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RESEARCH ARTICLE

Tradeoffs between fertility and child development attributes: evidence from coral bleaching in Indonesia

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Abstract

Coral bleaching is associated with large income shocks and a substantial decrease in protein consumption among the affected fishery households in Indonesia [Chaijaroen (2019) Long-lasting income shocks and adaptations: evidence from coral bleaching in Indonesia. *Journal of Development Economics* **136**, 119–136]. According to the health and economics literature, early childhood exposures to shocks such as those from coral bleaching can have long-lasting effects on health, schooling, and other later-life outcomes. This paper explores how the mass coral bleaching in 1998 affected household decisions on fertility and child development. Using the Indonesian Family Life Survey (IFLS) and a triple differences approach, results from 2000 suggest an increase in fertility and an increased likelihood of severe childhood stunting among the affected households. For comparison, rainfall shocks are associated with a decrease in fertility and smaller adverse effects on child health and schooling outcomes. This study suggests that the effects of coral bleaching might have been underestimated, and our findings yield more targeted policy recommendations on climate shock mitigation.

Keywords: coral bleaching; shocks; fertility; child outcomes

JEL classification: Q54; J13; O15

1. Introduction

Climate change is believed to affect humans in numerous ways. Rising temperatures and extreme weather events can lead to drastic changes in agricultural production, extinction of many plant and animal species, and increasingly dangerous natural disasters, among others. The literature on climate change has explored the effects of rising air temperatures in many aspects such as agricultural outputs, industrial outputs, labor productivity, and health outcomes.[1] However, less is known about the other aspects of climate change, such as changes in the oceans, as well as other ways it might be affecting the planet and its inhabitants, particularly those in the developing world.

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[1] See Dell *et al.* (2014) for a comprehensive literature review.

This paper seeks to fill in the literature gap by examining the effects of a major oceanic climate shock, coral bleaching, on fertility rates and child development in Indonesia. Coral bleaching is a phenomenon in which corals lose their colors and become weakened or die after a prolonged exposure to high sea surface temperatures. This phenomenon can adversely affect other marine species as well as humans whose livelihoods depend on marine ecosystems.

Coral bleaching affects humans in a number of ways, from decreasing catch and fisheries income to lowering tourism income and increasing chances of land erosion. Chaijaroen (2019) investigated the economic and labor effects of the massive coral bleaching in 1998 on Indonesian fishery households. The study found that the bleaching event was associated with large income shocks, changes in labor market behavior, and a substantial decrease in protein consumption in 2000.

The income shock as well as the decline in protein sources following coral bleaching can have substantial impacts on child growth and development. This paper examines these aspects as well as their effects on fertility. The effects of the coral bleaching in 1998 on fertility and children's health and schooling outcomes are identified using panel data from the Indonesian Family Life Survey (IFLS). The main specifications follow a triple differences framework using variations in industry, location, and time exposures to the coral bleaching event. The key identification assumption for external validity to other shocks is that coral bleaching is exogenous to household behaviors. This assumption is likely to hold because the bleaching event in 1998 was mainly caused by a severe El Niño. In addition, this event was the first of its kind to be widely recorded, so households were unlikely to expect or act on it *ex-ante*. As a result, the short-run effects of coral bleaching estimated in this paper can be interpreted as the effects before any adaptations.

It is well-established in the child development literature that the development of health and cognitive abilities *in utero* and in early childhood is crucial to birth and later life outcomes (Currie and Almond, 2011).[2] Positive and negative shocks in the first five years of life can have long-lasting impacts on growth, health outcomes, schooling outcomes, and wages, among others (e.g., Garces *et al.*, 2002; Behrman and Hoddinott, 2005; Currie and Vogl, 2013). This paper expands on a part of this literature on early-life exposures to weather and climate shocks. Most of this part of the literature is related to rainfall shocks (e.g., Hoddinott and Kinsey, 2001; Maccini and Yang, 2009; Kudamatsu *et al.*, 2012), natural disasters (e.g., Anttila-Hughes and Hsiang, 2013; Currie and Rossin-Slater, 2013), and extreme temperatures (Deschenes *et al.*, 2009). Compared to the other shocks in the literature, coral bleaching is unique in three ways: (1) it causes long-term shocks over which humans have little control, (2) it affects not only income but also food availability, and (3) humans have experienced it in just the past few decades whereas we have been dealing with other types of shocks for centuries. For these reasons, this paper offers a new perspective to the existing literature. This will be further elaborated on in section 6 of this paper, which highlights how coral bleaching differs from rainfall shocks, one of the most common shocks in the economics literature.

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[2] According to the fetal origins hypothesis and subsequent works, *in utero* and early childhood shocks affect later life outcomes through three main channels: (1) persistency of health effects from fetal and early life conditions, (2) latency of the health effects, and (3) genetic programming (Almond and Currie, 2011; Almond *et al.*, 2018). The observed effects in the literature include negative effects on adult height, cognitive functions, schooling, wages and per capita household expenditure, just to name a few. Almond and Currie (2011), Currie and Vogl (2013) and Almond *et al.* (2018) provide comprehensive reviews of this literature.

With more coral bleaching expected in the decades to come,[3] the findings from this paper can be useful for policy makers seeking to alleviate the effects of coral bleaching. Moreover, the results are also applicable to other marine-related shocks, such as ocean acidification, as well as other long-term shocks with similar temporal-spatial scales.

The remainder of the paper is organized as follows. Section 2 describes coral bleaching and its effects on marine resources and humans. Section 3 presents data sources and identification strategies. Section 4 discusses how coral bleaching affects fertility. Section 5 explores the effects of coral bleaching on child outcomes. Section 6 compares shocks due to coral bleaching with rainfall shocks to shed light on policy implications, and section 7 concludes.

2. Background on coral bleaching

A coral reef is a marine ecosystem in tropical seas characterized by reef-building corals. Covering less than 0.1 per cent of the word's ocean area, coral reefs form some of the Earth's most diverse ecosystems as they provide food and shelter to about 25 per cent of the ocean's fish (Spalding and Grenfell, 1997; NOAA, 2019). During the past few decades, the coral reefs have been threatened by many factors ranging from rising ocean temperatures to human actions, imposing risks on both the marine ecosystem and humans.

In this paper, we focus on coral bleaching, a natural phenomenon in which coral reefs are weakened due mainly to abnormally high sea surface temperatures (SST). When the SST exceeds a threshold, corals release symbiotic algae, which photosynthesize and feed the corals (Brown, 1997), resulting in bleached colors. If the SST reverts back to a normal range in a short period of time, corals can usually regain their colors, recover and survive. On the other hand, if the SST anomaly lasts over 4–6 weeks, the corals usually die (Hoegh-Guldberg, 1999; Wilkinson and Hodgson, 1999), and the reefs may or may not recover. If they recover, the recoveries take at least five years (e.g., Wilkinson and Hodgson, 1999; Graham *et al.*, 2007; Gilmour *et al.*, 2013). The recovery process begins with new coral larvae or polyps settling into the old reef structure. Then, these new corals grow, usually at a very slow rate (Barnes and Hughes, 1999; Veron and Stafford-Smith, 2000).[4] In the worst case scenario, the reefs are permanently damaged, and the corals will be replaced by algae.

Severe coral bleaching events are usually associated with deteriorating fish stocks, with severity varying by species and location.[5] Coral bleaching usually leads to a decline in coral reef species within three years of the bleaching event, and coral bleaching can also cause distress for non-reef species through ecological relationships.

These adverse effects of coral bleaching on marine resources negatively impact humans in a variety of ways. First, coral bleaching might decrease catch and income in the fisheries sector as fish stocks decline. Frequent and severe bleaching events also

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[3] Based on the NOAA's Bleaching Alert Level 2, many coral reefs around the world are expected to bleach in at least 90 per cent of the years in the 2050s (Burke *et al.*, 2011).

[4] Depending on species, corals grow at a rate between less than one inch to four inches per year (NOAA, 2021).

[5] For instance, Booth and Beretta (2002) found a lower recruitment of fish at bleached southern Great Barrier Reef sites than those at unbleached sites one year after the bleaching. Garpe *et al.* (2006) found that total abundance and taxonomic richness of species significantly declined relative to the initial level six years after the bleaching.

impose risks on future food security because fish is an important source of animal protein especially in coastal communities. Second, bleached corals and deteriorating reef fish stocks are less attractive for recreational activities such as SCUBA diving and snorkeling. Finally, coral reefs play a crucial role in shoreline preservation, and weakened reefs may result in more land erosion in the future.

This paper focuses on the mass coral bleaching in 1998 and the fisheries sector in Indonesia. During the severe El Niño in 1997–1998, ocean temperatures in the tropical zone around the world rose significantly, leading to the world's first widespread mass coral bleaching.[6] Numerous coral bleaching spots were found in the Indian and the Pacific Oceans spanning from the eastern coast of Africa to as far as Australia. Wilkinson (2000) estimates that 16 per cent of the world's corals were destroyed during this massive bleaching event. In Indonesia, coral bleaching was reported in West Sumatra, the south shore of Central Java, Bali and Lombok area, and Southern Sulawesi. The coral mortality rate in Bali area was estimated to be around 50 per cent (Goreau *et al.*, 2000). This bleaching episode is the first large-scale coral bleaching to be reported for Indonesia.[7] Households were unlikely to anticipate it because even scientists could predict it only a few days in advance (Hoegh-Guldberg, 1999). For this reason, this bleaching event gives us a unique opportunity to study a climate shock prior to any adaptations.

Chaijaroen (2019) studies the economic impacts of the mass coral bleaching in 1998 on the Indonesian fisheries sector. This bleaching event is associated with a large reduction in income among the affected fishery households in 2000, two years after the event occurred. As a result of this income shock, the affected households experienced an overall reduction in consumption in 2000; the fall in protein consumption was the largest among all consumption types. In response to the shocks, the affected households migrated more in 2000, but they were not able to increase their labor supply or switch to a new industry until 2007. Given these large income and protein consumption shocks in Chaijaroen (2019), coral bleaching might have imposed significant risks on child development. This paper explores these risks and elaborates on how government policies can be used to mitigate them.

3. Empirical framework

The goal of this paper is to evaluate the effects of coral bleaching on fertility and child development outcomes. These effects are estimated using a triple differences (DDD) framework on data from a household survey and a scientific paper on coral bleaching (Goreau *et al.*, 2000). In this empirical framework, those affected by the 1998 coral bleaching, i.e., the treatment group, consist of households that worked in fisheries and lived in areas with reported coral bleaching in 1997. This treatment group is compared against all other households in the survey while taking into account differences across sectors and areas of residence. We will elaborate on this empirical framework in this section.

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[6] Some sources take the bleaching event in 1983 as the first mass coral bleaching event. However, the 1998 event outscaled the 1983 event by many times. Less than 50 sites in 10 countries were reported as bleached in 1983 while there were more than 1,000 records of bleaching in almost 70 countries in 1998 (van Oppen and Lough, 2009). For this reason, some sources, including NOAA, counted the 1998 event as the first mass coral bleaching.

[7] The first record for coral bleaching in Indonesia was a concentrated event around Pari and Thousand Islands in 1983 (Brown and Suharsono, 1990; Hoeksema, 1991). After this event, there was no other reporting for Indonesia until 1998.

3.1. Data

This paper combines data from the IFLS household survey with data on coral bleaching and rainfall. The IFLS is a panel dataset that surveyed 7,224 Indonesian households in 1993. These households together with their spin-offs were resurveyed in 1997, 2000, 2007 and 2014. The IFLS covers 13 out of the 27 provinces of Indonesia and is representative of around 83 per cent of the Indonesian population. The dataset contains diverse socio-economic information on households, adult household members, children, women, and their communities. This paper utilizes data from the household, children, and women modules of the 1993, 1997, 2000 and 2007 waves of data (Frankenberg and Karoly, 1995; Frankenberg and Duncan, 2000; Strauss *et al.*, 2004, 2009).

The main source of coral bleaching data is the reported bleaching spots in Goreau *et al.* (2000). The paper collected coral bleaching reports from long-time reef observers around the world. This helps ensure that any damages reported were due to coral bleaching, not some other causes. However, it is possible that some coral bleaching might not get reported and potentially cause measurement errors. For this reason, SST anomalies from satellite maps are used as another measure of coral bleaching for robustness checks (see online appendix for details). Both measures of coral bleaching are merged with the IFLS data at a coastal area level, defined as one ocean coastline in one province. The exception to this definition is Bali and West Nusa Tengara – these two provinces are treated as one coastal area because they are small islands in the same area with similar SST anomalies.

Table 1 exhibits summary statistics based on the 1997 wave of data and shows the basic characteristics of our sample. Most households in the sample were led by middle-aged males with an average age of around 40 years old. Almost none of the household heads had a college degree. In the children sample, the summary statistics for anthropometric outcomes suggest that the children's health was below the World Health Organization (WHO) standards as indicated by the negative averages of height-for-age and weight-for-height z-scores in 1997. The enrollment rate for elementary school averaged 95 per cent for all children. In the women sample, above 80 per cent were married, and almost none had a college degree. When comparing the treatment group with the rest of the sample, we find that the treatment group differed from the rest on some fronts. These differences and how they affect our identification will be further discussed towards the end of this section.

3.2. Identification strategies

Most econometric estimation in this paper is based on a DDD framework that compares individuals in the same age group across time. In this framework, everyone in the survey is included in the sample as long as they fall within the right age range. In addition to the time exposure, the other two sources of variations for the triple differences come from geographic and sector exposures to the 1998 coral bleaching. Geographically, a household is considered to be within the coral bleaching area if in 1997 it lived in a coastal area with reported coral bleaching. Figure A1 in the online appendix shows a map of the IFLS coverage and coral bleaching areas. As for the sector exposure, the only sector that can be precisely identified as exposed to coral bleaching from the available data is fisheries. These time-invariant variations are based on household location and industry in 1997, and they are held fixed across all waves. Details on the estimation will be further discussed in the following sections.

Table 1. Summary statistics for key variables by groups before coral bleaching

	Treatment group in 1997			All others in 1997			
	Mean	SD	N	Mean	SD	N	*p*-value
Household head's characteristics							
Male	0.97	0.17	36	0.89	0.32	2,861	0.108
Age	37.86	11.18	36	42.54	28.03	2,861	0.317
College education	0.00	0.00	36	0.04	0.19	2,860	0.239
Child's characteristics							
Height-for-age	−0.73	1.86	25	−1.79	1.99	2,490	0.008
Weight-for-height	−0.42	1.22	34	−0.42	1.79	3,083	0.998
Severe stunting	0.00	0.00	36	0.16	0.37	3,177	0.009
Severe wasting	0.00	0.00	36	0.04	0.20	3,177	0.212
Fail	0.11	0.32	36	0.17	0.37	3,744	0.375
Ever enrolled	0.90	0.30	40	0.97	0.17	3,852	0.007
Enrolled	0.75	0.44	40	0.96	0.20	3,852	0.000
Mother's characteristics							
Age	29.46	6.72	35	30.21	6.49	3,091	0.495
Education	5.11	4.44	35	7.44	5.32	3,090	0.010
Height	152.73	5.17	35	150.24	5.31	3,028	0.006
Weight	52.94	11.82	35	50.13	8.60	3,028	0.056
Woman's characteristics							
Newborns	0.11	0.31	82	0.14	0.35	7,242	0.477
Married	0.87	0.33	87	0.80	0.40	7,417	0.102
Age	42.99	15.55	87	43.10	26.62	7,417	0.969
College education	0.00	0.00	87	0.02	0.12	7,417	0.244

Notes. P-values are from unpaired t-tests for differences in means between the treatment group and the control group. Mother's height is in centimeters. Education and age are in years. Height-for-age and weight-for-height are *z*-scores.

The main identification assumption for external validity is that coral bleaching is exogenous to households' reproductive and child-related decisions. This bleaching event is exogenous and hence considered a natural experiment for two reasons. First, Indonesian households did not directly cause the bleaching. The main cause of coral bleaching in 1998 was a substantial increase in temperatures during a severe episode of El Niño, a natural weather fluctuation in the Pacific Ocean. Second, the coral bleaching event was unexpected. The 1998 coral bleaching was the first mass coral bleaching to be widely reported, and even scientists could only predict it just a few days in advance (Hoegh-Guldberg, 1999). For these reasons, the 1998 coral bleaching was beyond the households' control, prevention, and *ex-ante* adaptation.

This exogeneity assumption is empirically investigated by exploring differences and trends in key variables prior to the coral bleaching in 1998. Table 1 compares summary statistics between the treatment group and others based on the 1997 wave of data. It suggests that the treatment group generally had a lower socioeconomic status than the others. The fertility rates of the two groups were similar in 1997. Children in the treatment group had better health outcomes, but a poorer enrollment rate and school attainment than the other children. These differences, however, are not a major identification threat as they are driven by the inherent differences between fisheries and other sectors. Specifically, many of the differences between fishery households in and outside of the coral bleaching areas are not statistically significant.[8] More importantly, pre-coral bleaching trends in all outcomes are not statistically significant.[9]

4. Fertility

The literature on the effects of shocks on fertility offers a mixed set of findings – some shocks lead to an increase in fertility, while others cause fertility to fall. This section explores how coral bleaching, which leads to income and protein consumption shocks, affects fertility in the short and medium terms. We use the first four waves of the IFLS – 1993, 1997, 2000 and 2007 – and a DDD framework to estimate the effects. Timing wise, the 1993 and 1997 waves were surveyed before coral bleaching happened in 1998, so they serve as pre-treatment waves. The 2000 wave data were collected roughly two years after the bleaching event, so this wave of data allows for the estimation of short-run effects. The 2007 wave then reveals information on medium-run effects. Our sample includes all women, regardless of their exposures to the fisheries sector and the coral bleaching event, provided that they are of child-bearing age. For each woman i living in a household h and province p, let Y_{it} be the woman's number of births given in period t. Then, the main estimating equation can be written as

$$\begin{aligned} Y_{it} = \beta_0 + \sum_{w=2000,2007} & (\beta_1^w CB_p Fish_h Post_t^w + \beta_2^w Fish_h Post_t^w \\ & + \beta_3^w CB_p Post_t^w + \beta_4^w Post_t^w) + \beta_5 CB_p Fish_h + \beta_6 CB_p \\ & + \beta_7 Fish_h + X'_{iht}\delta + \gamma_h + \eta_p + \lambda_t + \epsilon_{it}, \end{aligned} \tag{1}$$

where CB_p is a dummy indicator for living in the coral bleaching area in 1997, $Fish_h$ is a dummy indicator for working in the fisheries sector in 1997, and $Post_t^w$ are dummy indicators for waves 2000 and 2007. X_{iht} is a vector of household and individual control covariates which include the woman's age, education, and marital status as well as the household head's sex, age, and education. γ_h, η_p, and λ_t are household, province, and wave fixed effects, respectively. Our main coefficients of interest are β_1^{2000} and β_1^{2007}, which illustrate how coral bleaching changes Y_{it} in the treatment group relative to all other households while taking into account the differences across the sectors (fisheries vs non-fisheries) and the areas (bleaching vs non-bleaching).

Pregnancy history data in the ever-married women modules are used in the main estimation in this section. One caveat of this set of data is that not all of the women who had ever been married in the sampled households were surveyed. In the first wave

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[8] Results are available upon request. The only variables with significant differences between fishery households exposed and not exposed to coral bleaching are the child's and mother's height, the current enrollment status, and the woman's age. The treatment group was higher and less likely to be in school than other fishery households in 1997. These differences are the opposite of the regression results in the next section, so they, if anything, attenuate the estimated effects of coral bleaching.

[9] Results are available upon request.

of the IFLS, only the household head, his/her spouse, and a random 25 per cent of the remaining adult household members were selected for adult individual-level interviews. This sampling scheme was expanded to cover more individuals in the subsequent waves but still did not cover every ever-married child-bearing-age woman. For this reason, a similar analysis is performed using birth information from household rosters to ensure that results are robust. These alternative results are very similar to the main results and are available upon request.

We focus on live births that occurred within 19 months of the earliest survey date in each wave. This 19-month window is derived from the timing of the shock in 1998 in relation to the earliest survey date in 2000. Specifically, only babies that were conceived during or after coral bleaching (February 1998) should be considered as part of the treatment group, so the birth window for 2000 is restricted to 9 months after February 1998 or November 1998 onward. The 2000 IFLS was first surveyed in June 2000, so this time restriction yields a window of 19 months before the first survey date. In addition, only women in the child-bearing age range of 15–49 years old are included in our analysis.

Table 2 presents regression results on live births[10] based on (1). $\hat{\beta}_1^{2000}$, i.e., the coefficient on $Bleach * Fish * Post^{2000}$, in all columns suggest that women in the treatment group had around 0.13–0.17 more children than other women in 2000.[11] This is a significant increase considering the average births of 0.11 per woman in the treatment group in 1997. $\hat{\beta}_1^{2007}$, on the other hand, are not statistically significant at the usual significance levels.

The results presented in this section are consistent with one of the scenarios in Gary Becker's seminal fertility model. Becker and Lewis (1973) propose a framework linking income to the quantity and quality of children. In their model, a decrease in income lowers the demand for children through the direct income effect. The decrease in income would also result in a fall in child quality and hence would decrease the shadow price of the quantity of children. The lowered shadow price could then lead to an increase in the quantity of children through the substitution effect. The empirical results in the next section suggest that the quality of children declined after a fall in income, and the results presented in this section support the case where the substitution effect is greater than the income effect. That is, the affected households might have substituted the quantity over the quality aspects when they make their reproductive decisions.

The positive effect of coral bleaching on births is consistent with the empirical literature on certain shocks. In the United States, Dehejia and Lleras-Muney (2004) study fertility and unemployment rates and find that the substitution effect is strong for white mothers with low-education. Consequently, more births are observed from this group of mothers as the unemployment rate increases. Some shocks are also associated with a temporary increase in fertility. For example, Hurricane Mitch was associated with higher odds of births in Nicaragua (Davis, 2017). Blackouts can also cause an increase in fertility (e.g., Burlando, 2014*a*, 2014). In both cases, the increase in fertility is due to a timing shift of births rather than an increase in the total number of births.

The increase in fertility in this paper, however, is not in line with some findings in the literature on Indonesia. Kim and Prskawetz (2010) study different kinds of shocks

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[10] We have also examined if coral bleaching affected fetal and infant mortality. None of the treatment coefficients were statistically significant. Results are available upon request.

[11] Note that $\hat{\beta}_1^{2000}$ in all but the third column is statistically significant while $\hat{\beta}_1^{2000}$ in the third column is on the borderline with a p-value of 0.101.

Table 2. Effects of coral bleaching on fertility

	(1) Live births	(2) Live births	(3) Live births	(4) Live births
Bleach*Fish*Post2000	0.134** (0.0513)	0.146** (0.0597)	0.127 (0.0738)	0.167* (0.0834)
Bleach*Fish*Post2007	0.0526 (0.0882)	0.0730 (0.102)	0.0829 (0.140)	0.0854 (0.141)
Bleach*Fish	−0.0192 (0.0296)	−0.0120 (0.0289)		
Fish*Post2000	−0.0907** (0.0341)	−0.0914** (0.0398)	−0.0728 (0.0569)	−0.103* (0.0560)
Fish*Post2007	−0.00416 (0.0317)	−0.00856 (0.0301)	0.00564 (0.0470)	−0.0155 (0.0507)
Bleach*Post2000	−0.0432*** (0.0104)	−0.0351*** (0.0102)	−0.0203 (0.0143)	−0.0164 (0.0148)
Bleach*Post2007	0.00271 (0.0207)	−0.00111 (0.0236)	0.0112 (0.0287)	0.00555 (0.0274)
Constant	1.461*** (0.0867)	1.049*** (0.0830)	0.874*** (0.169)	1.068*** (0.182)
HHH characteristics	No	Yes	No	Yes
HH FE	No	No	Yes	Yes
Ever married only	Yes	Yes	Yes	Yes
N	26,531	23,640	26,531	23,640

Notes. Province-clustered standard errors are in parentheses. *, **, and *** denote statistical significance at the 0.1, 0.05, and 0.01 levels, respectively. The sample is women who were 15–49 years old in the 1993, 1997, 2000 and 2007 waves of data. The dependent variable is the number of children born within 19 months of the earliest interview date. All models include the woman's age, education, and marital status. Columns 2 and 4 also include household head's sex, education, and age. Wave and province fixed effects are included in all models. Columns 3 and 4 also contain household fixed effects.

and find that most of the shocks do not affect fertility. Only unemployment is associated with an increase in fertility. Sellers and Gray (2019) find that delays in monsoon onset led to a small increase in fertility intention and a fall in births. Both papers conjecture that households attempted to use the quantity of children to smooth consumption in times of shocks.

The observed increase in fertility in this paper is likely a temporary shift of fertility timing rather than a permanent increase in the quantity of children as a means for consumption smoothing. We find evidence for an increase in contraceptive use and a decrease in fertility intention in 2000. In addition, the total fertility in 2007 does not differ between the treatment and control groups.[12] The affected households were likely to view coral bleaching as a temporary shock during which the opportunity cost of children has gone down, so they decided to bring forward their birth timing.

The difference in the findings on fertility may also stem from inherent differences between coral bleaching and other shocks. First, rainfall shocks and droughts affect women more than coral bleaching does. Both men and women work in agriculture in Indonesia, while fisheries is a male-dominant industry. With deteriorated marine

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[12] Results are available upon request.

resources, households in fisheries did not increase their labor supply in 2000 but did so in 2007 (Chaijaroen, 2019). This implies a lower opportunity cost of children among the fishery households relative to those in agriculture, especially in 2000. Second, the adverse effects of climate shocks in fisheries might be easier to mitigate than those in agriculture. A severe drought may slash a wide variety of the food supply – from rice, a main food staple, to fruits, vegetables, and plant-based animal feed. A decline in availability of protein from fish, on the other hand, might be compensated by other sources of protein or even other food groups. Agriculture is also a much larger industry than fisheries, so shocks in the agriculture sector are more likely to spread and spill to other industries.

Nonetheless, evidence on child outcomes, to be discussed in the next section, suggests that the affected households were not able to fully overcome the adverse effects of coral bleaching. The effects of coral bleaching, either on marine resources or on humans, are longer-term and harder to be reversed than those of most shocks in the literature. For example, rainfall varies every growing season, and blackouts, even the longest ones, last only months. Humans can rebuild after natural disasters, but humans cannot directly mend the deteriorated marine resources. Therefore, our finding on fertility raises the questions of whether the affected households might have misconceived the effects of coral bleaching as short-term and easily recoverable, and whether policy makers should have stepped in to help with fertility planning.

5. Child outcomes

This section discusses the effects of coral bleaching on child development with a focus on anthropometric and schooling outcomes. The results in this section generally suggest that child development has been hampered after the coral bleaching in 1998, at least in the short run when the affected households experienced income and protein consumption shocks. By 2007, the income shock has recovered, but some evidence still indicates that the affected children were more likely to fail a grade in school despite a higher enrollment rate than the other children.

5.1. Anthropometric outcomes

The anthropometric outcomes considered in this paper are standardized height-for-age and weight-for-height, and dummy indicators for severe stunting and wasting during the first five years of life. Severe stunting is defined as the height-for-age that is at least three standard deviations below the median. Similarly, severe wasting is when the weight-for-height is at least three standard deviations below the median. The standardization of weight and height is based on the WHO scales which are available for ages up to five years old and for height up to 120 centimeters.

Data from the children modules in the 1997 and 2000 waves of the IFLS are used to estimate the effects of coral bleaching on child anthropometric outcomes. The estimation is based on a triple differences framework in which the sample includes children who were 0–5 years old in the 1997 and 2000 waves of data. The treatment group consists of children who were born to the households affected by coral bleaching between 1995–2000.

It is worth noting that we cannot follow the common identification strategy in the early life shock literature where the exact age at the time of shock is interacted with the shock exposure because the exact timing of the shocks from coral bleaching is unknown.

According to the marine science literature, the effects of coral bleaching on fish stocks take time to manifest; however, the exact length of time varies by reef site and depends on reef conditions, local fish stock profile, and bleaching severity. In the case of the 1998 bleaching event in Indonesia, there were no data or studies on fish stock to the best of our knowledge. It is only known that income and protein consumption shocks were realized by 2000 (Chaijaroen, 2019).

Let Y_{it} be the outcome of interest for child i living in household h, province p, and period t, then the main estimating equation takes the form

$$\begin{aligned} Y_{it} = {} & \beta_0 + \beta_1 CB_p Fish_h Post_t + \beta_2 CB_p Fish_h + \beta_3 CB_p Post_t \\ & + \beta_4 Fish_h Post_t + \beta_5 CB_p + \beta_6 Fish_h + \beta_7 Post_t + X'_{iht}\delta + \gamma_h + \epsilon_{it}, \qquad (2) \end{aligned}$$

where CB_p is a dummy indicator for living in coral bleaching areas in 1997, $Fish_h$ is a dummy indicator for the household's working in the fisheries sector in 1997, and $Post_t$ is a dummy indicator for the 2000 wave. X_{iht} is a vector of household and individual control covariates which include the child's sex, age and race; the household head's sex, age and education; and the mother's education and height. Finally, γ_h denotes household fixed effects.

Table 3 illustrates the results on anthropometric outcomes. To control for household-specific time-invariant factors such as upbringing and genetic factors, household fixed effects are included in columns 5–8. The results in columns 1 and 5 suggest that the 1998 coral bleaching does not statistically affect weight-for-height. Column 2 indicates that the bleaching event is associated with about half a standard deviation decrease in height-for-age. However, when the household fixed effects are included in column 6, the effect is not statistically significant. Both models for wasting (columns 3 and 7) suggest that coral bleaching might be associated with an increase in the likelihood of severe wasting, but the coefficients are not statistically significant. Finally, columns 4 and 8 point toward an increase in the likelihood of severe stunting after coral bleaching. Specifically, the results in column 8 indicate that children exposed to coral bleaching were 29.6 percentage points more likely to be severely stunted than other children after controlling for household time-invariant unobservables.

5.2. Schooling outcomes

Early-life shocks and their effects on health outcomes in the first few years of life can translate into poor schooling and other outcomes later in life (e.g., Kim and Prskawetz, 2010). In this section, we investigate how an exposure to coral bleaching in early childhood affects three schooling outcomes: 1) current enrollment status (*Enroll*), 2) whether a child has ever enrolled in school (*Ever Enrolled*), and 3) whether a child has ever failed a grade in school (*Fail*). These effects are estimated using a triple differences framework on the 1997 and 2007 waves of the IFLS. The models in this section compare elementary school age children (7–12 years old) in 2007 with those of the same ages in 1997. The estimating equation is similar to (2) except that $Post_t$ is now a dummy indicator for wave 2007. X_{iht} in this section includes the child's age dummy indicators and sex as well as the household head's sex, age, and education.

Table 4 contains regression results for the aforementioned schooling outcomes. Columns 1–4 show the results from models without household fixed effects while columns 5–7 illustrate the results with the household fixed effects. The treatment coefficients in the enrollment models are all positive, implying that an improvement in income

Table 3. Effects of coral bleaching on anthropometric outcomes in 2000

	(1) WHZ	(2) HAZ	(3) Wasting	(4) Stunting	(5) WHZ	(6) HAZ	(7) Wasting	(8) Stunting
Bleach*Fish*Post	0.142	−0.527*	0.0740	0.0587	0.490	−0.415	0.0372	0.296*
	(0.474)	(0.263)	(0.0485)	(0.0385)	(1.071)	(0.749)	(0.0781)	(0.149)
Fish*Post	0.0619	−0.0552	−0.0530	0.0207	−0.208	0.288	−0.0112	−0.103
	(0.442)	(0.272)	(0.0473)	(0.0324)	(1.044)	(0.603)	(0.0667)	(0.132)
Bleach*Fish	−0.0947	1.167***	−0.0841**	−0.237***				
	(0.431)	(0.206)	(0.0369)	(0.0560)				
Bleach*Post	0.270**	−0.0374	−0.0195	−0.00799	0.0302	0.393	−0.00502	−0.0687
	(0.114)	(0.129)	(0.0134)	(0.0270)	(0.193)	(0.310)	(0.0395)	(0.0400)
Bleach	−0.370***	−0.0786	0.0309*	0.0290				
	(0.0873)	(0.154)	(0.0148)	(0.0515)				
Fish	0.0460	−0.270	0.0273	0.0127				
	(0.430)	(0.155)	(0.0348)	(0.0434)				
Post	−0.134	0.0515	−0.00187	−0.0141	−0.0331	−0.0781	−0.0143	−0.00580
	(0.0770)	(0.0728)	(0.00697)	(0.0126)	(0.120)	(0.154)	(0.0284)	(0.0281)
Sex	−0.0206	−0.0634	0.00602*	0.0212*	−0.00593	0.0242	0.0159	0.00265
	(0.0404)	(0.0644)	(0.00341)	(0.0101)	(0.176)	(0.120)	(0.0216)	(0.0331)
Constant	−2.136***	−11.36***	0.127	2.225***	2.025	−2.940	−0.157	1.177
	(0.682)	(0.487)	(0.0869)	(0.167)	(3.632)	(3.139)	(0.656)	(1.338)
HH FE	No	No	No	No	Yes	Yes	Yes	Yes
N	4,850	4,850	4,850	4,850	4,850	4,850	4,850	4,850

Notes. Province clustered standard errors are in parentheses. *, **, and *** denote statistical significance at the 0.1, 0.05, and 0.01 levels, respectively. The sample is children who were 0–5 years old in the 1997 and 2000 waves. The dependent variables are standardized weight-for-height (WHZ) and height-for-age (HAZ), and dummy indicators for severe malnutrition based on the WHZ and HAZ ($Z < -3$, wasting and stunting, respectively). All models include the child's sex, age, race; the household head's sex, age, and education; as well as the mother's education and height as control covariates. Age and province fixed effects are included in all models. Models 5-8 also contain household fixed effects.

Table 4. Effects of coral bleaching on schooling outcomes in 2007

	(1) Enroll	(2) Ever Enrolled	(3) Fail	(4) Fail	(5) Enroll	(6) Ever Enrolled	(7) Fail
Bleach*Fish*Post	0.234** (0.0868)	0.104** (0.0359)	0.165** (0.0780)	0.160** (0.0803)	0.251 (0.150)	0.0752 (0.0641)	0.0898 (0.252)
Fish*Post	−0.0662** (0.0183)	−0.0832** (0.0268)	−0.0320 (0.0421)	−0.0300 (0.0423)	−0.0387 (0.0521)	−0.0352 (0.0573)	−0.109 (0.179)
Bleach*Fish	−0.147 (0.0849)	−0.0281 (0.0251)	0.0138 (0.0552)	0.00929 (0.0565)			
Bleach*Post	−0.00467 (0.0214)	−0.00185 (0.0169)	0.0180 (0.0208)	0.0171 (0.0209)	−0.0147 (0.0409)	−0.000418 (0.0280)	−0.0159 (0.0528)
Bleach	0.00351 (0.0150)	−0.00548 (0.00844)	−0.0220 (0.0165)	−0.0205 (0.0169)			
Fish	−0.0381 (0.0257)	−0.0192 (0.0196)	−0.0398 (0.0297)	−0.0283 (0.0333)			
Post	−0.0366*** (0.00916)	−0.0423*** (0.00627)	−0.0668*** (0.0140)	−0.0604*** (0.0139)	−0.0412 (0.0370)	−0.0453* (0.0218)	−0.0558 (0.0523)
Constant	0.824*** (0.0196)	0.818*** (0.0183)	0.0500 (0.0345)	0.0799** (0.0395)	0.368*** (0.0559)	0.750*** (0.0593)	−0.104 (0.138)
Method	OLS	OLS	OLS	Heckman	FE	FE	FE
HH FE	No	No	No	No	Yes	Yes	Yes
N	7,581	7,581	7,224	7,358	7,581	7,581	7,224

Notes. Province clustered standard errors are in parentheses. *, **, and *** denote statistical significance at the 0.1, 0.05, and 0.01 levels, respectively. The sample is children who were 7–12 years old in the 1997 and 2007 waves. The dependent variables are dummy variables equal to 1 if a child is currently enrolled in school, if a child has ever enrolled in school, and if a child has ever failed a grade in school. All models include the child's sex, and the household head's sex, age, and education. Age (in years) and province fixed effects are included in all models. Models 5–7 also contain household fixed effects.

after coral bleaching might increase school enrollment. For example, column 1 suggests that coral bleaching increases the chance that a child is currently enrolled in school by 23.4 percentage points.

On the performance side, the treatment coefficients for *Fail* are all positive. This, together with the results on enrollment, implies that children who had been exposed to coral bleaching were more likely to fail a grade in school even when they had an equal or even better chance to be in school. The lower performance might be due to two plausible reasons. First, an early childhood exposure to coral bleaching could have led to poor nutrition and health outcomes, imposing long-term risks on later life outcomes. Second, parents might have had less time to care for their children in 2007 as they started increasing their work hours.

5.3. Selection

It is worth mentioning that some treatment coefficients in this section, usually those from models with household fixed effects, are not statistically significant at the usual significance levels (columns 5–7 of table 3, and columns 5–7 of table 4). One possible reason is positive selection into births. In the cases where there were pre-treatment differences in child outcomes between the treatment and control groups, and the treatment group had more births than the control group, then OLS coefficients might be statistically significant even when the within-household effects are not. This explanation, however, is unlikely because the pre-treatment differences are the opposite of the regression results. For example, the affected children's average HAZ was higher than the rest of the children in 1997. Had coral bleaching not affected the HAZ, the OLS coefficients from (2) would have been positive, the opposite of our estimates in table 3. This rationale is also applicable to schooling outcomes. In 1997, children in the treatment group were less likely to fail a grade in school relative to their peers. The positive selection due to births would have resulted in a negative OLS estimate for the treatment effect on fail, but the OLS estimate in table 4 is positive.

A more plausible explanation for the imprecise estimates in this section is a low statistical power due to the small treatment group, especially in the fixed effect models. For anthropometric outcomes, the treatment group includes 25 children from 20 households. For schooling outcomes, the treatment group is slightly larger at 36 children from 29 households. In either case, the treatment group is very small relative to the whole sample that contains thousands of children.

The increased fertility aside, another plausible source of selection bias is stillbirths and infant mortality. Weaker infants are more likely to die, so this selection tends to bias our estimates on child development upward. Nonetheless, tests show that coral bleaching does not affect fetus and infant mortality,[13] so this selection bias can be ruled out.

In addition, the model for performance in school might suffer from selection due to enrollment. To this front, we also estimate the model using Heckman's maximum likelihood estimator and show the results in column 4 of table 4. This set of results is similar to the OLS one, and the likelihood-ratio test for the independence of the two parts yields a p-value of 0.0001. These suggest that the selection due to enrollment might not be a significant identification threat.

In summary, coral bleaching is associated with a decline in child development as measured by some anthropometric and schooling outcomes. The strongest statistical

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[13] Results available upon request.

evidence in this section indicates that the children exposed to coral bleaching face a large increase in the likelihood of severe stunting after controlling for household time-invariant unobservables. Reduced-form OLS-based evidence also suggests a lower early-life HAZ and an increased likelihood of failing a grade in elementary school among the affected children.

6. Comparison with rainfall shocks and policy implications

In this section, coral bleaching is compared against one of the most common economic shocks in the literature, rainfall shocks. Compared to rainfall shocks, coral bleaching is more long-term and novel, so the known policy implications in this literature might not apply to coral bleaching. Specifically, rainfall shocks usually last just a few months whereas the effects of coral bleaching on fish stocks span several years or even become permanent. Humans have experienced rainfall variations for as long as we have existed as a species, and we have learned to adapt in various ways to these shocks. Coral bleaching, on the other hand, is relatively new. The first known coral bleaching events were recorded in the 1980s, and the more severe ones only started in the late 1990s. With climate change, more long-term and novel shocks like coral bleaching are expected to occur. We should therefore investigate how these shocks differ from those studied in the current literature to shed light on relevant policies that would mitigate similar future climate shocks.

To estimate the effects of rainfall shocks, data from the IFLS are merged with rainfall data from the University of Delaware Air Temperature & Precipitation database. We then follow Maccini and Yang (2009) and construct the rainfall variable as the total rainfall in each child's birth year.[14] When estimating the effects of the rainfall shocks, we allow the effects to depend on whether a household is agriculture-based. Let Y_{it} be the outcome of interest for child i living in household h and year t, then the estimating equation can be written as

$$Y_{it} = \beta_0 + \beta_1 Rain_{it} + \beta_2 Agri_{ht} + \beta_3 Rain_{it} * Agri_{ht} + X'_{iht}\delta + \gamma_h + \epsilon_{it}, \tag{3}$$

where X_{iht} is a vector of control covariates, and γ_h is household fixed effects.

Table 5 contains key coefficients from (3) for anthropometric outcomes and illustrates the lesser effects of rainfall relative to coral bleaching. In particular, a transitory rainfall shock at birth only affects weight, a measure of short-term growth, but not other anthropometric measures. Specifically, the only treatment coefficient that is statistically significant at conventional significance levels is that on the interaction term in the WHZ model without household fixed effects (column 1), suggesting that rainfall has a positive effect on weight only among agriculture-based households. The average rainfall in this sample is 184 centimeters and the standard deviation is 48.97 centimeters, so a one standard deviation increase in rainfall is associated with an increase in weight by 0.17 standard deviations.

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[14] The birth year is defined to cover a full round of wet and dry seasons preceding a child's birth. The definition of the seasons varies by provinces and is based on the definitions in Kishore *et al.* (2000) and long-term monthly average precipitation from the University of Delaware database. Rainfall in the database is measured monthly in grid format. For a given month, a province's average precipitation is the grid-size weighted average of precipitation from all grids that fall within the province boundary. Then, the rainfall variable is the sum of monthly provincial averages over a child's birth year.

Table 5. Effects of birth year rainfall on anthropometric outcomes in 2000

	(1) WHZ	(2) HAZ	(3) Wasting	(4) Stunting	(5) WHZ	(6) HAZ	(7) Wasting	(8) Stunting
Rain*Agri	0.00295* (0.00165)	0.00137 (0.00164)	0.0000523 (0.000162)	−0.000518 (0.000308)	−0.00245 (0.00842)	0.000830 (0.00941)	0.000413 (0.00110)	−0.000890 (0.00136)
Rain	−0.00115 (0.00153)	−0.00167 (0.00115)	−0.000150 (0.0000947)	0.000131 (0.000165)	0.00229 (0.00595)	0.0000266 (0.00745)	0.0000979 (0.000502)	0.000364 (0.00104)
Agri	−0.562* (0.305)	−0.342 (0.290)	−0.00249 (0.0322)	0.0926 (0.0564)				
Constant	−1.042 (0.980)	−11.78*** (0.664)	0.0864 (0.139)	2.139*** (0.210)	7.873 (14.26)	9.372 (12.88)	0.658 (1.404)	−0.651 (3.570)
HH FE	No	No	No	No	Yes	Yes	Yes	Yes
N	2,880	2,880	2,880	2,880	2,880	2,880	2,880	2,880

Notes. Clustered standard errors are in parentheses. * and *** denote statistical significance at the 0.1 and 0.01 levels, respectively. The sample is children who were 0–5 years old in the 2000 wave of data. The dependent variables are standardized weight-for-height and height-for-age as well as dummy indicators for severe malnutrition based on the WHZ and HAZ ($Z < -3$). *Rainfall* is birth year wet season rainfall in centimeters at a province level. *Agri* is a dummy variable equal to 1 if the household engaged in agriculture in 2000. All models include the child's sex and race, the household head's sex, age, and education, as well as the mother's education and height as control covariates. Age (in years) and province fixed effects are included in all models.

Table 6. Effects of birth year rainfall on schooling outcomes in 2007

	(1) Enroll	(2) Ever Enrolled	(3) Fail	(4) Enroll	(5) Ever Enrolled	(6) Fail
Rain*Agri	0.0000449 (0.000197)	−0.0000109 (0.000188)	0.0000480 (0.000172)	−0.000386 (0.00123)	−0.000253 (0.00121)	0.000889 (0.00181)
Rain	0.0000203 (0.000126)	0.0000996 (0.000143)	−0.000215 (0.000245)	−0.000205 (0.000570)	−0.000186 (0.000629)	−0.00131 (0.00157)
Agri	−0.0110 (0.0344)	−0.00532 (0.0314)	−0.0150 (0.0399)			
Constant	0.742*** (0.0387)	0.708*** (0.0476)	0.130 (0.0759)	0.842*** (0.153)	0.826*** (0.175)	0.291 (0.273)
HH FE	No	No	No	Yes	Yes	Yes
N	3,686	3,686	3,546	3,686	3,686	3,546

Notes. Province clustered standard errors are in parentheses. *** denotes statistical significance at the 0.01 level. The sample is children who were 7–12 years old in 2007. The dependent variables are dummy indicators equal to 1 if a child is currently enrolled in school, if a child has ever enrolled in school, and if a child has ever failed a grade in school. *Rainfall* is birth year wet season rainfall in centimeters at a provincial level. *Agri* is a dummy variable equal to 1 if the household engaged in agriculture in 2000. All models include the child's sex, and the household head's sex, age, and education. Age (in years) and province fixed effects are included in all models.

This effect of rainfall on weight is relatively small compared to the effects of coral bleaching on height, a measure of long-term growth, and severe malnutrition. For example, coral bleaching increases the likelihood of severe malnutrition (severe wasting and severe stunting) by 4–30 percentage points. Coral bleaching is also associated with a 0.53 standard deviation decrease in standardized height, while the effects of birth year rainfall on standardized height and severe malnutrition are not statistically significant.

Relative to rainfall in birth year, an early-life exposure to coral bleaching also has stronger effects on schooling outcomes. Table 6 contains key coefficients from (3) for schooling outcomes. Similar to most of the results in table 5, the coefficients in this table are not statistically significant.

The results on rainfall shocks and anthropometric outcomes are consistent with Cornwell and Inder's (2015) nutritional effect finding in which an increase in rainfall boosts food availability and improves child health in rural Indonesia. Both the anthropometric and schooling results in this paper, however, are not consistent with the findings in Maccini and Yang (2009), due probably to structural differences across time. Maccini and Yang (2009) focuses on adults aged 25 and above in 2007. Their sample was exposed to the rainfall shocks at least 18 years before the sample in this paper. In a developing country setting, many factors could have changed over this time span. For example, irrigation and technological advancement might have lessened any adverse effects that low rainfall might have on agricultural income. In addition, healthcare might have significantly improved over the years, so small shocks in nutrition can be smoothed out.

What is also striking about the comparison of coral bleaching with rainfall shocks is the increase in fertility following the exposure to coral bleaching. The rainfall shocks in the Indonesian literature, on the other hand, are associated with a decrease in fertility (Sellers and Gray, 2019). Both coral bleaching and rainfall shocks hamper child development, but the effects are greater in the case of coral bleaching. This finding then raises the question of whether the effects of coral bleaching were underestimated, and stronger policy interventions should have been implemented.

Given that the increase in fertility is a timing shift of births, rather than an increase in total fertility, policies should mostly focus on providing support for mothers and children. Policy on fertility, if any, should emphasize the demand side as data on contraceptive use do not show any supply-side problems. Specifically, the policy should educate parents about the possible long-term effects of coral bleaching so they could correctly assess the costs associated with having children.

Right around the time of the coral bleaching in 1998, several policies were rolled out to fight against poverty and economic hardship following the 1997 Asian Financial Crisis, yet these policies were not greatly effective in eliminating the adverse effects of coral bleaching on child development. According to Daly and Fane (2002), the largest anti-poverty program during that time was the subsidized rice program OPK (Operasi Pasar Khusus), aiming to provide nutrition to the poor. Scholarship and school grants as well as healthcare cards and a supplementary nutrition program were also implemented during the same time. However, the results in this paper still indicate some malnutrition for those at the lower end of the distribution as well as an increased likelihood of failing a grade in school, suggesting that the existing policies were not particularly effective in mitigating the effects of coral bleaching.

There are at least three main problems with the policies during the 1997 crisis. First, the policies could not reach some of the poorest due to several glitches in policy coverage and targeting (Daly and Fane, 2002). Second, policies aiming to mitigate malnutrition following coral bleaching should have emphasized protein supplement, but the main food subsidy program at that time focused only on rice. Third, increasing enrollment through scholarships and school grants alone might not suffice in improving education outcomes. Future policies should therefore address these issues.

Since the Asian Financial Crisis, many other effective programs have been implemented in Indonesia; some of them could potentially help mitigate the effects of coral bleaching. Given that coral bleaching affected children through both the reductions in income and nutrition intakes, a conditional cash transfer (CCT) program with conditions on healthcare and school participation can be effective. For instance, Program Keluarga Harapan (PKH), a household-level CCT program, was rolled out in 2007 and contained conditions on iron supplement, postnatal care, child immunization and health checkups, and school attendance. In the same year, the government also started a village-level CCT program, Generasi, which provided annual block grants to support health and education. These programs help improve preventive healthcare utilization, increase protein consumption and nutrition, as well as decrease wasting and stunting (Kusuma *et al.*, 2007*a*, 2007; Aizawa, 2020; Cahyadi *et al.*, 2020). If these programs had been rolled out right after the coral bleaching event, some adverse effects of the shocks might have been mitigated.

In summary, the comparison of the 1998 coral bleaching to birth-year rainfall shocks suggests that the coral bleaching event had larger negative effects on child development. This, together with the increase in fertility after the event, calls for better policy interventions. Based on a literature survey of policies in Indonesia and the findings in this paper, policies addressing coral bleaching should focus on protein intakes, preventive healthcare for mothers and children, and student performance in school. For example, a CCT with conditions on those aspects could work well. This policy implication is directly applicable to climate shocks that result in nutrition and income losses, such as ocean acidification and shocks that permanently change agricultural production patterns. The income aspects of the results in this paper also apply to other long-term income shocks such as a permanent job loss.

7. Conclusion

In this paper, we investigate how income and consumption shocks due to coral bleaching impact the affected households' decisions on fertility and child development. In particular, this paper highlights how the effects of coral bleaching may differ from those of other shocks in the literature. Most of the literature on climate change and children focuses on the effects of rising air temperatures, changes in precipitation, and natural disasters. In contrast to rainfall shocks, coral bleaching affects both income and protein availability, and the effects of coral bleaching could last longer because marine resources usually take several years to recover. Most importantly, coral bleaching is a novel shock, at least in the context of this study, so it gives us a unique opportunity to evaluate the effects of climate shocks prior to adaptations.

We find that the coral bleaching in 1998 is associated with an increase in fertility shortly after. Children exposed to coral bleaching were 29.6 percentage points more likely to be severely stunted than their peers in 2000. Some evidence also suggests that they were more likely to fail a grade in school by 2007. In contrast, rainfall shocks are mostly associated with a decrease in fertility in Indonesia while their effects on children are smaller in magnitude than those of the coral bleaching. These results suggest that the effects of coral bleaching might have been underestimated. In addition, an early-life exposure to coral bleaching can greatly impede child development and human capital accumulation in the future.

Since coral bleaching is a climate shock, the findings in this paper provide insights into how policy makers can alleviate the adverse effects of climate change. In addition to the implications regarding coral bleaching and climate shocks, this paper also contributes to the literature on early life exposure to shocks in general because coral bleaching is exogenous to household behaviors. Even though this literature is well-established, most of the negative shocks in this literature are transitory. Long-term negative shocks are expected to become more common as the world's climate changes and more conflicts arise around the world, for instance. It is therefore important to learn more about these shocks and how we could alleviate their effects. One lesson to be learned from the findings in this paper is that children should not be overlooked when households experience a large long-lasting shock. On the positive side, although the effects of coral bleaching are larger than the effects of transitory rainfall shocks, the slow manifestation of coral bleaching effects allows the households time to adapt. Results from this paper then shed some light on how policy makers can facilitate the adaptation process – by using interventions on health and child development such as a conditional cash transfer, which may alleviate coral bleaching's long-term negative effects on children and human capital accumulation.

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