usually
29 29 accessible at specialized health facilities.
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3 1 The 2016 DHS included an additional question regarding ‘timing of decision to conduct
4 2 caesarean section (i.e., whether it was before or after the onset of labour pains)’. We used this
5 3 variable as a proxy to the types of caesarean birth (indicative of intrapartum or pre-labour
6 4 caesarean section) and conducted analysis to examine the association between types of
7 5 caesarean section and neonatal death. As this was confined only to 2016 data, we have
8 6 provided the results in the **Supplementary Table A1**.
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17 8 **Aggregate-level analysis**

19 9 Data on the caesarean section rate and proportion of neonatal deaths were disaggregated by
20 10 urban-rural areas for each of the nine regions and two city administrations in Ethiopia for
21 11 each of the surveys completed in 2000, 2005, 2011, and 2016. However, the urban-rural
22 12 stratification for Addis Ababa is only available for the 2005 survey. These results in a total of
23 13 85 data points (observations). In order to assess the correlation between caesarean section and
24 14 neonatal death at aggregate-level, we conducted simple linear regression for overall surveys
25 15 together and for individual surveys separately.
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35 17 **Application of the ‘Three Delays Model’**

37 18 The ‘Three Delays Model’ is a conceptual framework developed by Thadeus and Maine to
38 19 examine factors contributing to maternal mortality with specific focus on those that affect the
39 20 “interval between the onset of obstetric complication and its outcome”.²⁴ The ‘Three Delays
40 21 Model’ summarises the various factors that affect *this interval* into three phases of delay—
41 22 delay in deciding to seek care (*Phase I delay*); delay in identifying and reaching medical
42 23 facility (*Phase II delay*); and delay in receiving adequate and appropriate treatment (*Phase III*
43 24 *delay*). Some of the key factors that shape the model include status of women; distance from
44 25 health facility; availability and cost of transportation; condition of roads; distribution of
45 26 health facilities; shortage of supplies, equipment, and skilled birth attendants; and adequacy
46 27 of referral system.²⁴ The pictorial presentation of the ‘Three Delays Model’ is provided in the
47 28 **Supplementary Figures A1-A4**.
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3 1 As maternal and neonatal mortality share many risk factors, we adopted the ‘Three Delays
4 Model’ as a framework to help interpret the association between caesarean birth and neonatal
5 2 mortality within the context of Ethiopia in the 2016 survey because factors contributing to the
6 3 ‘three delays’ aggravate the underlying medical indications for caesarean intervention that
7 4 make neonatal death difficult to prevent. The 2016 survey was selected for interpretation of
8 5 the association between caesarean birth and neonatal death using the ‘Three Delays Model’
9 6 because the association was more pronounced in 2016 data. Previous studies conducted in
10 7 India,³⁵ Tanzania³⁶ and Uganda³⁷ have applied the ‘Three Delays Model’ to their analyses of
11 8 perinatal deaths.
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14 11 We have identified some contributing factors underlying the ‘Three Delays Model’ from the
15 12 2016 survey. For example, information regarding problems faced by women of reproductive
16 13 age (15-49 years) in accessing health care to obtain medical advice or treatment for
17 14 themselves when they are sick were gathered. It consisted of four questions: distance to
18 15 health facility (big problem/not big problem); getting money for treatment (big problem/not
19 16 big problem); getting permission to go for treatment (big problem/not big problem); and not
20 17 wanting to go alone (big problem/not big problem). Furthermore, data on skilled assistance
21 18 during delivery, and women’s socioeconomic and demographic status are also available in
22 19 the DHS. This information can particularly be important to understand and address the
23 20 barriers that women face in seeking care during pregnancy and delivery.³² We have,
24 21 therefore, analysed the 2016 DHS data to describe these factors empirically in the context of
25 22 Ethiopia.
26 23

24 **Patient and public involvement**

25 25 This research was done without patient involvement in setting the research question or the
26 26 outcome measures, and in the design and implementation of the study. No patients were
27 27 asked to advise on interpretation or writing up of results. There are no plans to disseminate
28 28 the results of this research to study participants or the relevant patient community.
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1 Results

2 **Table 1** shows the characteristics of mothers and children according to mode of delivery for
3 each of the surveys conducted in 2000, 2005, 2011, and 2016. Across the four DHS survey
4 waves, women who underwent caesarean delivery were more likely to live in urban areas,
5 had a higher level of education, and were from the richest quintile of household wealth. They
6 were also more likely to have male children. Caesarean deliveries were more frequent in
7 women in the age category of 20-29 years, and among infants who had either very large or
8 larger than average size of baby at birth. **Figure 1** shows that the proportion of institutional
9 deliveries increased from 5.0% in 2000 to 26.3% in 2016, whereas the national caesarean
10 section rate increased from 0.7% in 2000 to 1.9% in 2016. However, the rate of caesarean
11 delivery in Ethiopia varied widely across administrative regions (**Figure 2**). For instance,
12 Addis Ababa had the highest (21.4%) rate, while Somali region had the lowest (0.4%) in
13 2016. The national proportion of neonatal deaths decreased from 4.8% in 2000 to 2.9% in
14 2016, but the proportion varies among administrative regions of Ethiopia (**Figure 1 &**
15 **Supplementary Table A2**).

16
17 **Table 2** shows that the adjusted prevalence ratio (aPR) for neonatal death associated with
18 caesarean versus vaginal births in 2000 survey was 0.95 (95%CI, 0.29, 3.19) while in 2005, it
19 was 1.53 (95%CI, 0.52, 4.50). In 2011, the adjusted prevalence ratio (aPR) for neonatal death
20 associated with caesarean versus vaginal births was 1.15 (95%CI, 0.45, 2.93), while it was
21 2.81-fold higher risk of neonatal death (aPR, 2.81; 95%CI, 1.11, 7.13) in 2016.

22
23 **Table 3** summarises the findings of the subgroup analyses based on the 2016 data. When
24 women living in urban settings—Addis Ababa (caesarean section rate (21.4%)), and Harari
25 (9.0%)—were excluded from the analyses, the corresponding adjusted PR for neonatal death
26 was increased to 3.55 (95%CI, 1.31, 8.56). Similarly, when we restricted the analyses to
27 include only rural women, the prevalence ratio for neonatal death associated with caesarean
28 versus vaginal births was found to be 3.43 (95% CI, 1.22, 9.67). The respective risk of
29 neonatal death increased to 7.01 (95%CI, 0.92, 53.36) when the analysis was limited to
30 women from the lowest quintile of household wealth.

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3 1 When we restricted the analyses to Addis Ababa, the capital of Ethiopia, the relative risk for
4 2 neonatal death associated with caesarean versus vaginal births was 1.07 (95%CI, 0.20, 5.73).
5 3 Moreover, when the analysis was confined to women from the highest quintile of the
6 4 household wealth, the risk of neonatal death was 2.72 (95% CI, 0.55, 13.38).
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13 6 Lastly, **Figure 3** shows that an increase in caesarean section rate is weakly correlated with a
14 7 decrease in the proportion of neonatal deaths (correlation coefficient (r) = -0.1839) when
15 8 aggregate-level data for all surveys together was analyzed. However, the relationship
16 9 between caesarean birth and neonatal death is variable when the analysis is restricted to each
17 10 survey year separately (see **Figure 4**).
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1 Interpretation

2 The primary individual-level analyses showed that the adjusted prevalence ratios (aPR) for
3 neonatal death associated with caesarean versus vaginal births increased from 0.95 (95% CI,
4 0.29, 3.19) in 2000 to 2.81 (95% CI, 1.11, 7.13) in 2016. These findings suggest that the
5 circumstances for foetuses born in 2000 survey were different from the foetuses in 2016. Our
6 subgroup analyses using 2016 data suggest that the association between caesarean birth and
7 neonatal death was stronger among rural women (aPR (95% CI) 3.43 (1.22, 9.67)) and among
8 women from the lowest quintile of household wealth (aPR (95% CI) 7.01 (0.92, 53.36)), but
9 not for births in areas with wider availability of caesarean such as Addis Ababa (aPR (95%
10 CI) 1.07 (0.20, 5.73)). The changing association between caesarean birth and neonatal death
11 over time, and the stronger association observed among different subgroup analyses may be
12 attributable to changes in the pattern of confounding by indication due to contextual factors
13 such as unequal access, structural health-system deficiencies (insufficient equipment,
14 supplies, and drugs), infrastructural, and health workforce constraints.

15
16 The national caesarean section and institutional delivery rates in Ethiopia are still low though
17 increases in the past decade are notable. There is also substantial disparity in caesarean
18 section rates, with very low rates in rural areas and among the poorest women,²⁹ suggesting
19 unequal access which may be as a consequence of a range of geographic, social, and
20 economic barriers. The low caesarean rates may also be due to lack of skilled birth
21 attendants, and poor health infrastructure (e.g., shortage of medical care institutions,
22 deficiencies in surgical facilities, surgical and anaesthesia personnel and equipment, and
23 blood transfusion capacity).³⁸⁻⁴⁰ In Ethiopia, there are only 820 Obstetricians, 10,846 General
24 practitioners, 996 Emergency obstetric surgeons, 6,345 Health officers, 41,009 Nurses, 8,635
25 Midwives, 233 Anaesthesiologists, and 33,320 Health extension workers for the population
26 of over 90 million in 2015.⁴¹ Similarly, there are only 3,547 functional Health centres, 16,
27 447 functional Health posts, and 189 functional Hospitals in 2015.⁴²

28
29 We know from previous research that inadequate access to timely caesarean section may
30 result in perinatal asphyxia, uterine rupture, obstructed labour, and these can contribute to
31 maternal and newborn deaths.⁴³ Conversely, it was demonstrated that maternal and neonatal
32 mortality due to obstetric complications can be prevented with timely access to caesarean
33 section.^{43,44} Delay, therefore, emerges as relevant factor in worsening the underlying

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3 1 obstetric indications for caesarean intervention thereby contributing to neonatal death.
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5 2 Context specific factors that delay access to caesarean section may have the capacity to make
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7 3 women with labour problems undergo caesarean section after severe complication of labour
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9 4 or severe foetal compromise. Therefore, our interpretation is that caesarean section conducted
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11 5 after severe foetal compromise may not prevent neonatal deaths because they have already
12
13 6 experienced such severity of complications that although live born, neonatal death is difficult
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15 7 to prevent.
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17 8
18 9 There are two possible scenarios leading to caesarean section in Ethiopia. First, when women
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20 10 who have previously had a caesarean section, with breech presentation, or other risk factors
21
22 11 such as eclampsia attend specialised health facilities, they are usually allowed to undergo
23
24 12 caesarean section. Their caesarean section is commonly classified as ‘elective or scheduled
25
26 13 caesarean section’. Second, when caesarean section is performed for ‘emergency reasons’.
27
28 14 Full term mothers with or without signs of labour will be admitted to health facilities where
29
30 15 their progress is monitored and labour-augmenting or inducing medications may be
31
32 16 administered. Decisions to perform caesarean section in these facilities or decision to refer
33
34 17 the mother to nearby hospitals for caesarean delivery or other action depends on the condition
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36 18 of the mother and foetus during the progress of labour. In primary health facilities (i.e., health
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38 19 posts and health centres), obstetric care providers usually use a ‘Partograph’,^{45,46} a routine
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40 20 labour monitoring instrument (chart) which helps the health care providers to identify slow
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42 21 progress in labour and take appropriate action. In hospitals, the decision to perform a
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44 22 caesarean section is reached when the labour is prolonged and/or the second stage of labour is
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46 23 complicated risking the life of mother and foetus.
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48 24
49 25 Given these pathways to caesarean delivery in mind, our interpretation of the association
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51 26 between caesarean birth and neonatal death in Ethiopia using the 2016 survey may be shaped
52
53 27 by examining factors contributing to delays in the ‘Three Delays Model’. This is because
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55 28 delays to caesarean section aggravate the underlying medical indications for caesarean
56
57 29 intervention. **Table 4** shows factors affecting the length of delays in the ‘Three Delays
58
59 30 Model’ according to sociodemographic characteristics in 2016 Ethiopia DHS.
60

31 32 **Phase I delay: deciding to seek care**

33 In Ethiopia, poorer and less-educated women are more likely to select a nearby health

1 facility, especially in rural areas, where there is limited access to caesarean section and the
2 possibility of benefiting from caesarean section is mainly through referral to higher levels of
3 care. Women are more likely to undergo a caesarean section if they present to specialized
4 health facilities. However, the outcome of delivery depends on how quick/competent the
5 health care provider is in referring the mother or on intervening, and the severity of the
6 underlying obstetric complications for caesarean intervention which may be affected by the
7 delay in women's or family's decision to seek care. Poor health decision-making depends on
8 numerous factors such as educational status, distance to health facility, economic status,
9 sociocultural factors (e.g., unsupportive spouse, and lack of autonomy), and quality of
10 care.^{24,47,48}

11
12 **Table 4** shows that 'distance to health facility' was a big problem in accessing health care for
13 about 60% of rural and 17% of urban women in Ethiopia. Similarly, 'getting money for
14 treatment' is a big problem to access health care and was reported by 61% of rural and 35%
15 of urban women in 2016. On the other hand, the status of women in a given society affects
16 the decision to seek care. For instance, efforts to seek timely care is influenced by women's
17 limited mobility because they need permission to travel from spouse and/or mother-in-law.²⁴
18 In Ethiopia, about 37% of rural and 15% of urban women reported 'getting permission to go
19 for treatment' was a big problem to access health care.

20 21 **Phase II delay: identifying and reaching a medical facility**

22 Delay in reaching health care may occurs when women who encounter obstetric complication
23 live farther from health facilities, where the availability and cost of transportation is
24 problematic. In one study conducted in rural India, Kumar *et al.*⁴⁷ found that health facility
25 births occur less likely among women living farther away from the health facilities,
26 suggesting distance as an important barrier to in-facility births for rural women. In addition to
27 the travel distance, the scarcity of transportation which may be accompanied by poor roads is
28 also another obstacle for women with labour complications to timely reach even the closest
29 health facility. As a result of this, women who arrive at the nearby facility following obstetric
30 complications probably will travel further to specialised hospital due to emergency referral. It
31 is clear that the obstetric complications encountered by mothers reaching nearby primary
32 health facilities will be compounded by additional delays when they are referred for
33 caesarean section. These scenarios highlight the likelihood of adverse delivery outcome

1 followed by aggravated obstetric complications due to delays in reaching medical facility as
2 high.

3
4 In Ethiopia, about 50% of women of reproductive age (15-49 years) reported ‘distance to
5 health facility’ as a big problem to access health care (see **Table 4**). Moreover, access to
6 caesarean situation in Ethiopia is worse than in most other settings.

7 8 **Phase III delay: receiving adequate and appropriate treatment**

9 Phase III delays occur within any health facilities and are indicators of inadequate care due to
10 lack of facilities; inadequately trained obstetric care givers (skilled birth attendants); and
11 deficiencies in surgical facilities, surgical and anaesthesia personnel and equipment, and
12 blood transfusion as well as inadequate and inappropriate referral systems. These
13 deficiencies will limit women’s access to lifesaving procedures such as caesarean section. In
14 Ethiopia, only 28.0% of all births were delivered by ‘skilled providers’ (i.e., doctor, nurse,
15 midwife, health officer, and health extension worker) in 2016 survey. **Table 4** also shows that
16 there are disparities in the proportion of births attended by skilled birth attendants by urban-
17 rural place of residence, region, level of mother’s education, and household wealth. It is quite
18 clear that insufficient number of skilled birth attendants at any health facility will lead to
19 delay in receiving appropriate treatment among women with obstetric complications.

20 Although health posts and health centres (primary health care unit) are the most accessible to
21 the general population in Ethiopia, they are not fully equipped to deal with obstetric
22 complications.^{41,42} As a result of this, women with obstetrics complications will have to travel
23 on to better equipped institutions (secondary and tertiary level of health care) with caesarean
24 section capacity (e.g., general hospitals and specialized hospitals) through referral. By the
25 time women reach these well-equipped health facility, the delays will have further aggravated
26 the obstetric complications on the way. A schematic representation of the Ethiopian health
27 system structure is provided in **Supplementary Figure A5**.

28
29 On the other hand, delay in caesarean intervention may even happen if mothers with less
30 severe obstetric complications were referred and presented to specialised health facilities in a
31 timely manner. This is because a trial of labour is usually attempted before a decision to have
32 caesarean section. For instance, some women who are referred from primary health facilities
33 undergo induction and augmentation of labour because these interventions are only provided

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1 in health facilities with the capacity to provide caesarean section in Ethiopia. These practices,
2 in turn, will result in delay in receiving caesarean section leading to worsening of the already
3 existing obstetric complications. Thus, any delays to caesarean intervention have a higher
4 chance of aggravating the already existing complications and increase the risk of neonatal
5 death.

6

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1 Discussion

2 Our study examined the changing temporal association between caesarean birth and neonatal
3 death within the context of Ethiopia from 2000 to 2016. The association between caesarean
4 section and neonatal death increased over time and was variable among population
5 subgroups. These changes over time, and variation across population subgroups may be
6 attributable to changes in the pattern of confounding by indication due to contextual factors
7 such as improvement in health service coverage, unequal access (e.g., due to a range of
8 geographic, social, and economic barriers), and structural, and health workforce constraints.

9
10 In Ethiopia, the proportion of women aged 15-49 years who received any antenatal care from
11 a skilled provider has increased from 27% in 2000 to 62% in 2016.³² Health facility-based
12 deliveries have increased from 5% in 2000 to 26% in 2016 (increased from 2% in 2000 to
13 20% in 2016 for rural women, and increased from 32% in 2000 to 79% in 2016 for urban
14 women).³² The proportion of births in health facilities assisted by skilled birth attendants
15 increased from 6% in 2000 to 28% in 2016.³² These figures reflect improvement in health
16 service coverage in Ethiopia.

17
18 Moreover, since 2003, with the implementation of the Health Extension Programme—a
19 community-based primary health care programme—the Ethiopian government has increased
20 the number of health posts from 4,211 in 2005 to 16,447 in 2015.^{42,49} Likewise, the number
21 of health centres were increased from 600 in 2005 to 3,586 in 2015.^{42,49} However, due to
22 limitations in proper monitoring of labour for making timely decisions, especially on whether
23 or not to initiate a referral from primary health facilities to higher level facilities, and due to
24 poor transport and road networks which are still the common problems in low income
25 countries,⁵⁰ the underlying medical indications for caesarean intervention will be worsened
26 by factors contributing to ‘delays’. Delay in receiving adequate and appropriate care is still a
27 common problem in low income countries due to deficiencies in surgical facilities, surgical
28 and anaesthesia personnel and equipment, blood transfusion capacity, and shortage of skilled
29 birth attendants.⁵¹⁻⁵³ There is also an inequitable distribution of the health workforce across
30 urban and rural areas. For example, the majority of specialist doctors in Ethiopia serve in
31 urban areas, where the total population distribution is only 19.4%.^{41,42} These situations often
32 result in poor quality care to rural women, and the caesarean section conducted after a
33 complicated labour may be associated with increased neonatal mortality due to confounding

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7 3 Unlike previous studies, the present study takes into account the interpretation of the
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9 4 association between caesarean birth and neonatal death within the context of Ethiopia using
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11 5 DHS data. The change in the strength of effect estimates across DHS waves, and the different
12
13 6 subgroup analyses suggest that neonatal mortality can be reduced by increasing timely access
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15 7 to caesarean section and timely decision for caesarean delivery via increasing health service
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17 8 coverage, improving infrastructure (e.g., increasing number of health facilities), increasing
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19 9 the number of skilled birth attendants, improving quality of care, and increasing awareness
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21 10 about antenatal care and health facility delivery among women. Moreover, provision of
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23 11 training to skilled birth attendants on close monitoring of labour and early detection of
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25 12 complications, equipping the primary health facilities (e.g., health centres) to the level of
26
27 13 caesarean capacity, and continuous financial investment in primary health facilities will be an
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29 14 important strategy to reduce neonatal mortality.
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32
33 16 It appears that previous studies which used individual-level data are more likely to report an
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35 17 increased risk of neonatal death among infants born by caesarean section than the ecological
36
37 18 studies. This may be due to the indications for the caesarean delivery (e.g., the severity of the
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39 19 underlying causes) was involved in causing both caesarean delivery and neonatal death in
40
41 20 studies which used individual-level data, suggesting the role of confounding by indication in
42
43 21 the association between caesarean birth and neonatal death because an intended effect of
44
45 22 caesarean birth is prevention of neonatal death. Therefore, the increased risk for neonatal
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47 23 death associated with caesarean birth, compared with vaginal birth, would appear to be
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49 24 intuitive given the fact that neonatal death rates after emergency caesarean section is strongly
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51 25 dependent upon the underlying medical indication (e.g., antenatally diagnosed foetal
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53 26 malformation or foetal growth restriction) for caesarean intervention.
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57 28 In Ethiopia, the national rate of caesarean section increased from 0.7% in 2000 to 1.9% in
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59 29 2016. On the other hand, neonatal mortality rate declined from 49 deaths per 1,000 live births
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61 30 in 2000 to 29 deaths per 1,000 births in 2016.³² Similarly, the pregnancy-related mortality
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63 31 ratio decreased from 871 pregnancy-related deaths per 100,000 live births in 2000 to 412
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65 32 pregnancy-related deaths per 100,000 live birth in 2016.³² Our analyses based on aggregate-
66
67 33 level data from Ethiopian DHS showed that an increase in caesarean section rate is correlated

1 with a decrease in the proportion of neonatal deaths. Even though similar context-specific
2 interpretation is applicable to ecological studies, additional explanation may also be
3 necessary to interpret the association. For example, a change in neonatal mortality rate may
4 be attributable to changes acting on the population as a whole—i.e., changes in health
5 coverage indicators, such as an increase in births attended by skilled birth attendants
6 (increased from 6% in 2000 to 28% in 2016)³² and immunization coverage (was 86.4% in
7 2015).⁴²

8 We acknowledge the following limitations of this study. Firstly, as both the proportion of
9 institutional deliveries and caesarean section rate is low in Ethiopia, especially in rural areas,
10 the number of neonatal deaths following caesarean section may be low. However, since our
11 analyses are weighted, we believe that the weight improves the representativeness of the data
12 in terms of size, distribution and characteristics of the Ethiopian population. The weight may
13 also ensure that our estimates are unbiased though the confidence interval for some subgroup
14 analyses are somewhat wide. Secondly, the interpretation of our study is specific to the
15 context of Ethiopia and may not be generalizable to other developing countries in Africa or
16 elsewhere. Another limitation is the mother's recall of the child's size at birth was used as a
17 substitute for the child's birth weight in this study because the data for birth weight was not
18 collected for more than 50% of the neonates in DHS.

1
2
3 **1 Conclusions**
4

5
6 2 A naïve interpretation of the changing temporal association between caesarean birth and
7
8 3 neonatal death from 2000 to 2016 is that caesarean section is increasingly associated with
9
10 4 neonatal death. However, the changing temporal association likely reflects improvements in
11
12 5 health service coverage and secular shifts in the characteristics of Ethiopian women
13
14 6 undergoing caesarean section after complicated labour or severe foetal compromise.
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14 **Ethical approval:** Not required.

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19 aspects of the study have been omitted; and that any discrepancies from the study as planned
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1 1 **References**

- 2 1. United Nations Inter-agency Group for Child Mortality Estimation (UN IGME).
3 Levels and Trends in Child Mortality: Report 2017, Estimates Developed by the UN Inter-
4 agency Group for Child Mortality Estimation. New York: United Nations Children's Fund,
5 2017.
- 6 2. UN General Assembly. Transforming our world: the 2030 Agenda for Sustainable
7 Development, 21 October 2015, A/RES/70/1, available at:
8 <https://www.refworld.org/docid/57b6e3e44.html> [accessed 28 June 2019].
- 9 3. Costello A, Osrin D. Epidemiological transition, medicalisation of childbirth, and
10 neonatal mortality: three Brazilian birth-cohorts. *Lancet* 2005; **365**(9462): 825-6.
- 11 4. Gibbons L, Belizan JM, Lauer JA, Betran AP, Merialdi M, Althabe F. Inequities in
12 the use of cesarean section deliveries in the world. *Am J Obstet Gynecol* 2012; **206**(4): 331
13 e1-19.
- 14 5. Leone T, Padmadas SS, Matthews Z. Community factors affecting rising caesarean
15 section rates in developing countries: an analysis of six countries. *Soc Sci Med* 2008; **67**(8):
16 1236-46.
- 17 6. de Mello e Souza C. C-sections as ideal births: the cultural constructions of
18 beneficence and patients' rights in Brazil. *Camb Q Healthc Ethics* 1994; **3**(3): 358-66.
- 19 7. Dumont A, de Bernis L, Bouvier-Colle MH, Breart G, MOMA study group.
20 Caesarean section rate for maternal indication in sub-Saharan Africa: a systematic review.
21 *Lancet* 2001; **358**(9290): 1328-33.
- 22 8. Vogel JP, Betran AP, Vindevoghel N, et al. Use of the Robson classification to assess
23 caesarean section trends in 21 countries: a secondary analysis of two WHO multicountry
24 surveys. *Lancet Glob Health* 2015; **3**(5): E260-E70.
- 25 9. Ye J, Betran AP, Guerrero Vela M, Souza JP, Zhang J. Searching for the optimal rate
26 of medically necessary cesarean delivery. *Birth* 2014; **41**(3): 237-44.
- 27 10. World Health Organization. WHO Statement on Caesarean Section Rates. Geneva:
28 World Health Organization, 2015.
- 29 11. Betran AP, Merialdi M, Lauer JA, et al. Rates of caesarean section: analysis of global,
30 regional and national estimates. *Paediatr Perinat Epidemiol* 2007; **21**(2): 98-113.
- 31 12. Molina G, Weiser TG, Lipsitz SR, et al. Relationship Between Cesarean Delivery
32 Rate and Maternal and Neonatal Mortality. *JAMA* 2015; **314**(21): 2263-70.

- 1 13. Ye J, Zhang J, Mikolajczyk R, Torloni MR, Gulmezoglu AM, Betran AP. Association
2 between rates of caesarean section and maternal and neonatal mortality in the 21st century: a
3 worldwide population-based ecological study with longitudinal data. *BJOG* 2016; **123**(5):
4 745-53.
- 5 14. Althabe F, Sosa C, Belizan JM, Gibbons L, Jacquerioz F, Bergel E. Cesarean section
6 rates and maternal and neonatal mortality in low-, medium-, and high-income countries: an
7 ecological study. *Birth* 2006; **33**(4): 270-7.
- 8 15. Lumbiganon P, Laopaiboon M, Gulmezoglu AM, et al. Method of delivery and
9 pregnancy outcomes in Asia: the WHO global survey on maternal and perinatal health 2007-
10 08. *Lancet* 2010; **375**(9713): 490-9.
- 11 16. Villar J, Carroli G, Zavaleta N, et al. Maternal and neonatal individual risks and
12 benefits associated with caesarean delivery: multicentre prospective study. *BMJ* 2007;
13 **335**(7628): 1025.
- 14 17. MacDorman MF, Declercq E, Menacker F, Malloy MH. Infant and neonatal mortality
15 for primary cesarean and vaginal births to women with "no indicated risk," United States,
16 1998-2001 birth cohorts. *Birth* 2006; **33**(3): 175-82.
- 17 18. MacDorman MF, Declercq E, Menacker F, Malloy MH. Neonatal mortality for
18 primary cesarean and vaginal births to low-risk women: application of an "intention-to-treat"
19 model. *Birth* 2008; **35**(1): 3-8.
- 20 19. Kallen K, Olausson PO. Neonatal mortality for low-risk women by method of
21 delivery. *Birth* 2007; **34**(1): 99-100; author reply 1-2.
- 22 20. Shah A, Fawole B, M'Imunya J M, et al. Cesarean delivery outcomes from the WHO
23 global survey on maternal and perinatal health in Africa. *Int J Gynaecol Obstet* 2009; **107**(3):
24 191-7.
- 25 21. Kyu HH, Shannon HS, Georgiades K, Boyle MH. Cesarean delivery and neonatal
26 mortality rates in 46 low- and middle-income countries: a propensity-score matching and
27 meta-analysis of Demographic and Health Survey data. *Int J Epidemiol* 2013; **42**(3): 781-91.
- 28 22. Begum T, Rahman A, Nababan H, et al. Indications and determinants of caesarean
29 section delivery: Evidence from a population-based study in Matlab, Bangladesh. *PLoS One*
30 2017; **12**(11): e0188074.
- 31 23. Belizan JM, Minckas N, McClure EM, et al. An approach to identify a minimum and
32 rational proportion of caesarean sections in resource-poor settings: a global network study.
33 *Lancet Glob Health* 2018; **6**(8): e894-e901.

- 1
2
3 1 24. Thaddeus S, Maine D. Too far to walk: maternal mortality in context. *Soc Sci Med*
4 1994; **38**(8): 1091-110.
- 5
6 3 25. Stanton CK, Dubourg D, De Brouwere V, Pujades M, Ronsmans C. Reliability of data
7 on caesarean sections in developing countries. *Bull World Health Organ* 2005; **83**(6): 449-55.
- 8
9 4 26. Channon AA. Can mothers judge the size of their newborn? Assessing the
10 determinants of a mother's perception of a baby's size at birth. *J Biosoc Sci* 2011; **43**(5): 555-
11 73.
- 12
13 5 27. Filmer D, Pritchett LH. Estimating wealth effects without expenditure data--or tears:
14 an application to educational enrollments in states of India. *Demography* 2001; **38**(1): 115-
15 32.
- 16
17 8 28. Filmer D, Scott K. Assessing asset indices. *Demography* 2012; **49**(1): 359-92.
- 18
19 10 29. Yisma E, Smithers LG, Lynch JW, Mol BW. Cesarean section in Ethiopia: prevalence
20 and sociodemographic characteristics. *J Matern Fetal Neonatal Med* 2019; **32**(7): 1130-5.
- 21
22 11 30. Souza JP, Gulmezoglu A, Lumbiganon P, et al. Caesarean section without medical
23 indications is associated with an increased risk of adverse short-term maternal outcomes: the
24 2004-2008 WHO Global Survey on Maternal and Perinatal Health. *BMC Med* 2010; **8**: 71.
- 25
26 14 31. Ronsmans C, Etard JF, Walraven G, et al. Maternal mortality and access to obstetric
27 services in West Africa. *Trop Med Int Health* 2003; **8**(10): 940-8.
- 28
29 16 32. Central Statistical Agency - CSA/Ethiopia, ICF. Ethiopia Demographic and Health
30 Survey 2016. Addis Ababa, Ethiopia: CSA and ICF, 2017.
- 31
32 17 33. Boerma T, Ronsmans C, Melesse DY, et al. Global epidemiology of use of and
33 disparities in caesarean sections. *Lancet* 2018; **392**(10155): 1341-8.
- 34
35 19 34. Boatin AA, Schlottheuber A, Betran AP, et al. Within country inequalities in caesarean
36 section rates: observational study of 72 low and middle income countries. *BMJ* 2018; **360**:
37 k55.
- 38
39 21 35. Upadhyay RP, Rai SK, Krishnan A. Using three delays model to understand the social
40 factors responsible for neonatal deaths in rural Haryana, India. *J Trop Pediatr* 2013; **59**(2):
41 100-5.
- 42
43 23 36. Mbaruku G, van Roosmalen J, Kimondo I, Bilango F, Bergstrom S. Perinatal audit
44 using the 3-delays model in western Tanzania. *Int J Gynaecol Obstet* 2009; **106**(1): 85-8.
- 45
46 25 37. Waiswa P, Kallander K, Peterson S, Tomson G, Pariyo GW. Using the three delays
47 model to understand why newborn babies die in eastern Uganda. *Trop Med Int Health* 2010;
48 **15**(8): 964-72.
- 49
50
51
52
53
54
55
56
57
58
59
60

- 1
2
3 1 38. Holmer H, Lantz A, Kunjumen T, et al. Global distribution of surgeons,
4 anaesthesiologists, and obstetricians. *Lancet Glob Health* 2015; **3 Suppl 2**: S9-11.
- 5 2
6 3 39. Ologunde R, Vogel JP, Cherian MN, Sbaiti M, Merialdi M, Yeats J. Assessment of
7 cesarean delivery availability in 26 low- and middle-income countries: a cross-sectional
8 study. *Am J Obstet Gynecol* 2014; **211**(5): 504 e1- e12.
- 9 4
10 5
11 6 40. Say L, Raine R. A systematic review of inequalities in the use of maternal health care
12 in developing countries: examining the scale of the problem and the importance of context.
13 *Bull World Health Organ* 2007; **85**(10): 812-9.
- 14 7
15 8 41. WHO. Primary health care systems (PRIMASYS): case study from Ethiopia, abridged
16 version. Geneva: World Health Organization; 2017. Licence: CC BY-NC-SA 3.0 IGO.
- 17 9
18 10 42. Federal Ministry of Health. Health and health related indicators 2007 E.C. (2014/15
19 G.C.). Addis Ababa, Ethiopia: Federal Ministry of Health; 2015.
- 20 11
21 12 43. Betran AP, Torloni MR, Zhang JJ, Gulmezoglu AM, WHO Working Group on
22 Caesarean Section. WHO Statement on Caesarean Section Rates. *BJOG* 2016; **123**(5): 667-
23 70.
- 24 13
25 14 44. Thomas S, Meadows J, McQueen KA. Access to Cesarean Section Will Reduce
26 Maternal Mortality in Low-Income Countries: A Mathematical Model. *World J Surg* 2016;
27 **40**(7): 1537-41.
- 28 15
29 16 45. Yisma E, Dessalegn B, Astatkie A, Fesseha N. Knowledge and utilization of
30 partograph among obstetric care givers in public health institutions of Addis Ababa, Ethiopia.
31 *BMC Pregnancy Childbirth* 2013; **13**(1): 17.
- 32 17
33 18 46. Yisma E, Dessalegn B, Astatkie A, Fesseha N. Completion of the modified World
34 Health Organization (WHO) partograph during labour in public health institutions of Addis
35 Ababa, Ethiopia. *Reprod Health* 2013; **10**(1): 23.
- 36 19
37 20 47. Kumar S, Dansereau EA, Murray CJL. Does distance matter for institutional delivery
38 in rural India? *Applied Economics* 2014; **46**(33): 4091-103.
- 39 22
40 23 48. Anselmi L, Lagarde M, Hanson K. Health service availability and health seeking
41 behaviour in resource poor settings: evidence from Mozambique. *Health Econ Rev* 2015;
42 **5**(1): 62.
- 43 24
44 25 49. Federal Ministry of Health. Health and health related indicators 1997 E.C. (2004/05
45 G.C.). Addis Ababa, Ethiopia: Federal Ministry of Health; 2005.
- 46 26
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3 1 50. Atuoye KN, Dixon J, Rishworth A, Galaa SZ, Boamah SA, Luginaah I. Can she make
4 2 it? Transportation barriers to accessing maternal and child health care services in rural Ghana.
5 3 *BMC Health Serv Res* 2015; **15**(1): 333.
6 4
7 8 51. Bergstrom S. Training non-physician mid-level providers of care (associate clinicians)
8 9 to perform caesarean sections in low-income countries. *Best Pract Res Clin Obstet Gynaecol*
9 10 2015; **29**(8): 1092-101.
10 11
11 12 52. Orji EO, Ojofeitimi EO, Esimai AO, Adejuyigbe E, Adeyemi AB, Owolabi OO.
12 13 Assessment of delays in receiving delivery care at a tertiary healthcare delivery centre in
13 14 Nigeria. *J Obstet Gynaecol* 2006; **26**(7): 643-4.
14 15
15 16 53. Miller S, Abalos E, Chamillard M, et al. Beyond too little, too late and too much, too
16 17 soon: a pathway towards evidence-based, respectful maternity care worldwide. *Lancet* 2016;
17 18 **388**(10056): 2176-92.
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1 **Table 1.** Characteristics of the study participants according to the mode of delivery, Ethiopia DHS 2000, 2005, 2011, and 2016

	Mode of delivery							
	DHS 2000		DHS 2005		DHS 2011		DHS 2016	
	Caesarean (n= 86) %	Vaginal (n= 12,174) %	Caesarean (n= 111) %	Vaginal (n= 11,052) %	Caesarean (n= 175) %	Vaginal (n= 11,697) %	Caesarean (n= 213) %	Vaginal (n= 10,810) %
Neonatal death								
Yes	4.5	4.8	6.7	3.9	5.5	3.7	8.3	2.7
No	95.5	95.2	93.3	96.1	94.5	96.3	91.7	97.3
Types of residence								
Urban	76.2	9.9	68.8	6.7	70.9	12.0	60.4	10.1
Rural	23.8	90.1	31.2	93.3	29.1	88.0	39.6	89.9
Region								
Tigray	4.0	6.4	5.4	6.3	12.5	6.2	6.8	6.5
Afar	2.5	1.0	0.6	1.0	1.4	1.0	0.4	1.0
Amhara	3.7	26.3	15.2	23.6	19.4	22.4	22.1	18.7
Oromia	46.3	40.7	28.5	39.6	14.6	42.6	21.2	44.5
Somali	2.3	1.2	4.2	4.3	1.4	3.1	1.0	4.7
Benishangul-Gumuz	3.1	1.0	0.1	0.9	1.0	1.2	0.6	1.1
SNNP	18.5	21.2	21.6	22.4	17.4	21.1	21.0	20.8
Gambela	0.6	0.2	0.5	0.3	2.0	0.3	0.2	0.2
Harari	0.9	0.2	0.7	0.2	1.2	0.2	1.1	0.2
Addis Ababa	16.9	1.4	22.1	1.2	27.6	1.5	24.5	1.8
Dire Dawa	1.1	0.3	1.2	0.3	1.4	0.3	1.2	0.4
Mother's age at birth								
<20	19.4	12.0	13.3	13.4	10.5	10.9	6.4	10.0
20-29	70.8	51.3	59.8	51.2	62.8	55.7	58.4	54.6
30-39	9.8	30.0	24.1	29.3	23.7	28.7	31.7	30.9
40-49	0.0	6.7	2.9	6.2	3.3	4.7	3.4	4.5
Mother's education								
No education	15.7	82.5	30.1	79.7	19.9	70.0	22.8	66.9
Primary	21.8	13.0	14.5	16.6	44.7	26.8	35.1	26.6

Secondary	56.4	4.3	46.5	3.4	22.2	1.9	15.3	4.5
Higher	6.2	0.2	8.9	0.3	13.2	1.2	26.8	2.0
Place of delivery[§]								
Public	96.3	4.0	90.2	3.9	83.5	7.6	84.0	23.6
Private	1.3	0.1	5.9	0.3	13.6	0.8	13.7	0.9
NGO	2.4	0.2	3.8	0.1	3.0	0.2	2.4	0.2
Home	0.0	95.6	0.0	95.7	0.0	91.4	0.0	75.2
Birth order								
1	75.5	18.6	53.2	17.0	53.5	18.5	41.4	18.2
2	17.5	16.5	26.0	15.5	17.0	17.0	25.6	16.0
3	2.2	13.7	5.7	14.5	10.3	14.2	18.2	14.2
4	1.0	11.3	1.5	12.9	6.0	12.6	3.3	12.5
5	0.6	10.4	2.2	10.8	8.4	10.5	5.3	11.4
6+	3.2	29.5	11.4	29.4	4.7	27.2	6.3	27.6
Sex of child								
Male	61.8	51.2	51.3	51.3	57.2	51.9	54.0	51.9
Female	38.2	48.8	48.7	48.7	42.8	48.1	46.0	48.1
Size of baby at birth*								
Very large	9.8	5.3	30.7	22.3	25.8	19.2	26.5	17.6
Larger than average	32.0	25.4	11.4	9.5	11.7	12.7	16.0	13.8
Average	34.6	35.7	37.4	40.0	42.3	38.2	36.1	41.7
Smaller than average	19.7	27.5	9.4	7.3	4.9	8.7	7.0	10.1
Very small	3.7	5.9	9.5	20.6	14.8	20.6	12.7	16.0
Don't know	0.2	0.2	1.1	0.4	0.6	0.4	1.7	0.8
Wealth quantile								
Poorest	1.9	21.1	0.6	22.1	2.0	23.1	7.2	24.2
Poorer	4.9	21.0	5.9	21.3	8.4	22.6	12.2	23.1
Middle	4.1	22.0	3.9	22.5	9.0	20.7	10.8	20.9
Richer	6.1	20.5	9.7	20.0	6.5	19.3	9.3	18.3
Richest	83.0	15.5	79.9	14.2	74.1	14.2	60.4	13.5

1 NB: *n*=weighted; [§]Missing for 2000 (n = 9); *Mother's estimate of baby's size at birth; **DHS**, Demographic and Health Survey

Table 2. Crude and multivariable-adjusted prevalence ratios for neonatal death associated with caesarean versus vaginal delivery, Ethiopia DHS 2000, 2005, 2011, and 2016

	Prevalence Ratio (95% CI) for neonatal death
Ethiopia DHS 2000	
Vaginal delivery	1 [<i>Ref.</i>]
Caesarean delivery, crude (n= 10,873)	0.93 (0.38, 2.30)
Caesarean delivery, model 1 ^a (n= 10,853)	0.95 (0.29, 3.19)
Ethiopia DHS 2005	
Vaginal delivery	1 [<i>Ref.</i>]
Caesarean delivery, crude (n= 9,861)	1.74 (0.67, 4.51)
Caesarean delivery, model 1 ^a (n= 9,861)	1.53 (0.52, 4.50)
Ethiopia DHS 2011	
Vaginal delivery	1 [<i>Ref.</i>]
Caesarean delivery, crude (n= 11,654)	1.49 (0.62, 3.61)
Caesarean delivery, model 1 ^a (n= 11,654)	1.15 (0.45, 2.93)
Ethiopia DHS 2016	
Vaginal delivery	1 [<i>Ref.</i>]
Caesarean delivery, crude (n= 10,641)	3.02 (1.37, 6.66)
Caesarean delivery, model 1 ^a (n= 10,641)	2.81 (1.11, 7.13)

^aAdjusted for place of delivery, type of residence (urban/rural), sex of child, size of baby at birth, Mother's age at birth, Mother's education, Birth order, Household wealth.

Table 3. Crude and multivariable-adjusted prevalence ratios for neonatal death associated with caesarean versus vaginal delivery, Ethiopia DHS 2016

	Prevalence Ratio (95% CI) for neonatal death
Main analysis	
Vaginal delivery	1 [<i>Ref.</i>]
Caesarean delivery, crude (n= 10,641)	3.02 (1.37, 6.66)
Caesarean delivery, model 1 ^a (n= 10,641)	2.81 (1.11, 7.13)
Subgroup analyses	
Restricted to Addis Ababa ^b (n= 461)	1.07 (0.20, 5.73)
Excluded Addis Ababa and Harari ^a (n= 9,575)	3.35 (1.31, 8.56)
Restricted to births in public facility ^a (n= 3,023)	2.78 (1.16, 6.63)
Restricted to rural mothers ^b (n= 8,636)	3.43 (1.22, 9.67)
Restricted to women from lowest quintile of household wealth ^c (n=3,958)	7.01 (0.92, 53.36)
Restricted to women from highest quintile of household wealth ^c (n=2,092)	2.72 (0.55, 13.38)

^aAdjusted for place of delivery, type of residence (urban/rural), sex of child, size of baby at birth, Mother's age at birth, Mother's education, Birth order, Household wealth.

^bAdjusted for place of delivery, sex of child, size of baby at birth, Mother's age at birth, Mother's education, Birth order, Household wealth.

^cAdjusted for place of delivery, sex of child, size of baby at birth, Mother's age at birth, Mother's education, Birth order.

Table 4. Factors contributing to the ‘Three Delays Model’, according to sociodemographic characteristics, Ethiopia DHS 2016

	Delivery by skilled provider [§]	Number of births	Problems in accessing health care by women aged 15-49 years*					Number of women
			Distance to health facility	Getting money for treatment	Getting permission to go for treatment	Not wanting to go alone	At least one problem accessing health care	
Types of residence								
Urban	80.1	1216	17.0	34.7	15.1	21.4	45.6	3476
Rural	21.2	9807	59.8	60.5	37.0	47.9	76.9	12207
Region								
Tigray	59.3	716	37.4	46.1	15.3	24.6	60.7	1129
Afar	16.4	114	54.3	51.7	28.2	41.8	66.6	128
Amhara	27.7	2072	33.7	35.3	15.4	34.6	55.7	3714
Oromia	19.7	4851	68.9	70.1	58.3	57.0	82.9	5701
Somali	20.0	508	47.3	63.0	25.7	32.2	72.6	459
Benishangul-Gumuz	28.6	122	57.4	62.4	36.5	43.8	76.8	160
SNNPR	28.6	2296	52.7	59.1	18.4	39.5	75.4	3288
Gambela	46.9	27	41.0	44.3	24.3	33.7	61.2	44
Harari	51.2	26	18.1	28.2	16.3	13.8	30.8	38
Addis Ababa	96.8	244	10.8	29.2	8.7	14.5	40.0	930
Dire Dawa	56.7	47	57.4	64.5	58.7	55.2	71.4	90
Mother's education								
No education	17.2	7284	59.2	62.9	37.6	47.1	78.0	7498
Primary	38.6	2951	50.3	55.7	31.9	43.2	71.1	5490
Secondary	78.4	514	27.8	33.2	18.2	27.8	48.1	1817
More than secondary	93.2	274	20.6	23.8	15.9	20.4	39.8	877
Wealth quintile								
Poorest	11.0	2636	67.7	70.9	40.0	54.5	85.3	2633

Poorer	20.8	2520	66.8	67.0	42.1	52.7	82.9	2809
Middle	24.2	2280	59.4	61.0	35.2	47.6	77.3	2978
Richer	28.5	1999	49.8	50.2	33.8	41.2	68.2	3100
Richest	70.3	1588	22.1	35.2	17.0	23.4	47.7	4163
Total	27.7	11023	50.3	54.8	32.1	42.0	70.0	15683

§Percentage delivered by a skilled provider (includes doctor, nurse, midwife, health officer, and health extension worker)

*Percentage of women age 15-49 who reported that they have serious problems in accessing health care for themselves when they are sick, by type of problem, according to sociodemographic characteristics, Ethiopia DHS 2016

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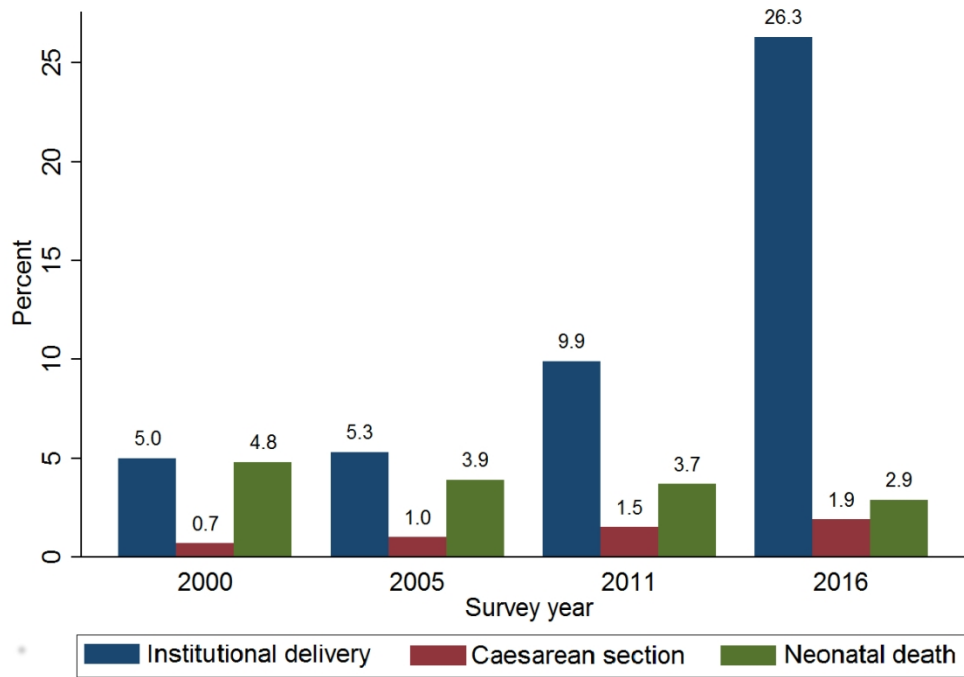


Figure 1. Trends in proportion of institutional deliveries, caesarean section and neonatal death in the 5 years before each of the surveys, Ethiopia DHS 2000, 2005, 2011 and 2016

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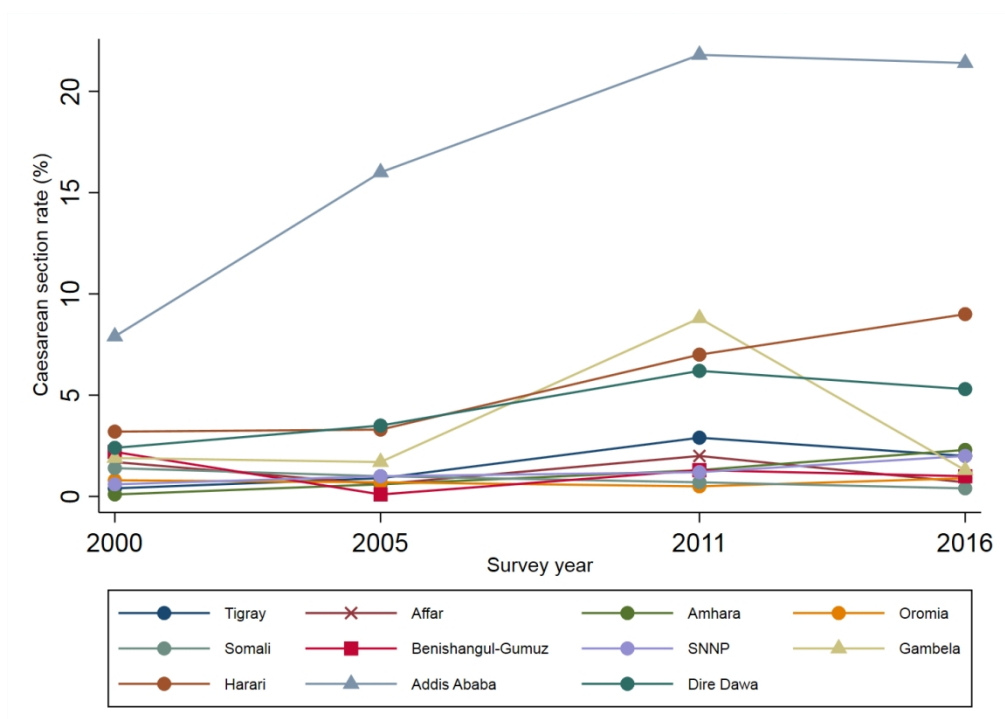


Figure 2. Trends in caesarean section rates in the 5 years before each of the surveys by region of residence, Ethiopia DHS 2000, 2005, 2011 and 2016

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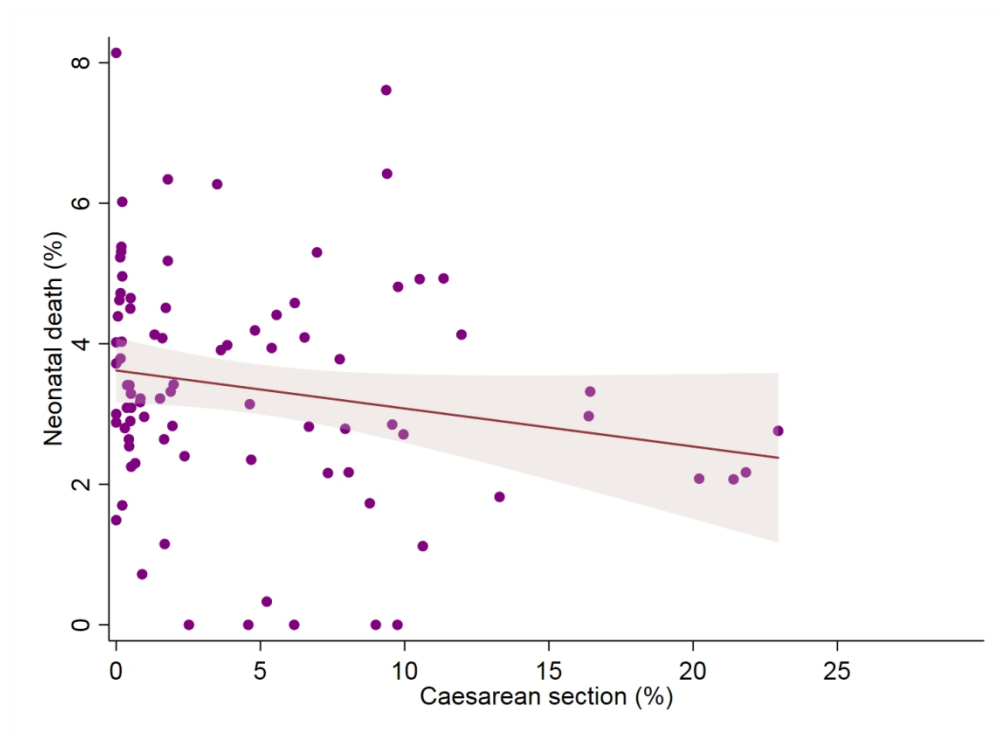


Figure 3. The relationship between caesarean section rate and neonatal death in Ethiopia

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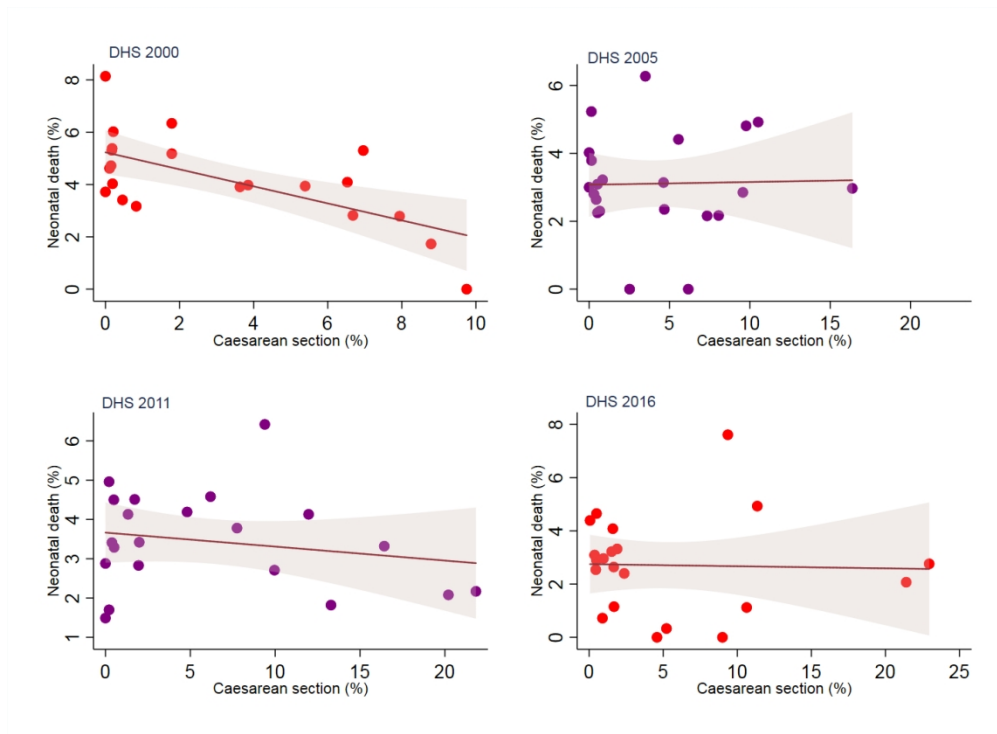


Figure 4. The relationship between caesarean section rate and neonatal death by survey years

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SUPPLEMENTARY MATERIAL

This file includes supplementary analyses that complement the main findings and pictures that describe the ‘Three Delays Model’ and the Ethiopian health system structure cited in the full text of the article.

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Table A1. Crude and multivariable-adjusted prevalence ratios for neonatal death associated with ‘timing of decision to conduct caesarean section’ versus vaginal delivery, Ethiopian DHS, 2016

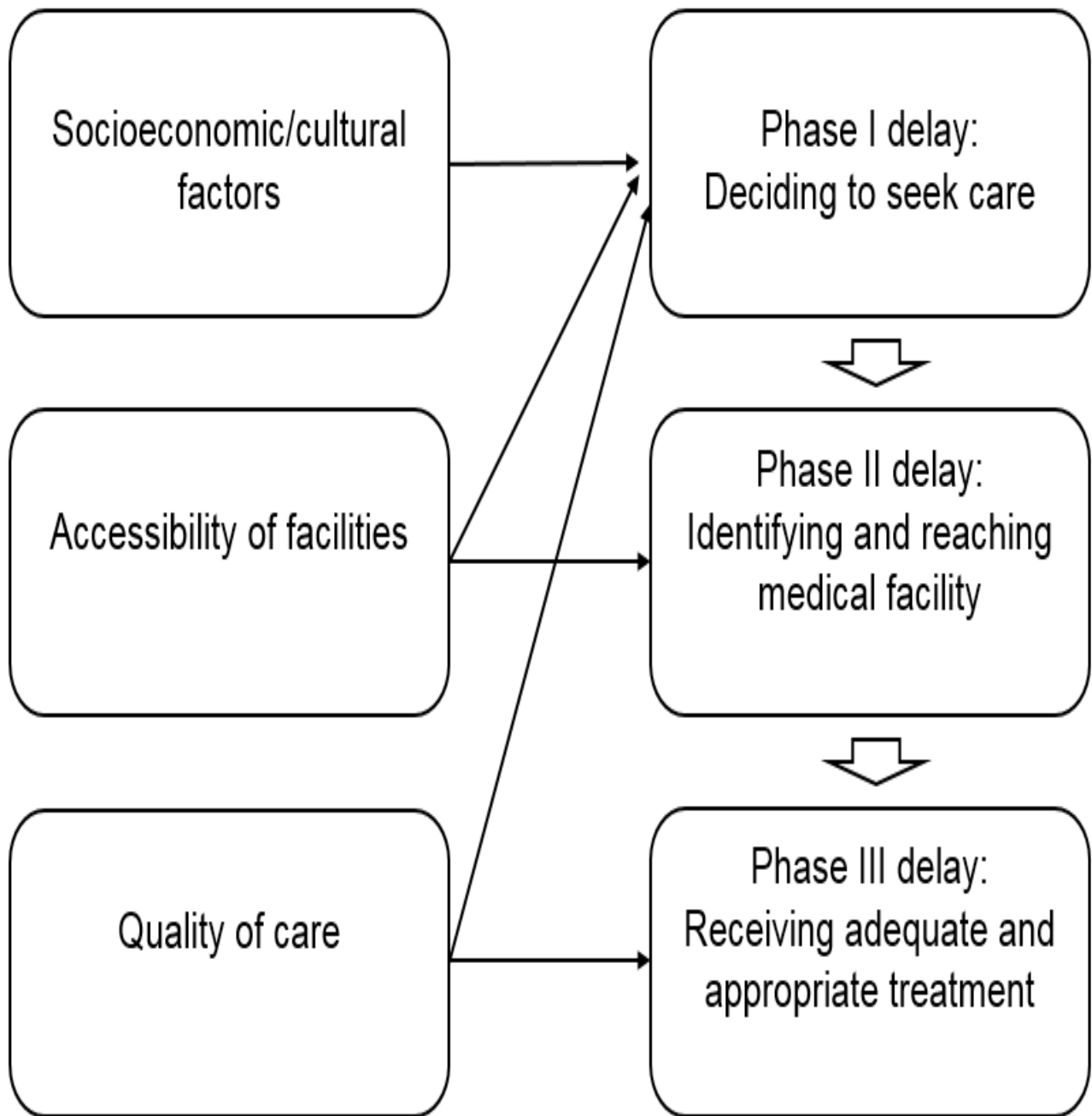
	Prevalence Ratio (95%CI) for neonatal death
Unadjusted (n= 10 641)	
Vaginal delivery	1 [<i>Ref.</i>]
Caesarean section decided before onset of labour	4.21 (1.34, 13.19)
Caesarean section decided after onset of labour	2.31 (0.84, 6.41)
Adjusted^a (n=10 641)	
Vaginal delivery	1 [<i>Ref.</i>]
Caesarean section decided before onset of labour	3.79 (1.03, 13.93)
Caesarean section decided after onset of labour	2.26 (0.75, 6.82)

^aAdjusted for place of delivery, type of residence (urban/rural), sex of child, size of baby at birth, Mother’s age at birth, Mother’s education, Birth order, Household wealth

NB: ‘Timing of decision to conduct caesarean section’—caesarean section that was planned before the onset of labor pains and caesarean section that was decided after the onset of labor pains—was used as a proxy to types of caesarean section.

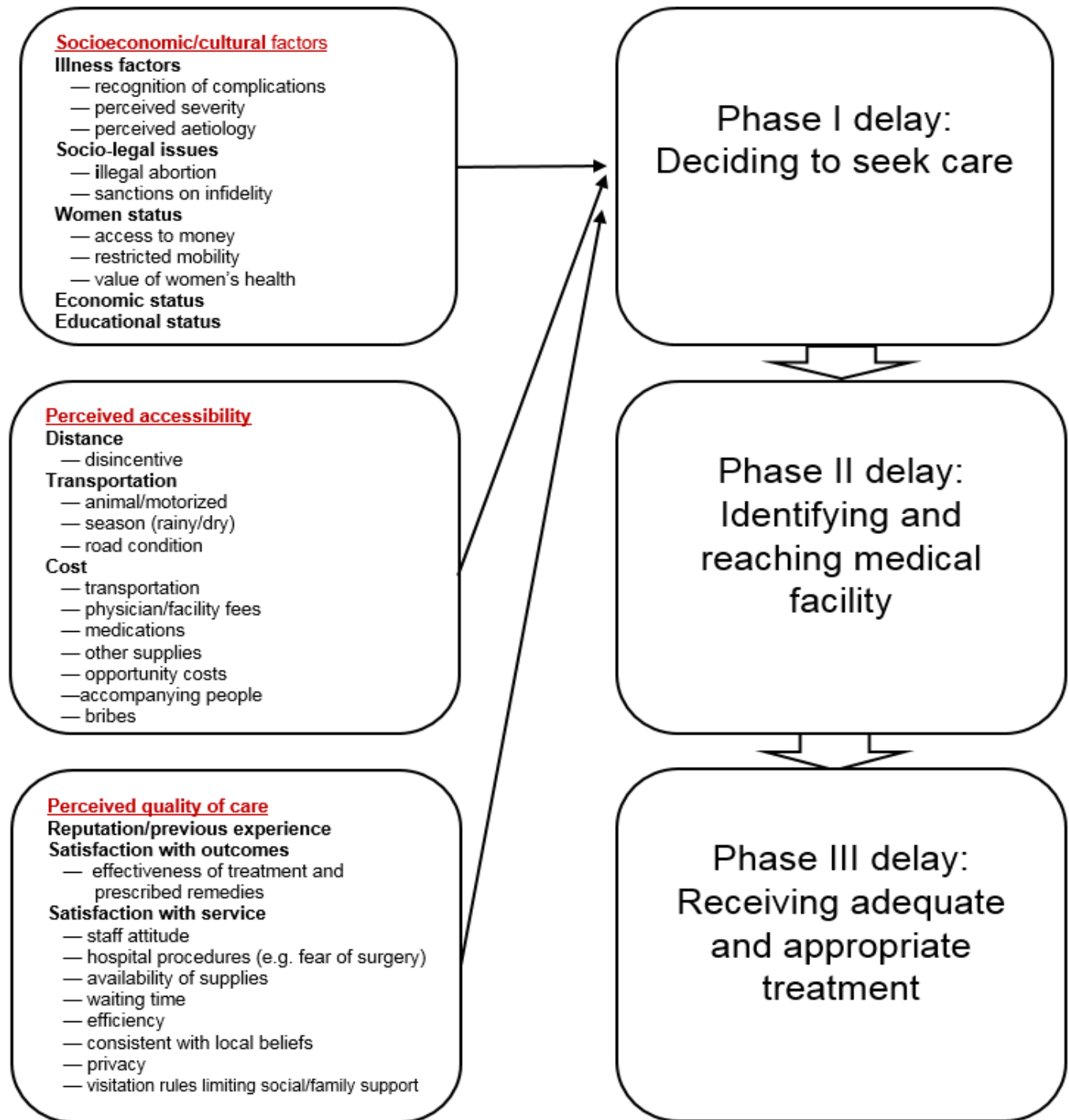
Table A2. Trends in proportion of neonatal deaths in the 5 years before each of the surveys by region of residence, Ethiopia DHS 2000, 2005, 2011, and 2016

	Survey year								
	2000 %	Number of births	2005 %	Number of births	2011 %	Number of births	2016 %	Number of births	Absolute change %
Types of residence									
Urban	4.4	1277	4.4	815	3.9	1528	3.4	1216	-1.0
Rural	4.8	10983	3.9	10348	3.7	10344	2.8	9807	-2.0
Region									
Tigray	5.3	788	2.7	698	4.1	753	2.7	716	-2.6
Afar	2.9	126	2.9	107	1.9	121	2.6	114	-0.3
Amhara	4.8	3202	5.2	2621	4.5	2656	3.2	2072	-1.6
Oromia	5.3	4999	3.8	4411	3.4	5014	2.8	4851	-2.5
Somali	3.8	142	3.0	477	2.9	364	4.1	508	+0.3
Benishangul- Gumuz	6.3	124	3.8	105	4.8	140	2.9	122	-3.4
SNNP	4.0	2602	3.4	2500	3.5	2494	2.5	2296	-1.5
Gambela	5.3	29	2.4	31	3.6	40	2.8	27	-2.5
Harari	3.7	25	2.2	22	4.1	29	3.1	26	-0.6
Addis Ababa	2.8	182	2.9	153	2.2	222	2.1	244	-0.7
Dire Dawa	3.7	40	2.7	37	1.6	39	3.0	47	-0.7
Total	4.8	12260	3.9	11163	3.7	11872	2.9	11023	-2.0



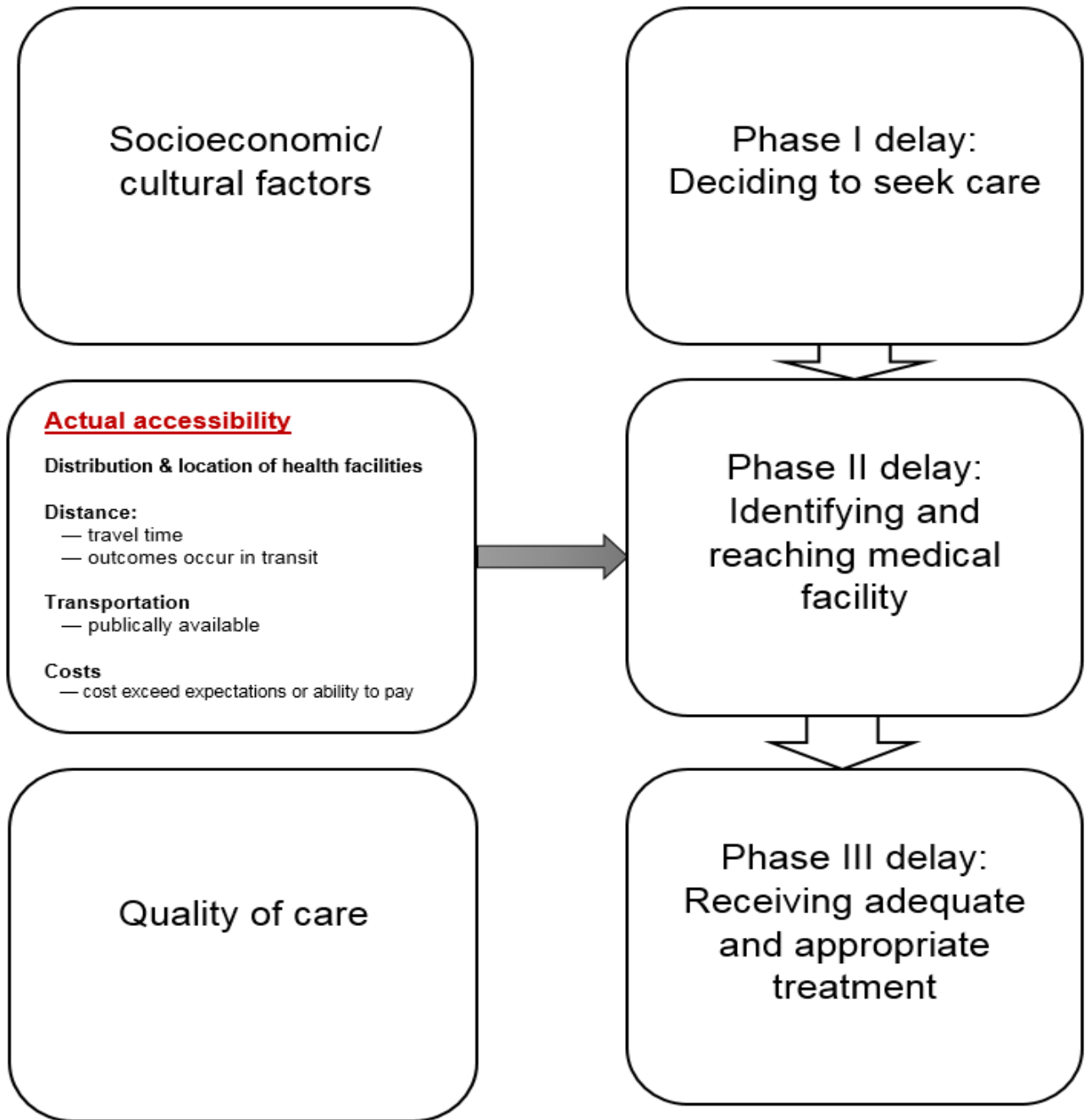
Source: *Soc Sci Med*, 1994; **38**(8): 1091-110.¹

Figure A1. The 'Three Delays Model'



Source: *Soc Sci Med*, 1994; 38(8): 1091-110.¹

Figure A2. Phase I delay, detail

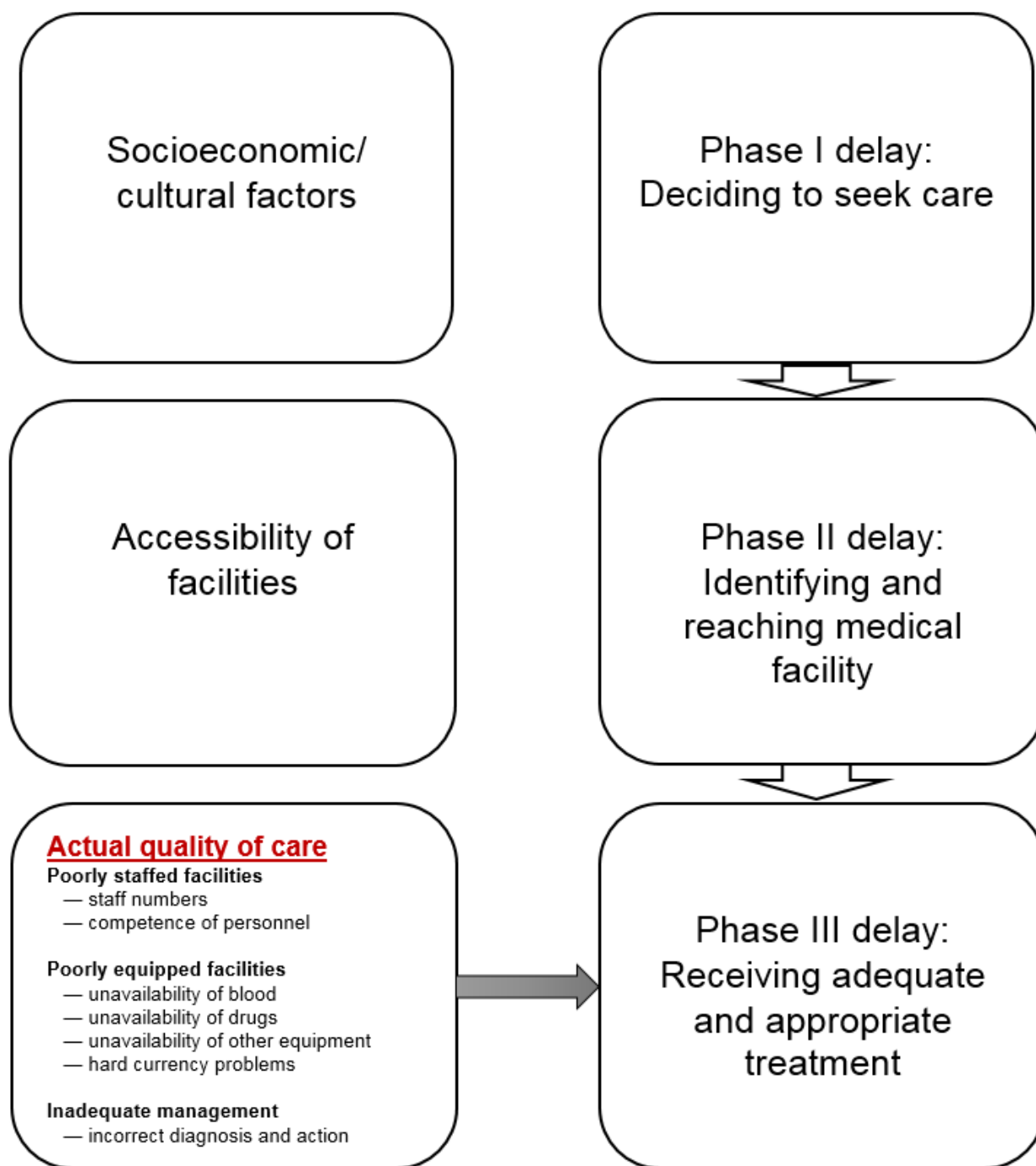


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Source: *Soc Sci Med*, 1994; **38**(8): 1091-110.¹

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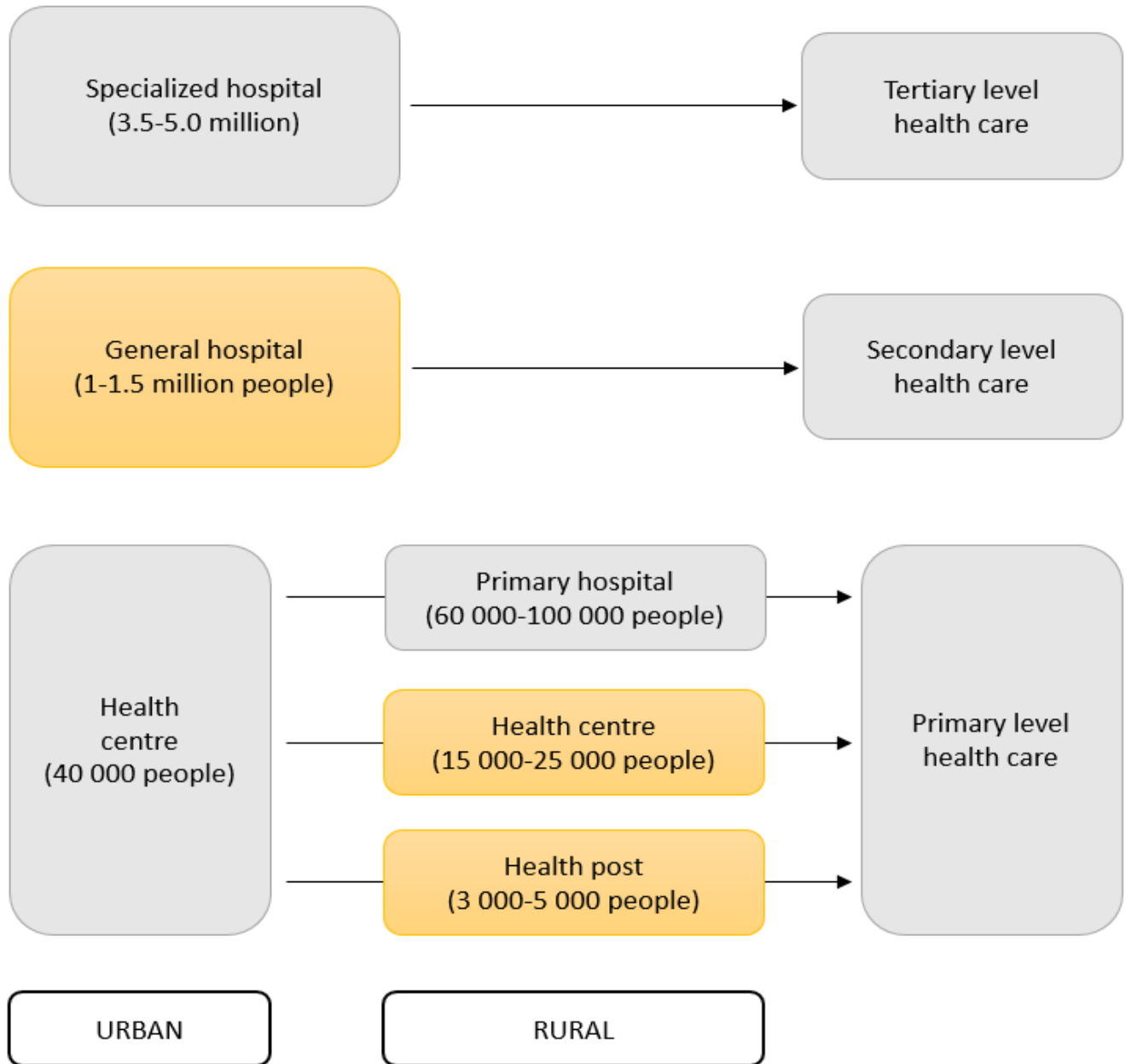
Figure A3. Phase II delay, detail



47 *Source: Soc Sci Med, 1994; 38(8): 1091-110.*¹

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50 **Figure A4.** Phase III delay, detail

Ethiopian health tier system



Source: Ethiopian Health Sector Transformation Plan, 2015,² and World Health Organization, 2017.³

Figure A5. Ethiopian health system structure

References

1. Thaddeus S, Maine D. Too far to walk: maternal mortality in context. *Soc Sci Med* 1994; **38**(8): 1091-110.
2. Ministry of Health. Health Sector Transformation Plan. Addis Ababa: Federal Democratic Republic of Ethiopia; 2015.
3. WHO. Primary health care systems (PRIMASYS): case study from Ethiopia, abridged version. Geneva: World Health Organization; 2017. Licence: CC BY-NC-SA 3.0 IGO.

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STROBE Statement—Checklist of items that should be included in reports of *cross-sectional studies*

	Item No	Recommendation	Page No.	Relevant text from manuscript
Title and abstract	1	(a) Indicate the study's design with a commonly used term in the title or the abstract	Page 1-3	(See Title and Abstract): “The changing temporal association between caesarean birth and neonatal death in Ethiopia: secondary analysis of nationally representative surveys”
		(b) Provide in the abstract an informative and balanced summary of what was done and what was found	Page 2	(see Abstract: Main outcome measures; Results)
Introduction				
Background/rationale	2	Explain the scientific background and rationale for the investigation being reported	Page 4-5	(see Introduction)
Objectives	3	State specific objectives, including any prespecified hypotheses	Page 5	“We use Ethiopian DHS data from 2000, 2005, 2011, and 2016 to examine the changing temporal association between caesarean birth and neonatal death. We then apply the ‘Three Delays Model’ developed by Thadeus and Maine to facilitate the interpretation of the association between caesarean birth and neonatal death in Ethiopia using the 2016 data.”
Methods				
Study design	4	Present key elements of study design early in the paper	Page 6	(see Methods—Study design and data samples)
Setting	5	Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection	Page 6	(see Methods—Study design and data samples)
Participants	6	(a) Give the eligibility criteria, and the sources and methods of selection of	Page 6	“The DHS questionnaire asks

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women about pregnancy, antenatal, and delivery care for livebirths they have reported in the past 5 years. For this study, the exposure group were children delivered by caesarean section and unexposed group comprised children born vaginally.”

Variables	7	Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable	Page 6-9	(see Methods—Exposure, Outcome and Confounding)
Data sources/ measurement	8*	For each variable of interest, give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group	Page 6	<p>“Exposure</p> <p>The DHS questionnaire asks women about pregnancy, antenatal, and delivery care for livebirths they have reported in the past 5 years. The data on caesarean section and other variables in the DHS was collected based on mothers’ self-report. For example, the self-reported data on caesarean section was collected by asking women a question that reads, “Was (NAME) delivered by caesarean section, that is, did they cut your belly open to take the baby out?” Stanton and colleagues²⁵ in their study demonstrated that the DHS caesarean section rates, compared with facility-based records of caesarean section rates, are reliable for national and global monitoring</p>

in developing countries. For this study, the exposure group were children delivered by caesarean section and unexposed group comprised children born vaginally.

Outcome

Neonatal death includes children who were born alive in the 5 years before the survey, but died within the first 28 days of life. The outcome variable, neonatal death, was measured from two variables (whether the child is alive and age at death (in days)).”

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Bias	9	Describe any efforts to address potential sources of bias	Page 7-10	(see Methods—Statistical analysis)
Study size	10	Explain how the study size was arrived at	Page 6	(see Methods—Study design and data samples): “We used data from the Ethiopian DHS completed in 2000, 2005, 2011, and 2016. The Ethiopian DHS are nationally representative cross-sectional surveys conducted in nine regions (Tigray, Afar, Amhara, Oromia, Somali, Benishangul-Gumuz, SNNPR, Gambela, and Harari), and two city administrations (Addis Ababa and Dire Dawa).”
Quantitative variables	11	Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen and why	Page 6-7	(see Methods— Confounding)
Statistical methods	12	(a) Describe all statistical methods, including those used to control for confounding	Page 7-8	(see Methods—Statistical analysis)

		(b) Describe any methods used to examine subgroups and interactions	Page 8-9	(see Methods—Statistical analysis)
		(c) Explain how missing data were addressed		Not applicable
		(d) If applicable, describe analytical methods taking account of sampling strategy	Page 7	“All analyses (i.e., Ethiopian DHS 2000, 2005, 2011 and 2016) were weighted to be nationally representative. As women may have had more than one births within the five-year survey periods, we also accounted for both clustering of caesarean deliveries within women as well as the complex survey design during the data analyses using the unit of analysis (i.e., children) study number and sample weights.”
		(e) Describe any sensitivity analyses		Not applicable
Results				
Participants	13*	(a) Report numbers of individuals at each stage of study—eg numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analysed	Page 11	(see Results): “Table 1”
		(b) Give reasons for non-participation at each stage		Not applicable
		(c) Consider use of a flow diagram		Not applicable
Descriptive data	14*	(a) Give characteristics of study participants (eg demographic, clinical, social) and information on exposures and potential confounders	Page 11	(see Results)
		(b) Indicate number of participants with missing data for each variable of interest		Not applicable
Outcome data	15*	Report numbers of outcome events or summary measures	Page 11-12	(see Results)
Main results	16	(a) Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (eg, 95% confidence interval). Make clear which confounders were adjusted for and why they were included	page 11-12	(see Results)
		(b) Report category boundaries when continuous variables were categorized	Page 11-12	(see Results)
		(c) If relevant, consider translating estimates of relative risk into absolute risk for a		

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		meaningful time period		Not applicable
Other analyses	17	Report other analyses done—eg analyses of subgroups and interactions, and sensitivity analyses	Page 11-12	(see Results)
Discussion				
Key results	18	Summarise key results with reference to study objectives	Page 13 & page 18	(See Interpretation and Discussion sections)
Limitations	19	Discuss limitations of the study, taking into account sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias	Page 20	(See Discussion: “We acknowledge the following limitations of this study. Firstly, as both the proportion of institutional deliveries and caesarean section rate is low in Ethiopia, especially rural area, the number of neonatal deaths following caesarean section may be low. However, since our analyses are weighted, we believe that the weight improves the representativeness of the data in terms of size, distribution and characteristics of the Ethiopian population. The weight may also ensure that our estimates are unbiased though the confidence interval for some subgroup analyses are somewhat wide. Secondly, the interpretation of our study is specific to the context of Ethiopia and may not be generalizable to other developing countries in Africa or elsewhere. Another limitation is the mother’s recall of the child’s

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				size at birth was used as a substitute for the child's birth weight in this study because the data for birth weight was not collected for more than 50% of the neonates in DHS")
Interpretation	20	Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence	Page 13-20	(See Interpretation and Discussion sections)
Generalisability	21	Discuss the generalisability (external validity) of the study results	Page 20	(See Discussion)
Other information				
Funding	22	Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based	Page 22	(See Funding—The first author is fully supported by an Australian Government Research Training Programme (RTP) Scholarship. The funder does not have role in the design of the study.)

*Give information separately for exposed and unexposed groups.

Note: An Explanation and Elaboration article discusses each checklist item and gives methodological background and published examples of transparent reporting. The STROBE checklist is best used in conjunction with this article (freely available on the Web sites of PLoS Medicine at <http://www.plosmedicine.org/>, Annals of Internal Medicine at <http://www.annals.org/>, and Epidemiology at <http://www.epidem.com/>). Information on the STROBE Initiative is available at www.strobe-statement.org.