

©Copyright 2016
Pasita Chaijaroen

Essays on Economic Impacts of Coral Bleaching:
Evidence from Indonesia

Pasita Chaijaroen

A dissertation
submitted in partial fulfillment of the
requirements for the degree of

Doctor of Philosophy

University of Washington

2016

Reading Committee:

Rachel Heath, Chair

Brian Dillon

Elaina Rose

Program Authorized to Offer Degree:
Economics

University of Washington

Abstract

Essays on Economic Impacts of Coral Bleaching:
Evidence from Indonesia

Pasita Chaijaroen

Chair of the Supervisory Committee:
Assistant Professor Rachel Heath
Department of Economics

This dissertation explores the economic effects of the 1998 massive coral bleaching on Indonesian households. The first chapter explores the effects on income and labor-related outcomes among fishery households. Results suggest a 27 % reduction in income in the short run as well as a short-run increase in migration, and long-run changes in labor supply. Given the income shock and the shock to the fish resource, effects on various consumption categories among the fishery group were investigated in the second chapter. Finally, the third chapter discusses how the effects observed among the fishery households spill over to other households in the economy.

TABLE OF CONTENTS

	Page
List of Figures	iii
List of Tables	iv
Chapter 1: Long-Lasting Income Shocks and Labor-Related Adaptations among Fishery Households	1
1.1 Introduction	1
1.2 Background on Coral Bleaching and Fishery in Indonesia	4
1.3 Theoretical Framework for Consumption, Labor Supply, and Migration	6
1.4 Empirical Framework	10
1.5 Empirical Results	20
1.6 Conclusion	31
Chapter 2: Changes in Consumption among Fishery Households	33
2.1 Introduction	33
2.2 Background on Effects of Coral Bleaching in Indonesia	35
2.3 Empirical Framework	36
2.4 Empirical Results	40
2.5 Policy Implications and Conclusion	50
Chapter 3: Beyond the Sea: Spillover Effects of Coral Bleaching to Non-Fishery Sectors	51
3.1 Introduction	51
3.2 ENSO, Coral bleaching, and Human	54
3.3 Empirical Framework	56
3.4 Empirical Results	61
3.5 Policy Implications and Conclusion	75

Bibliography	76
Appendix A: Details on Theoretical Model and Additional Empirical Results	81
A.1 Theoretical Framework– Further Details	81
A.2 Additional Empirical Results	85

LIST OF FIGURES

Figure Number	Page
1.1 Reported coral bleaching spots in the Indian and western Pacific oceans in 1998 from Goreau et al. [2000]	5
1.2 Theoretical relationships between initial fish resource endowment (δ), inputs, and fishery profit obtained from CES resource functions	11
1.3 IFLS provinces and treated area	13
1.4 Distribution of SST anomaly days among fishery households	15
1.5 log(real household income per worker) of fishery households and other households in bleaching area	17
1.6 log(real household income per worker) among fishery households in bleaching and non-bleaching areas	19
2.1 log(protein consumption expenditure per household member) of fishery households and other households in bleaching area	39
2.2 log(protein consumption expenditure per household member) of fishery households in and outside of bleaching areas	40
3.1 Trends in log(real household income per worker) among non-fishery household in and outside of coral bleaching areas	59
3.2 Comparison of spillover effects: all areas vs remote areas	70
A.1.1 Theoretical relationships between initial fish resource endowment (δ), inputs, and fishery profit obtained from Cobb-Douglas and linear resource functions	84
A.2.1 Robustness of spillover effects to different functional forms of transitory rainfall	90

LIST OF TABLES

Table Number	Page
1.1	Number of households by waves and areas 14
1.2	Number of households in 1997 by area and fishery status 14
1.3	Summary statistics by treatment status, 1997 wave 18
1.4	Effects of coral bleaching on income - geographic control group 22
1.5	Effects of coral bleaching on income - fishery control group 23
1.6	Effects of coral bleaching on labor market outcomes - geographic control group 25
1.7	Effects of coral bleaching on income - triple differences 28
1.8	Effects of coral bleaching on labor market outcomes - triple differences . . . 29
1.9	Robustness check - IV estimation 30
1.10	Robustness check - placebo treatment on control area 30
2.1	Effects of coral bleaching on consumption - geographic control group 41
2.2	Effects of coral bleaching on consumption - fishery control group 42
2.3	Effects of coral bleaching on consumption purchases and consumption of house- hold production - fishery control 44
2.4	Effects of coral bleaching on consumption - spillover 46
2.5	Effects of coral bleaching on consumption - triple differences 48
2.6	Effects of coral bleaching on consumption - IV 49
2.7	Results from placebo treatment test 49
3.1	Summary statistics by treatment area, 1997 wave 59
3.2	Spillovers of coral bleaching to non-fishery households–labor market outcomes 62
3.3	Spillovers of coral bleaching to non-fishery households–income 64
3.4	Spillovers of coral bleaching to non-fishery households–interactions with sectors 65
3.5	Spillovers of coral bleaching to non-fishery households–interactions with tourism areas 68
3.6	Spillovers of coral bleaching to non-fishery households–consumption 71
3.7	Spillovers of coral bleaching to non-fishery households–homegrown consumption 72

3.8	Spillovers of coral bleaching to non-fishery households—forest fire areas included	73
3.9	Spillovers of coral bleaching to non-fishery households—controlling for rainfall	74
A.2.1	Effects of coral bleaching on labor market outcomes - fishery control group	85
A.2.2	Effects of coral bleaching on consumption purchases and consumption of household production - geographical control	87
A.2.3	Effects of coral bleaching on consumption purchases and consumption of household production - triple differences	88
A.2.4	Spillovers of coral bleaching to non-fishery households—controlling for 1997 rainfall	89
A.2.5	Model specifications for rainfall	91

ACKNOWLEDGMENTS

First and foremost, I would like to express my deepest gratitude to my advisor, Professor Rachel Heath, for her invaluable support and for seeing my potential. I am thankful for her immense knowledge, guidance, suggestions, questions, patience, and motivation. I am also indebted to my committee, Professor Elaina Rose, Professor Brian Dillon, and Professor Chris Anderson, for their guidance, feedback, and continuous support. Their advices and guidance helped build up my skills and tremendously advance my work.

In addition to my committee, I would like to thank Professor Gregory Duncan, my great supervisor and mentor. I truly appreciate his advice and suggestions on everything, from research to career. My sincere thanks also goes to Professor Judith Thornton for giving me the opportunity to work with her, and for her cheerful encouragement and support. Her support brightened up my days and smoothed out many bumps throughout my PhD years.

I thank Supasorn Suwajanakorn for his great love and support. Thanks is not enough for what he has done for me. I am grateful for valuable, life-long support from my friends: Kunlapath Sukcharoen, Passaporn Sikkakosol, and Thanadtha Manitpisalkul. I also thank my fellow friends in the PhD program for their suggestions and discussions about my work, and for their moral support for the last five years. In particular, I thank Jenny Ho for her continuous support and our numerous conversations—from those on research to those that kept me sane during difficult times.

Last but not least, I would like to thank my family; my dad, my aunt, and my brother; for their understanding and countless support. They are the most important part of life, and I could not have done this without them.

Chapter 1

LONG-LASTING INCOME SHOCKS AND LABOR-RELATED ADAPTATIONS AMONG FISHERY HOUSEHOLDS

Abstract

This chapter explores how people adapt after a climate shock, coral bleaching, that has long-lasting impacts on income. Coral bleaching, which is mainly caused by abnormally high sea surface temperature, has significant effects on fish and other marine life. Using panel data from Indonesia and exogenous variation in bleaching, I find that fishery households in coral bleaching areas experienced a fall in income relative to other households. Affected households were also more likely to migrate in the short run. In the medium to long run, they tended to increase their labor supply, take second jobs, and switch to another industry.

1.1 Introduction

The world climate has been changing with the expectation that the temperature will continue to rise for the coming centuries. Climate change could lead to long-term changes in agricultural output.¹ Equally important but much less studied are the potential negative impacts of rising sea temperatures. With 61% of the world GNP coming from coastal areas² and 16.7% of global animal protein consumption coming from fish [FAO, 2014], these impacts can be substantial.

This chapter explores the relationship between climate change, income shock, and adaptation mechanisms, with an emphasis on the ocean. In particular, I investigate how labor market outcomes and consumption change as households experience a fall in income due to coral bleaching. Coral bleaching is a natural phenomenon where coral reefs are weakened due to abnormally high sea surface temperature (SST). Coral reefs are a habitat and a food

¹For instance, Schlenker et al. [2006] found a large negative impact of climate change on U.S. farm land values using a hedonic approach, and Deschênes and Greenstone [2012] found that the effect of climate change on U.S. agricultural profit can range from negative to statistically insignificant. Dell et al. [2014] comprehensively discuss this literature.

²Coastal areas here are defined as those within 100 kilometers of the coastline [UNEP, 2006].

source for many species, so coral bleaching can lead to an income shock to people who make their livelihoods out of the ocean. This income shock can persist for many years because marine resources take time to recover.

I develop a simple theoretical framework to guide the empirical study. The model is a variation of an agricultural household model where a household jointly engages in fishery production and consumption. This framework suggests that labor-related adaptations after a shock to the fish stock resource can differ between the short run and the long run. In particular, the changes in migration and labor input in the fishery production are greater in the short run than in the long run. Despite these adaptations, the household still experiences a fall in fishery profit, and consumption declines with income.

I test the theoretical findings using panel data from the Indonesian Family Life Survey (IFLS), which has been tracking a sample of Indonesian households since 1993. Identification relies on the premise that coral bleaching is exogenous to household behavior. This should be the case for the massive coral bleaching in 1998 which was mainly induced by El Niño, a natural shift in the world tropical climate. With reported bleaching spots in some of the IFLS provinces, the identification strategy compares fishery households that lived in coral bleaching areas to non-fishery households in the same areas as well as to other fishery households that lived outside of coral bleaching areas. In addition to the reported bleaching spots, I also construct the SST measure based on remote sensing data and utilize it as another proxy for coral bleaching. I then explore how the treatment effects vary over the years after coral bleaching because adaptations can be different over time.

Two main results emerge. First, households that engaged in fishery in the coral bleaching areas experienced a significant drop in income in 2000, two years after coral bleaching, but not in 2007³. Second, the affected households were more likely to migrate in the short run, and more likely to switch to a new industry and increase their labor supply in the long run. These adaptive mechanisms helped to bring the affected households' income back to a level comparable to other households' in 2007.

This paper is related to two main strands of literature. The first is the large literature on the impacts of climate change on humans. Most of the past economic literature related to climate change has dealt with the U.S. agricultural sector. A number of papers find negative impacts of an increase in temperature on agricultural land values and agricultural profits in the U.S., for example, [Schlenker et al. \[2006\]](#) and [Deschênes and Greenstone \[2012\]](#). Such

³The IFLS is currently available for 1993, 1997, 2000, and 2007.

impacts tend to be large in developing countries due to both the severity of the climate change, and the lack of adequate safety net and risk sharing mechanisms in these countries. Nonetheless, the literature on climate change in the developing world is scarce. One of the few studies is [Taraz \[2015\]](#) who investigates impacts of the long-term change in monsoon pattern in India and finds that loss recovery is small despite agricultural adaptations such as irrigation investments and crop mix adjustment. Another is [Schlenker and Lobell \[2010\]](#) who find that an increase in temperature is associated with a decrease in crop yields in Sub-Saharan Africa. This literature indicates that global warming could potentially cause a long-term income loss in the agricultural sector. This paper also explores the impacts of climate change in a developing country context and shows that the adverse impacts of climate change are not limited to the agricultural sector. The fishery sector could also suffer from an income loss as temperature rises. Furthermore, climate change might impose risks on nutrition intakes, especially in vulnerable communities in developing countries. Consistent with the findings in [Taraz \[2015\]](#), adaptations after climate change in this paper happened mostly in the long run. However, the adaptations studied in this paper are labor-related activities whereas those in [Taraz \[2015\]](#) are mostly technological.

Second, this paper contributes to the income shock literature. Most income shocks in the economic literature are relatively short-term shocks such as a crop loss from a temporary change in rainfall pattern [e.g. [Wolpin, 1982](#), [Paxson, 1993](#)], or expected long-term shocks such as a birth of a girl and an associated future dowry payment [[Deolalikar and Rose, 1998](#)]. This paper offers a unique opportunity to investigate how economic agents adapt after a long-lasting and unexpected fall in income. As the world climate changes, unexpected, large, and long-lasting shocks are becoming more common. Understanding how people react to this kind of income shocks is very crucial because these shocks may have larger impacts on economic agents than short-term or anticipated shocks. In the existing literature, savings and risk sharing mechanisms allow households to smooth consumption after a crop loss [e.g. [Paxson, 1993](#), [Townsend, 1994](#)]. Agricultural households also respond to the crop income loss by increasing labor supply and labor force participation [[Kochar, 1999](#), [Rose, 2001](#)]. Adaptation mechanisms in this paper are similar to those in this literature, but most adaptations considered here happened years after the shock rather than within a couple of months or years. This might be because the income shock from climate change is long-lasting and hard to mitigate.

The rest of the paper is organized as follows. Section 2 provides details on coral bleaching

and the fishery sector in Indonesia. Section 3 outlines a theoretical framework for fishery, consumption, labor supply, and migration. Section 4 discusses the empirical framework including data and identification. Section 5 presents the empirical results. Section 6 suggests some policy implications and concludes.

1.2 Background on Coral Bleaching and Fishery in Indonesia

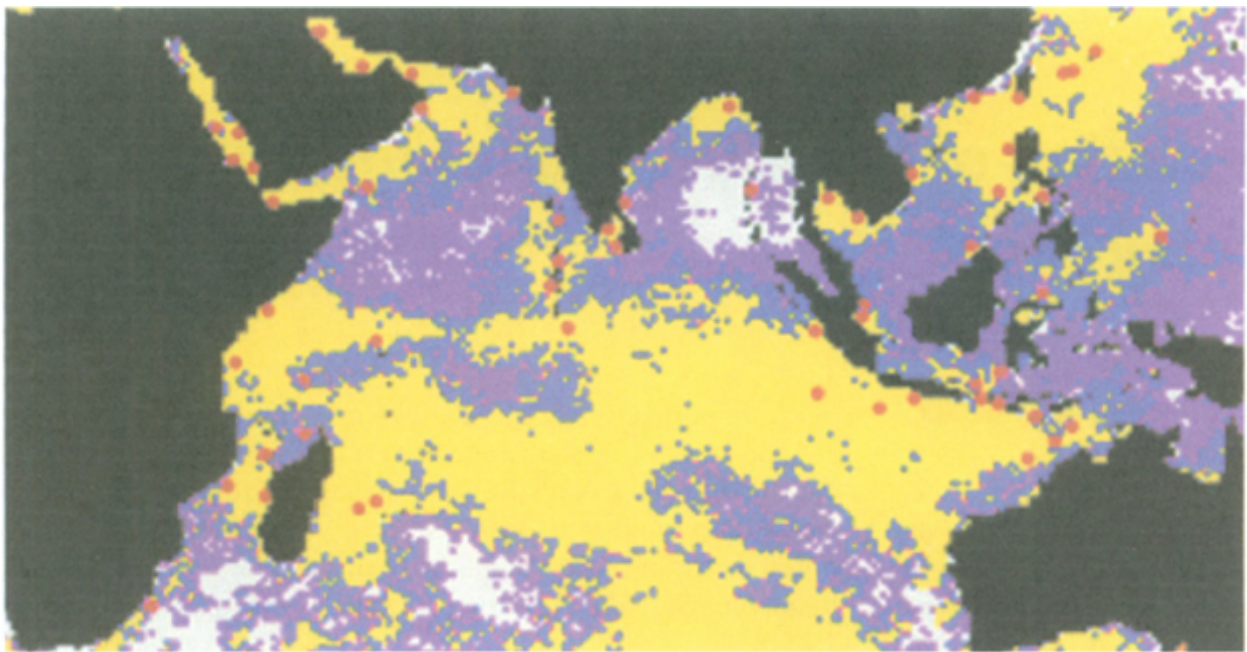
Coral bleaching is a natural phenomenon by which coral reefs lose their colors due mainly to abnormally high sea surface temperature (SST). As SST rises, corals expel the symbiotic algae on which they feed [Brown, 1997]. Corals usually regain their colors in a few months if they survive the bleaching process. However, if the temperature remains high for a long period of time, corals usually die [Wilkinson and Hodgson, 1999, Hoegh-Guldberg, 1999]. In this case, it will take many years for the reef to recover. New coral larvae or polyps must settle into the old reef structure and regrow [Barnes and Hughes, 1999, Veron and Stafford-Smith, 2000]. Corals usually grow at a rate between less than one inch to four inches per year, depending on species [NOAA].

During the past few decades, massive coral bleaching events were reported in 1998 and 2010. As the impact of coral bleaching can be long-term, I focus on the 1998 bleaching. Coral bleaching in 1998 was a result of severe El Niño. The SST anomaly spanned from the eastern coast of Africa to as far as Japan and Australia during the first half of 1998. This resulted in a number of reported bleaching spots in the Indian Ocean and the Pacific Ocean (see Figure 1.1) [Goreau et al., 2000]. In Indonesia, there were reported bleaching spots in West Sumatra, the south shore of Central Java, Bali and Lombok area, and Southern Sulawesi. Coral mortality rates in the Indian Ocean ranged from 70-99%; this rate was estimated to be around 50% in Bali area [Goreau et al., 2000]. Wilkinson [2000] estimated that 16% of the world corals were lost during this bleaching event.

Coral mortality has a devastating effect on fish that depend on corals for food, habitat, and recruitment [Pratchett et al., 2008]. Scientific studies find varying degrees of coral bleaching impacts on fish stock depending on species and locations⁴. In general, coral depletion leads to a rapid decline in abundance of coral reef species in the short to medium

⁴For example, Garpe et al. [2006] found that total abundance and taxonomic richness of species increased right after coral bleaching in Tanzania, but both measures significantly declined below the initial level six years after the bleaching. Booth and Beretta [2002] found a lower recruitment of fish at bleached southern Great Barrier Reef sites relative to unbleached sites one year after the bleaching.

Figure 1.1: Reported coral bleaching spots in the Indian and western Pacific oceans in 1998 from [Goreau et al. \[2000\]](#)



Color codes: black = land; red spots = coral bleaching spots; yellow = oceans with SST anomaly (SST > 1°C above mean); blue and purple = oceans with high SST (SST between 0.4 – 1°C above mean)

run (up to three years after coral bleaching). In the long run, if corals fail to recover, fish composition will change, and the overall abundance and diversity will decline [van Oppen and Lough, 2008].

The evidence for coral and fish stock recovery after coral bleaching in 1998 is quite sparse. This is because the event was the first one to be widely documented, so data for the pre-bleaching period was limited. The existing literature suggests that damaged corals take at least five years to recover provided that the reef is not permanently ruined [e.g. Graham et al., 2007, Wilkinson and Hodgson, 1999]. Graham et al. [2007] studied the long-run impact of the 1998 coral bleaching in Seychelles. They found that coral reefs did not fully recover by 2005, and that fish reproduction was minimal. A follow-up study in the same area in 2011 indicates that 11 out of 21 reef sites recovered while 9 sites were permanently ruined and replaced by algae [Graham et al., 2015].

Coral bleaching can affect human through at least three channels. Firstly, bleached corals are less attractive to tourists, so severe coral bleaching could cause an income shock to the tourism sector. Secondly, coral bleaching may lead to an income shock to the fishery sector as coral bleaching is associated with a reduction in both abundance and diversity of other marine life over time. Finally, coral reefs are crucial to land preservation. More erosion is expected once the reefs are weakened. This paper focuses on the impacts of coral bleaching on the fishery sector in Indonesia.

Coral bleaching is expected to have large impacts on small-scale fishery households because small boats cannot travel to distant unaffected areas. Most of the Indonesian fishery sector is considered small or medium scale, characterized by non-power or outboard-engine boats. More than half of the fishing boats in coral bleaching areas are non-power and outboard-engine. Except for Central Java and Bali, the majority of fishing boats in the coral-bleaching areas were non-power in 2000. In Bali, where most of the fishery households in the IFLS live, around 40% of fishing boats were non-power and less than 5% were inboard-engine [Statistics Indonesia].

1.3 Theoretical Framework for Consumption, Labor Supply, and Migration

In this section, I develop a theoretical framework to demonstrate how labor activities and consumption change after an exogenous shock to fish stock resource. The model is based on the agricultural household framework, in which a household engages in fishery production and consumption. In its fishery production, the household cannot change the state variable

representing the fish stock, but it can migrate in search of better fishing conditions if it wishes to. This theoretical framework implies that a household responds to a resource endowment shock by increasing migration and total labor supply. In addition, consumption changes in tandem with household income, and a decline in natural resource leads to a fall in both income and consumption. The changes in labor market decisions and consumption are generally larger in the short run than in the long run as the short-run migration gives access to a healthy fish stock for a longer period of time.

1.3.1 Model Setup

The household maximizes their utility, $u(C_t, l_t)$, where C_t represents consumption and l_t represents leisure, subject to a budget constraint. The household may engage in fishing, and it can also supply labor to and hire extra labor from the labor market. Fishery production requires two inputs: fish stock resource, and labor. The fish stock resource is a function of initial fish endowment and migration, $R(\delta, M_t)$, where δ denotes the initial fish stock and M_t denotes migration distance. The initial fish endowment is given and exogenous, but the household can improve the fish stock resource in each period by migration. Labor input in the fishery production function, L_t , equals the sum of household's labor allocated to fishery, L_t^{HH} , and hired-in labor, L_t^{In} . The fishery profit is then equal to fishery revenues minus costs of migration and hired-in labor. Fish is the only consumption good in this model.

To illustrate that adaptations in the short run and the long run can be different, the model contains two periods—immediately after the shock and the long run. The key difference between the two periods is the marginal benefits of migration. Migration in the first period can improve fish stock resource in both periods, but migration in the second period affects only the second period fish stock.

Assume a log-linear utility function, then the household's optimization problem can be written as

$$\begin{aligned}
\max \quad & \log C_1 + \log l_1 + \phi(\log C_2 + \log l_2) \\
\text{s.t.} \quad & C_1 + pC_2 + w_1L_1^{In} + w_2L_2^{In} \\
& \leq F(L_1, R(\delta, M_1)) - m_1M_1 + pF(L_2, R(\delta, M_1, M_2)) - m_2M_2 + w_1L_1^{Out} + w_2L_2^{Out} \\
& E^L = L_t^{HH} + L_t^{Out} + l_t; t = 1, 2 \\
& L_t = L_t^{HH} + L_t^{In}; t = 1, 2,
\end{aligned}$$

where L_t^{Out} denotes household labor supplied to the labor market, w_t denotes wage in period t , ϕ denotes a discount factor, and p denotes fish price in the long run relative to the short run. $F(\cdot)$ is a fishery production function with two inputs: total fishery labor, L_t , and the coral reef resource, $R(\delta, M_t)$. If the household chooses to migrate, it will incur a cost of m_t per unit of migration distance. Finally, time endowment equals E^L , so leisure and household labor supplies to fishery production and labor market must sum to E^L .

Fishery Production

The model assumes that a fishery household is endowed with an initial fish stock resource and uses this resource as one factor of production. The household can improve the fish stock it faces in each time period by migration. The second factor of production is labor, which is a sum of the household's labor and hired-in labor.

The fishery production function has the usual diminishing return assumption—output is a concave function of labor and fish stock resource. The fish stock is a function of initial resource condition at home and migration. Migration improves the fish stock in current and future periods, but it cannot alter past resource conditions⁵. Additionally, an increase in fish stock resource through either a better initial endowment or an increase in migration would enhance the marginal product of labor. These characteristics are formulated in Assumption 1.

Assumption 1. *The fishery production function satisfies following conditions:*

1. *Concavity:* $\frac{\partial^2 F_t}{\partial L_t^2} \leq 0$ and $\frac{\partial^2 F_t}{\partial R_t^2} \leq 0$;
2. *Marginal product of migration:* $\frac{\partial R_1}{\partial M_1} > 0$, $\frac{\partial R_2}{\partial M_2} > 0$, $\frac{\partial R_2}{\partial M_1} > 0$, and $\frac{\partial R_1}{\partial M_2} = 0$.
3. *Fish stock resource and marginal product of labor:* $\frac{\partial^2 F_t}{\partial L_t \partial \delta} > 0$, $\frac{\partial^2 F_t}{\partial L_t \partial M_t} > 0$, and $\frac{\partial^2 F_{t+1}}{\partial L_t \partial M_t} > 0$

⁵It is assumed that migration always improves fish resource condition here. When migration may not improve the resource, but the household knows the distribution of this possible improvement, all of the main results hold. However, when ρ is low, labor inputs, migration, and fishery profit are lower in the case with risk than in the case without.

The fishery production function, $F(\cdot)$, is assumed to take the usual Cobb-Douglas functional form. The fish stock resource in the first period is a function of initial resource, δ , and first period migration, M_1 . In the second period, the resource function is a function of the initial resource endowment and both periods' migration, $R(\delta, M_1, M_2)$. Rather than modeling migration as a discrete choice between migrating and staying, I model migration as continuous to reflect the spatial diffusion nature of the shock. In the case of weakened coral reef, the further the migration distance, the better the coral resource. In a baseline model, I impose a constant elasticity of substitution (CES) functional form on the resource functions to allow for predictions on the relationship between the substitutability between the initial fish resource and migration, and subsequent labor and consumption outcomes. The resource functions can then be written as

$$R_1 = (\delta^\rho + M_1^\rho)^{\frac{1}{\rho}},$$

$$R_2 = (\delta^\rho + M_1^\rho + M_2^\rho)^{\frac{1}{\rho}}.$$

1.3.2 Interior Solution

Figure 1.2 exhibits the theoretical findings based on the CES resource functions with different values of ρ . All results indicate that a fall in initial fish resource leads to declines in fishery labor inputs, fishery profit, and consumption; and an increase in total household labor supply. The results on migration differs with ρ . A fall in initial resource endowment is associated with drops in migration when ρ is small but increases in migration when ρ is large. In the case where ρ is small, the marginal fish resource from an increase in migration substantially decreases as the initial fish endowment declined⁶. In this case, it might not be optimal for the household to migrate in response to the resource endowment shock as migration incurs costs while there is no cost to the resource endowment. On the other hand, when ρ is large, the marginal fish resource from an increase in migration only slightly declines as the initial fish stock deteriorates. As a result, only a small increase in migration is required to alleviate the effect of fish stock reduction compared to the case with small ρ . Thus, migration rises when there is an initial fish endowment shock in this case. Empirical results presented in

⁶This corresponds to the low elasticity of substitution between the two factors. Note that the elasticity of substitution here is loosely defined as the initial fish endowment is exogenous to household behaviors.

the next section support the case of high substitutability between migration and initial fish stock.

These findings also suggest different magnitudes of changes between the short run and the long run. The short-run changes in migration, total household labor supply, and consumption are always greater than the long-run changes. In contrast, the long-run change in fishery labor input is greater than its short-run counterpart only in models with positive relationship between migration and resource endowment. These time differences stem from the difference in benefits of short-run and long-run migration as well as the size of discount rate relative to inflation.

Appendix A.1 discusses theoretical findings based on alternative functional forms at the extreme values of ρ , the Cobb-Douglas and the linear resource functions. The findings based on the Cobb-Douglas functional form are consistent with the low ρ scenario, and those based on the linear functional form are similar to the case of high ρ .

1.4 Empirical Framework

1.4.1 Data

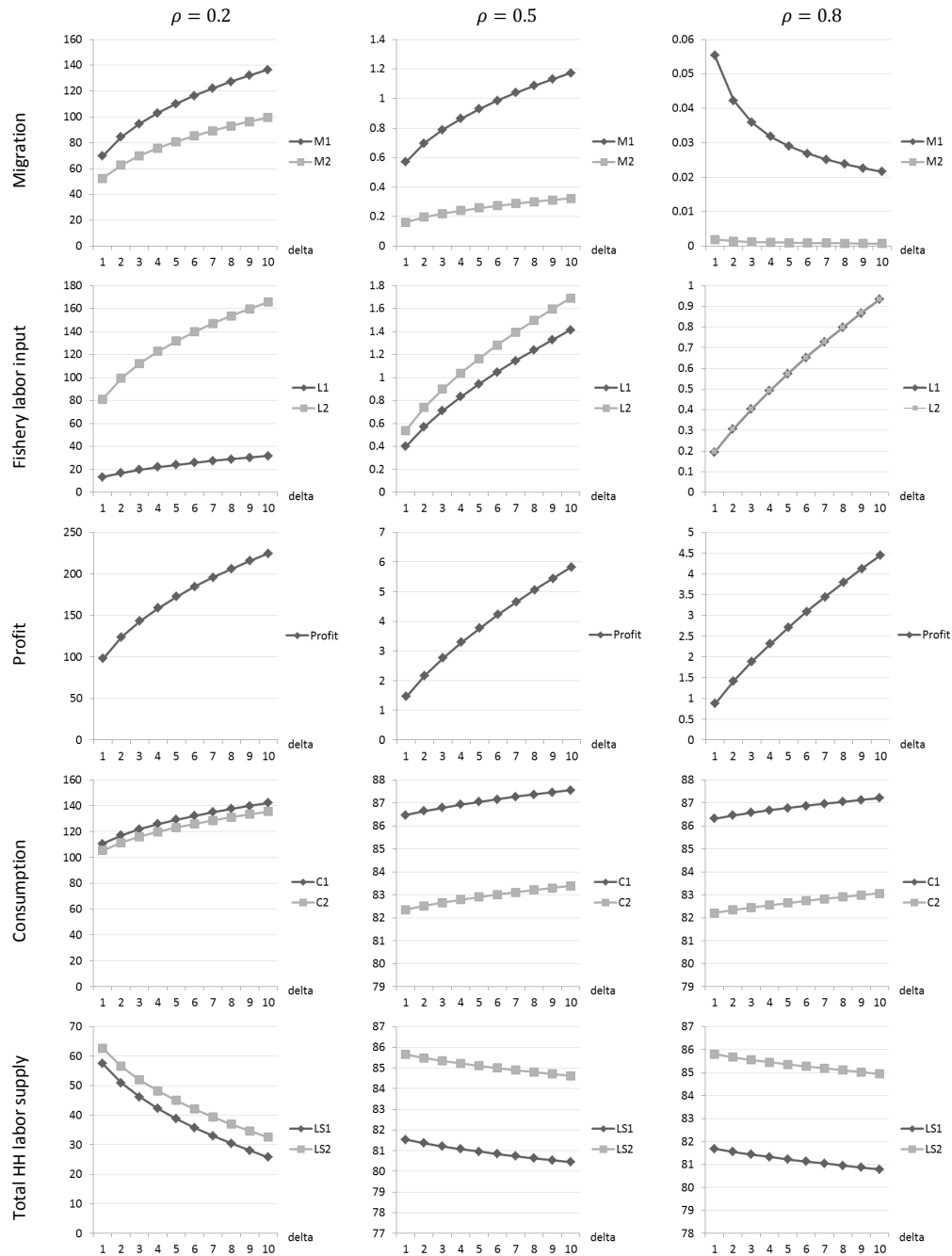
The main sources of data in this paper are the Indonesian Family Life Survey (IFLS)⁷, reported coral bleaching spots from Goreau et al. [2000], and SST anomaly from National Oceanic and Atmospheric Administration (NOAA) satellite map. The IFLS is a panel that has been tracking 7,224 Indonesian households since 1993. The survey includes detailed information on socioeconomic status, consumption, labor market history, migration, and so on. As we explore labor-related outcomes, including migration, attrition might be a concern. The IFLS's overall attrition rate is relatively low compared to other panel datasets in developing countries. Among the fishery households, the re-contact rate among the original 1993 households in 2007 is 95.83%. This re-contact rate is 93.6% among all original IFLS households. A simple test⁸ indicates that attrition is not significantly different between the treated and the control groups.

The IFLS is then combined with data on coral bleaching. The first source of coral bleaching data is reported coral bleaching spots from Goreau et al. [2000]. This paper

⁷Frankenberg and Karoly [1995], Frankenberg and Duncan [2000], Strauss et al. [2004], and Strauss et al. [2009]

⁸A test where a dummy indicator for failure to contact a household is regressed on all regressors appeared in the main estimating model.

Figure 1.2: Theoretical relationships between initial fish resource endowment (δ), inputs, and fishery profit obtained from CES resource functions



Fishery production function takes the form $F_t(L_t, R_t) = L_t^\alpha R_t^\beta$. These results are obtained from numerical optimization with the following parameters: $\alpha = 0.3, \beta = 0.5, \gamma = 1, w_1 = 1, w_2 = 1.05, p = 1.05, m_1 = 1.08, m_2 = 1.08$, and $E^L = 168$.

gathers reef data primarily from long-term observers who observed the reefs before and after coral bleaching. This helps guarantee that the damage reported was actually due to coral bleaching, not other factors that might have damaged the corals prior to coral bleaching. Nonetheless, as with other reported data, coral bleaching spots here might not be comprehensive. Some bleaching spots might not get reported. Consequently, I also use number of days with SST anomaly in 1998 as another proxy for coral bleaching.

A popular mass coral bleaching model [Hoegh-Guldberg, 1999] postulates that coral bleaching is likely to occur when SST is more than 1°C above the normal summer average for at least 3-4 weeks. NOAA has been using this SST anomaly measure to predict coral bleaching since the 1990's and has been successful in predicting mass bleaching events shortly before coral bleaching actually occurred [Hoegh-Guldberg, 1999]. The number of days with SST anomaly in this paper is constructed from NOAA satellite images. NOAA published a map that illustrates SST anomaly once every 1-7 days during 1998. For each coastal area, defined as one ocean coastline in one province⁹, I calculate days with SST anomaly based on the maps from January to June 1998, the period during which SST anomaly occurred. Then, this SST anomaly days are merged with the household data at a coastal area level.

1.4.2 Methodology

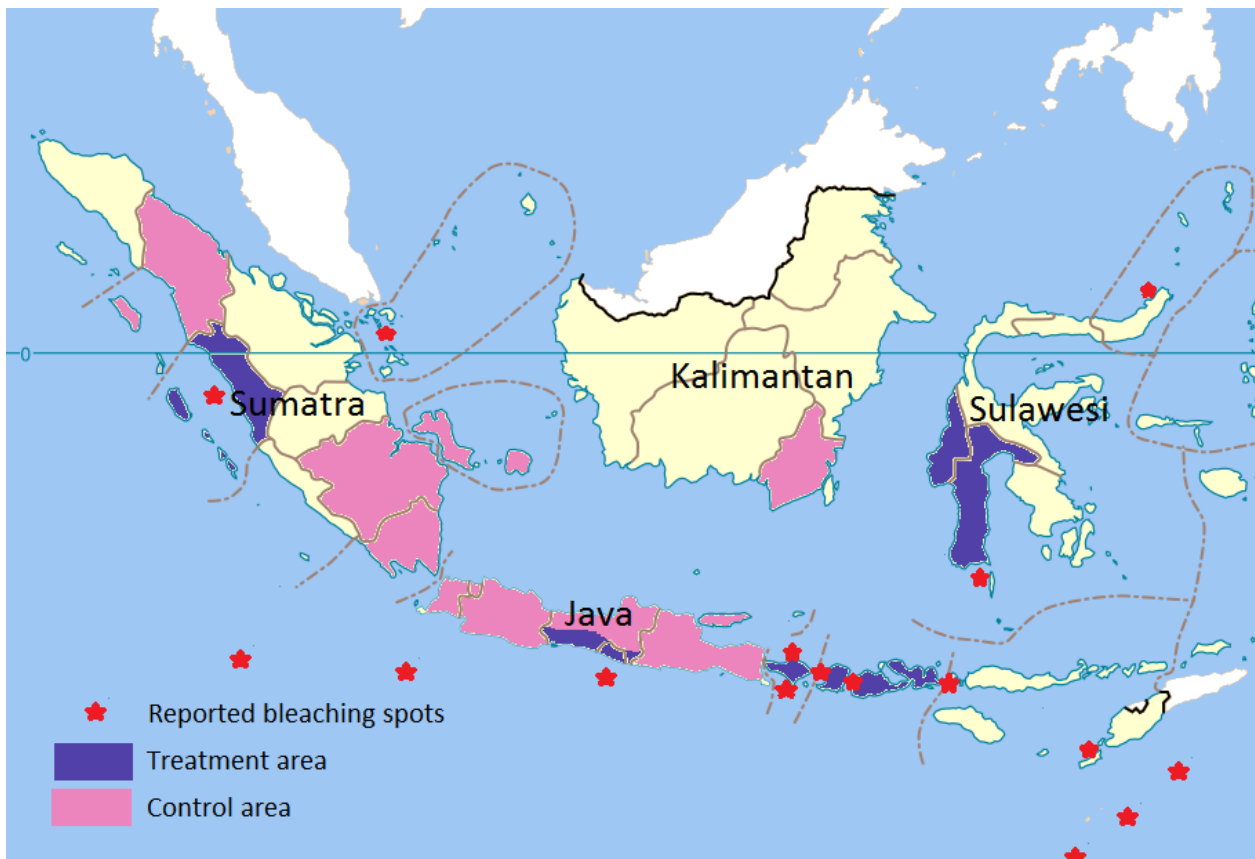
Treatment Specification

Identification in this paper is based on the difference-in-difference technique. The treated households are defined as households that engaged in fishery and lived in the affected area in 1997. The affected (treated) area includes provinces with reported bleaching spots in Goreau et al. [2000], namely Bali, West Nusa Tenggara, West Sumatra, the Indian Ocean coastal area of Central Java, Yogyakarta, and South Sulawesi (See Figure 1.3). This treatment status is held constant across all waves of data.

The IFLS is currently available for 1993, 1997, 2000, and 2007. The major coral bleaching in Indonesia happened in 1998, so there are two waves of data for the pre-treatment period and two waves for the post-treatment period. Specifically, the 2000 wave serves as a short-run post-treatment period, and the 2007 wave represents the long run. Table 1.1 illustrates the numbers of households by coral bleaching and control areas in each wave. Table 1.2 shows

⁹The exception to this rule is Bali and West Nusa Tenggara where the two provinces are treated as one coastal area. This is due to the small-island nature of these provinces and the fact that SST anomaly was similar in the whole area.

Figure 1.3: IFLS provinces and treated area



the number of households who were affected by coral bleaching based on the 1997 wave of data. Of the 7,516 households in 1997, 2,191 households lived in the areas with reported coral bleaching spots, and 196 engaged in fishing. Among these households, 76 fished and lived in the coral bleaching area and hence constitute the treated group.

Table 1.1: Number of households by waves and areas

Waves	Control area	Coral bleaching area	Total
1993	4,898	2,248	7,146
1997	5,325	2,191	7,516
2000	6,873	2,929	9,802
2007	7,465	3,351	10,816
Total	24,561	10,719	35,280

Table 1.2: Number of households in 1997 by area and fishery status

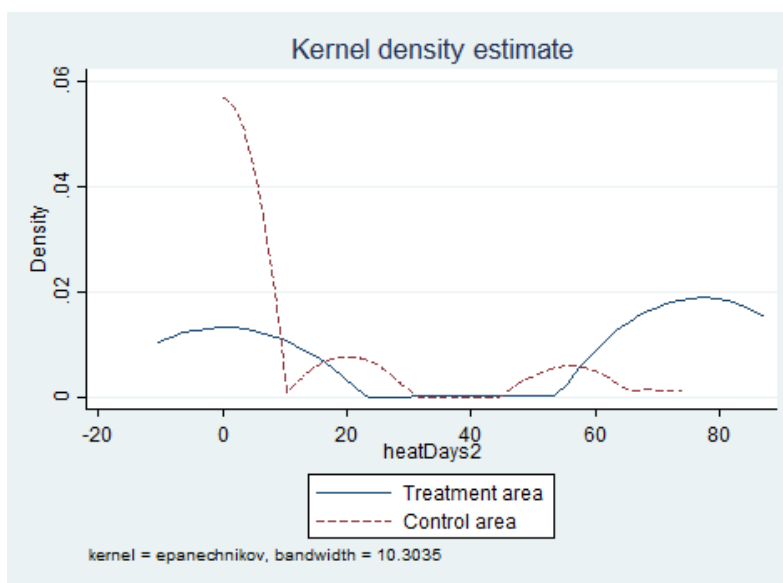
	Non-fishery	Fishery	Total
Control area	5,205	120	5,325
Treated area	2,115	76	2,191
Total	7,320	196	7,516

Based on this binary treatment specification, there are two possible control groups—non-fishery households in coral bleaching areas, and fishery households in non-coral bleaching areas. Using the geographical control group makes intuitive sense as people in the same geographical location experience similar shocks and changes. For example, households in the same geographic area usually face similar prices and weather-related shocks. Using the fishery households in other areas as a control group is motivated by dramatic changes in macroeconomic factors during the period of study. The Asian Financial Crisis started in 1997 and resulted in a significant depreciation of Rupiah. The fishery sector responded to this macroeconomic change by shifting to fishing for live fish for exports instead of fishing for domestic consumption. Moreover, aggressive fishing methods were used more widely than before. Using the fishery control group helps control for trends in these non-observables in the fishery sector. One drawback of using the fishery control group is the small sample size as illustrated in Table 1.2.

The treatment using the SST anomaly days is defined based on both the actual SST anomaly days for each coastal area, and the household's occupation. In particular, SST anomaly days equals zero for all non-fishery households, and it is equal to the actual SST anomaly days in the household's area for all fishery households. SST anomaly days can then be greater than zero for fishery households that lived outside of coral bleaching areas. Figure 1.4 compares the distribution of SST anomaly days among fishery households that lived in and outside of coral bleaching areas. Specifically, the fishery households that lived in areas with reported coral bleaching spots experienced more SST anomaly days relative to those that lived outside of these areas.

The regression samples that constitute the SST anomaly days models mimic those under the binary treatment specifications. In particular, one regression sample is all fishery households regardless of where they lived, and another sample is all households in areas with reported coral bleaching.

Figure 1.4: Distribution of SST anomaly days among fishery households



Identification

The ultimate goal of this empirical study is to identify how households adapt after a shock with coral bleaching serving as a natural experiment. A fall in income due to coral bleaching should be exogenous for a couple of reasons. First, households did not directly cause coral

bleaching. The 1998 coral bleaching in Indonesia was mainly induced by El Niño, a natural shift in the tropical climate. Second, these households were unlikely to anticipate coral bleaching. By monitoring the SST anomaly, scientists predicted the 1998 coral bleaching only days in advance [Hoegh-Guldberg, 1999]. In addition, even though coral bleaching events are associated with El Niño episodes, the correlation is not perfect, and it is also difficult to accurately predict El Niño well in advance.

The empirical modeling involves identifying an impact of coral bleaching on income and investigating an aftermath of the income shock. The main estimating equation is a difference-in-difference model where the treatment effect is allowed to vary by time post-treatment. This identification strategy is motivated by the fact that impacts of coral bleaching could be different over time. For example, as the theoretical model suggests, the effects of coral bleaching on migration, labor supply, and consumption can be larger in the short run than in the long run.

Let Y_{ht} be a dependent variable of interest. Then, the estimating equation when using a binary treatment definition can be written as

$$Y_{ht} = \alpha + \delta_1 Treat_h + \delta_2 Post_t + \sum_{\tau=2000,2007} \beta_\tau I(wave = \tau) * Treat_h + X'_{ht}\gamma + \mu_h + \lambda_t + \epsilon_{ht}, \quad (1.1)$$

where h is a subscript for household and t is a subscript for time. $I(wave = \tau)$ is an indicator function for each wave of the post-treatment period, $Treat_h$ is the treatment status, and \mathbf{X}_{ht} is a vector of control covariates. The model also contains household fixed effects, μ_h , and wave fixed effects, λ_t . Control covariates include a set of dummy variables for provinces of residence in 1997, and household head's characteristics such as age and education. As a result, the model accounts for predetermined factors that are constant within households, any particular wave, and provinces of residence prior to the shock. Note that δ_1 and δ_2 are not identified as the model contains wave and province fixed effects.

Similar to (1.1), the estimating equation under the SST anomaly days specification takes the form

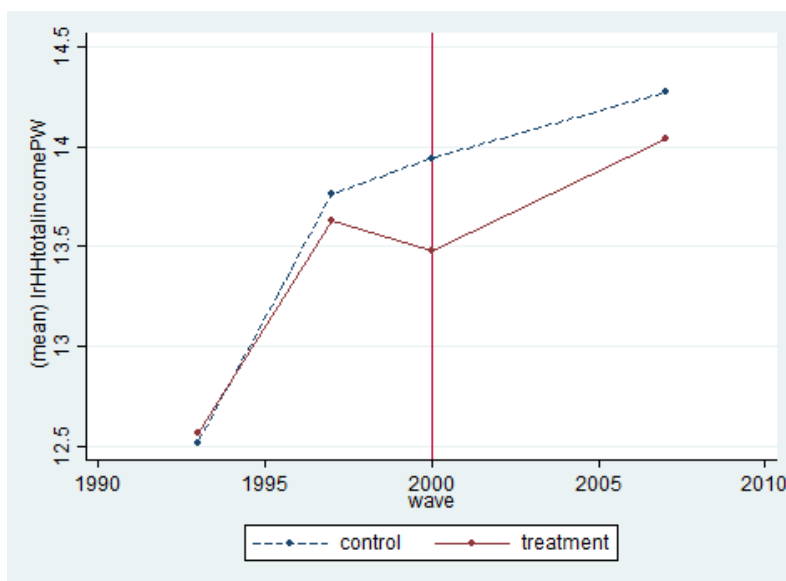
$$Y_{ht} = \alpha + \delta_1 SSTdays_h + \delta_2 Post_t + \sum_{\tau=2000,2007} \beta_\tau I(wave = \tau) * SSTdays_h + X'_{ht}\gamma + \mu_h + \lambda_t + \epsilon_{ht}, \quad (1.2)$$

where $SSTdays_h$ denotes the number of SST anomaly days household h faced during the

1998 coral bleaching.

Table 1.3 compares summary statistics of key variables between treatment and control groups in 1997. These statistics indicate that the treated households work harder on average than both control groups. Moreover, some of the treated group's consumption expenditures are smaller relative to the control groups'. The differences between the treatment and the control groups prior to coral bleaching are not an identification concern as long as the three groups have similar trends in dependent variables before the treatment. For example, the Asian Crisis, which started in 1997, must have affected the treatment and the control groups in the same way. Figures 1.5 and 1.6 help validate this assumption by comparing the treatment group's and the control groups' trends of log of real household income over time¹⁰. Log real household income is quite similar among the three groups prior to the 2000 wave. After coral bleaching in 1998, the treatment group's income dropped in 2000 before increasing in 2007.

Figure 1.5: log(real household income per worker) of fishery households and other households in bleaching area



Averages are calculated from households with positive income

Another way to estimate the treatment effect in this setting is the triple difference specification, which allows for identification even when there exist both the unobservables that

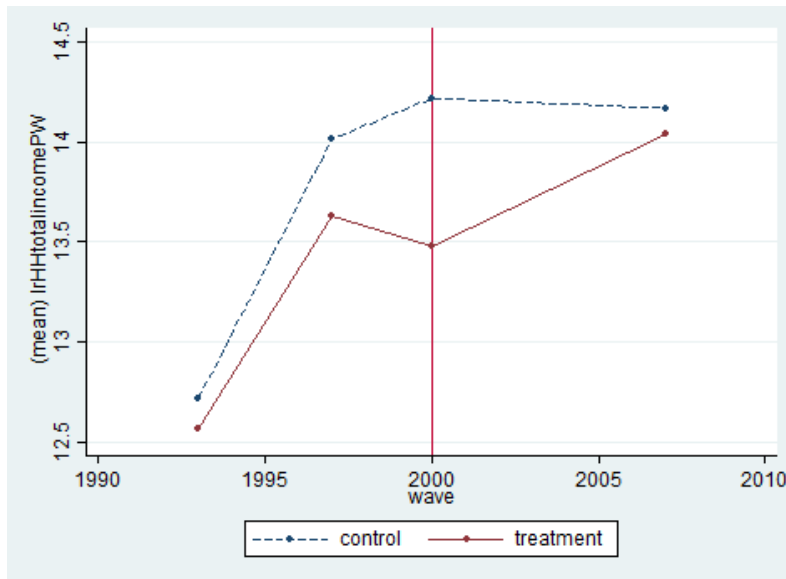
¹⁰Similar graphs for other outcome variables are available upon request.

Table 1.3: Summary statistics by treatment status, 1997 wave

	Treated group			Geographic control			Fishery control			
	Mean	SD	N	Mean	SD	N	Mean	SD	N	p-value
HH head's age	43.25	12.27	72	48.98	33.74	1,948	43.91	11.91	112	0.1511
Male HH head	0.972	0.165	72	0.805	0.396	1,948	0.929	0.259	112	0.0004
Number of members in fishery	1.184	0.647	76	0.000	0.000	2,115	1.183	0.580	120	1.0000
Fraction of labor in fishery	0.421	0.212	76	0.000	0.000	2,115	0.431	0.185	120	1.0000
SST anomaly days	58.39	32.90	76	0.00	0.00	2,115	8.66	20.45	120	1.0000
Real HH income	1,413,430	2,124,524	73	1,884,484	7,467,620	1,777	2,847,497	7,248,134	112	0.5907
Second job	0.539	0.871	76	0.356	0.601	2,115	0.192	0.473	120	0.0102
Fraction of female labor	0.201	0.201	76	0.273	0.292	2,115	0.112	0.184	120	0.0325
Working weeks per year	38.63	20.09	76	32.85	21.16	2,110	27.76	12.19	120	0.0192
Working hours per week	33.22	17.54	76	27.62	18.85	2,112	27.97	15.95	120	0.0107
Total food consumption expdt	6,128	4,134	76	8,324	17,927	2,110	8,116	7,169	120	0.2862
Protein consumption expdt	1,444	1,457	76	2,096	5,815	2,110	1,828	1,831	120	0.3288
Nonfood consumption expdt	39,347	60,296	76	102,742	257,106	2,052	71,509	118,671	116	0.0319

Remarks: p-values from unpaired t-tests for difference in means between the treated group and each control group.

Figure 1.6: log(real household income per worker) among fishery households in bleaching and non-bleaching areas



Averages are calculated from households with positive income

affect all fishery households, and the unobservables that affect all households in coral bleaching areas. For example, if there are both a change in fishery regulation and drought in coral bleaching areas, then the treatment effect can be identified only in the triple difference specification. Under the double difference specification, the change in fishery regulation is not controlled for when using the geographical control group, and the drought could potentially bias the treatment effect estimated under the fishery control group specification. The estimating equation based on the triple difference specification can be written as

$$\begin{aligned}
 Y_{ht} = & \alpha + \delta_p Post_t + \delta_f Fish_h + \delta_b Bleach_h + \phi_1 Post_t * Fish_h + \phi_2 Post_t * Bleach_h + \phi_3 Fish_h * Bleach_h + \dots \\
 & \dots + \sum_{\tau=2000,2007} \beta_\tau I(wave = \tau) * Fish_h * Bleach_h + X'_{ht} \gamma + \mu_h + \lambda_t + \epsilon_{ht}. \quad (1.3)
 \end{aligned}$$

Identification based on the triple difference specification, nonetheless, comes at a cost of power. This is a particular concern when the treatment group is small, as is the case here. The results from the triple difference model are slightly less precisely estimated than those from the double difference specifications and are presented in the next section as a robustness

check.

The second empirical consideration is measurement error. The current measures of coral bleaching in this paper contain varying extents of measurement error. The binary treatment definition based on reported bleaching spots suffers from under-reporting. There could be other bleaching spots that were not reported. The second measure, number of days with SST anomaly, is more continuous and does not suffer from underreporting. However, it suffers from an imperfect correlation between SST and the actual bleaching events. The SST threshold can vary by locations and coral species [Hughes et al., 2003]. In addition, even though the SST anomaly is the most important cause of mass coral bleaching, other factors, such as light, water salinity, and depth of water, could also adversely affect the coral reefs. These factors are unlikely to confound the empirical results because these factors were mostly uncorrelated with the outcomes¹¹. In either case, the classic measurement error biases the OLS estimates towards zero. Despite the measurement error, I find significant impacts of coral bleaching on various outcomes using both measures of coral bleaching and both definitions of control groups.

The empirical analysis proceeds as follows. I first investigate if coral bleaching is associated with a reduction in income among the affected households relative to other households. Y_{ht} in this case is a natural logarithm of real household income per worker. Then, I explore how the affected households adjust relative to the control groups in terms of labor market decisions. The labor market decisions include decisions to migrate, supply labor, and switch to another industry. The empirical analysis on consumption will be discussed in the next chapter.

1.5 Empirical Results

Using the proposed empirical models, I find a robust adverse impact of the 1998 coral bleaching on household income two years after coral bleaching but not nine years after. Given the income shock, the affected households tended to have limited adaptation options in the short run, but these options opened up in the long run. Specifically, the only labor-related adaptation that statistically changed in 2000 is migration; however, there is evidence for an increase in labor supply and industry switching in the long run. These findings suggest that coral bleaching and income shock could result in a decline in nutrition intake among the affected

¹¹These factors may have weak second-order effects on fish catch. However, they are likely to be persistent over time and should be controlled for under the difference-in-difference specification.

households. This section explains all empirical results in detail. First, the results on income are discussed. Then, I turn to labor-related adaptations.

1.5.1 *Income shock*

Tables 1.4-1.5 show the estimates of the key coefficients from equations (1.1)-(1.2) with log real household income per worker as a dependent variable. These models suggest that coral bleaching is associated with a relatively large income shock among the affected fishery households in 2000, two years after coral bleaching. Their income increased over time, so the income was at a level comparable to the control groups' in 2007, nine years after coral bleaching.

Columns 2 in Tables 1.4-1.5 show the treatment effect coefficients using the geographical and fishery control groups, respectively. The coefficients on an interaction term $I(2000) * treat_h$ are negative and large in magnitude under both control group specifications. Using the geographic control group, the coefficient on $I(2000) * Fish$ is estimated to be -0.3236. This implies the treatment group's income fell around 27% compared to the average income of non-fishery households in the same area. The coefficient on $I(2000) * Bleach$ using the fishery control group is -0.6213, which translates into a 46.3% average drop in income among the treated group relative to other fishery households. This finding is also confirmed under the SST anomaly specifications— the coefficients on $I(2000) * SSTdays_h$ are also negative and translated into a 29.6% decline in income relative to the geographical control group, and a 38.1% decline in income relative to the fishery control group¹². On the other hand, the coefficients for 2007 are not statistically significant in any specifications. The F-Test with the null hypothesis $H_0 : \beta_{2000} = \beta_{2007}$ also suggests that income changed from 2000 to 2007. These results together indicate that the income shock is mitigated over time. This can be due either to fish stock recovery or household adaptations, or both.

As the dependent variable is log of real household income per worker, households with negative or zero income are dropped from the regressions. These households account for 9.4% of the geographical sample, and 6.8% of the fishery sample. To ensure that this exclusion is not systematically different between the treatment and the control groups, I estimate equation (1.1) with a dummy indicator for zero or negative income as a dependent variable. The treatment effect coefficients are not statistically significant in any specifications.

¹²These percentage changes are calculated based on a median SST anomaly days of 77. $\%change = exp(\beta_{2000} * 77) - 1$.

Table 1.4: Effects of coral bleaching on income - geographic control group

	(1) log(income)	(2) Has zero or negative income
<i>A: Binary treatment</i>		
2000*Fish	-0.3236* (0.1821)	-0.0034 (0.0294)
2007*Fish	-0.0012 (0.2)	0.0165 (0.0322)
F-Test p-value	0.0886	0.3381
<i>B: SST anomaly days</i>		
2000*SSTdays	-0.0046* (0.0027)	0.0005 (0.0003)
2007*SSTdays	0.0001 (0.0029)	0.0006 (0.0004)
F-Test p-value	0.1053	0.4680
N	7,722	9,544
Mean dependent variable	13.776	0.094

Remarks: Panel A contains selected coefficients from equation (1.1), and panel B contains selected coefficients from equation (1.2). Clustered standard errors are in parenthesis. *, **, *** denote statistical significance at 10%, 5%, and 1%, respectively. F-test $H_0 : \beta_{2000} = \beta_{2007}$. All models include household head's gender, age, and education as control covariates. Wave, province and household fixed effects are included in all specifications. Dependent variables are a dummy indicator for zero or negative household income and log of real household income per worker.

Table 1.5: Effects of coral bleaching on income - fishery control group

	(1) log(income)	(2) Has zero or negative income
<i>A: Binary treatment</i>		
2000*Fish	-0.6213** (0.2562)	0.0068 (0.0414)
2007*Fish	-0.0616 (0.2849)	0.0071 (0.044)
F-Test p-value	0.0187	0.9898
<i>B: SST anomaly days</i>		
2000*SSTdays	-0.0062* (0.0036)	0.0004 (0.0006)
2007*SSTdays	0.0008 (0.0039)	0.0004 (0.0006)
F-Test p-value	0.0310	0.9477
N	736	881
Mean dependent variable	13.684	0.068

Remarks: Panel A contains selected coefficients from equation (1.1), and panel B contains selected coefficients from equation (1.2). Clustered standard errors are in parenthesis. *, **, *** denote statistical significance at 10%, 5%, and 1%, respectively. F-test $H_0 : \beta_{2000} = \beta_{2007}$. All models include household head's gender, age, and education as control covariates. Wave, province and household fixed effects are included in all specifications. Dependent variables are a dummy indicator for zero or negative household income and log of real household income per worker.

1.5.2 Labor market outcomes

The income shock discussed in the previous section resulted from a shock to natural resource. As there are other factors contributing to fishery production and household income, we can investigate several mechanisms through which the households mitigate this income shock. In particular, households could adjust other factors of fishery production, labor supply and migration, as well as other labor-related behaviors such as labor supply to the labor market. The most important take away among many labor-related findings is that labor market responses are higher in the long run. The empirical evidence suggests that these households were still in fishery in 2000. The only labor-related behavior that changed in 2000 is migration. The affected households did not change their labor supply, as measured by working time, in 2000. Coral bleaching might have reduced the marginal fishery product of labor, so households did not find it worthwhile to increase fishery labor input. In addition, these households might not be able to supply labor in other industries due possibly to a lack of skills and labor market frictions. In the long run, however, the affected households were less likely to be in fishery. They also increased their labor supply by increasing their working time and taking additional jobs. These findings could have resulted from labor market frictions, such as high search cost in the short run relative to the long run, or skill acquisition over time.

Table 1.6 illustrates effects of coral bleaching on labor-related outcomes using the geographic control group. The only labor-related behavior with a statistically significant change in 2000 is migration. The effect using a binary treatment variable is estimated to be an increase of 11.2 percentage points in the likelihood of migration. The 2007 effect on migration is not statistically significant. These estimates imply that the affected households are more likely to migrate 2 years after the shock rather than 9 years¹³. One plausible explanation is that earlier migration allows the affected households to reap the benefits of improved fish resource sooner. If the cost of migration is constant over time, then sooner migration has a greater payoff than later migration.

One caveat of the results on migration is that the average treatment effect does not account for the general equilibrium effect. Since the treatment status is defined based on job industry and area of residence prior to the shock, there is no changes in group composition over time. However, this specification does not take into account the effects of the treated

¹³Migration is coded as a flow, so this result implies that households did not migrate back in 2007.

Table 1.6: Effects of coral bleaching on labor market outcomes - geographic control group

	(1)	(2)	(3)	(4)	(5)
	Migration	Work hours	Work weeks	Second jobs	Fishermen
<i>A: Binary treatment</i>					
I(2000)*Fish	0.1121** (0.0445)	1.1372 (3.1596)	3.8924 (3.5959)	-0.1205 (0.0837)	-0.0807 (0.1311)
I(2007)*Fish	-0.0584 (0.0703)	5.7516* (3.0533)	13.7718*** (3.8307)	0.1865** (0.0748)	-0.3874*** (0.1301)
F-Test p-value	0.0442	0.1320	0.0156	0.0003	0.0244
<i>B: SST anomaly days</i>					
I(2000)*SSTdays	0.0007*** (0.0002)	-0.0141 (0.047)	0.0317 (0.0585)	-0.0023* (0.0013)	-0.0018 (0.0019)
I(2007)*SSTdays	0.0005 (0.0009)	0.0786* (0.0463)	0.2317*** (0.0586)	0.0028** (0.0012)	-0.0056*** (0.002)
F-Test p-value	0.8007	0.0357	0.0017	0.0002	0.1064
N	7,407	9,530	9,558	9,572	9,135
Mean dependent variable	0.213	31.340	35.502	0.343	0.039

Remarks: Panel A contains selected coefficients from equation (1.1), and panel B contains selected coefficients from equation (1.2). Clustered standard errors are in parenthesis. *, **, *** denote statistical significance at 10%, 5%, and 1%, respectively. F-test $H_0 : \beta_{2000} = \beta_{2007}$. All models include household head's gender, age, and education as control covariates. Wave, province and household fixed effects are included in all specifications. Work hours is per week and per worker. Work weeks is per year and per worker. Second job is equal to one if at least one worker in a household has a secondary job. Fishermen is the number of household workers in fishery.

group's decision to migrate on the control groups' decisions. For example, the treated group's migration to a new area might lead to an increase in competition in that area. This can cause the locals, who potentially are in the control group, to migrate. The spillover test where fishery and non-fishery households in control area are compared indicates that this hypothesis is not true. The coefficient on $I(2000) * Fish$ is not statistically significant with the p-value around 0.34¹⁴.

Almost a decade after the shock, the affected households were able to find more adaptation channels. There is statistical evidence for an increase in labor supply and industry switching in 2007 but not in 2000. In particular, coefficients on working hours per week and working weeks per year are positive and statistically significant only in 2007, and the magnitudes of these effects are quite large. Under the binary treatment and the geographic control group specification, the estimated relative increase in working hours is 5.7 hours per week, and the relative increase in working weeks is 13.8 weeks per year. In addition to working time, I also find that the affected households were less likely to have second jobs in 2000 but were more likely to do so relative to the control groups in 2007. Finally, compared to other households in the same area, the affected fishery households are less likely to be in fishery in the long run.

Similar results can also be obtained under the fishery control group specification, albeit some weaker results and a flipped effect on migration between the short run and the long run under the SST days specification. These results are presented in Table A.2.1 in appendix A.2.

Taken together, these findings have a couple of implications. Firstly, it reflects that a fall in fish stock resource cannot be easily substituted with an increase in labor input in the short run. One possible reason why the affected households did not increase their labor supply in 2000 is that the fish stock resource back then was so poor. An increase in labor could have not improved the marginal product at that level of fish resource. However, migration might have helped improve the fish resource that the affected households have access to.

Secondly, the marine resource in Indonesia might have recovered after coral bleaching, but the recovery process happened rather slowly. The presence of income shock in 2000 and the finding that no other labor activities changed during that time imply that the resource condition two years after coral bleaching was still poor. The increase in labor supply and the presence of secondary jobs in 2007 could be as a result of marine resource recovery. However, the result on the declined likelihood to stay in fishery in the long run somewhat weakens this

¹⁴Full spillover results are available upon request.

hypothesis.

Another reasonable explanation is that the treated households might not be able to work outside of fishery in the short run due to a lack of skills or labor market frictions. As a result, so they could not increase their labor supply or take additional jobs in 2000. This effect was alleviated over time as people acquired new skills and market frictions decline over time. This results in a rise in labor supply, an increase in presence of secondary jobs, and a higher likelihood to leave fishery in 2007.

In short, households that faced the resource/income shock from coral bleaching tend to mitigate the impact of the shock by migration in the short run. However, the affected households still experienced a drop in income in 2000. There is no statistically significant evidence for an increase in labor supply or industry switching in the short run. Nonetheless, labor market responses were larger in the long run. These households were able to increase labor supply both through increasing their working time and taking secondary jobs. Moreover, they were less likely to be in fishery in the long run relative to other households. These findings suggest that the fish stock resource recovery was incomplete by 2007 and that households' skill acquisition took time. As a result, policies that help households transition into other industries would be useful.

Robustness Checks

This section examines the robustness of the empirical results using the triple difference specification, the instrumental variable approach, and the placebo treatment test. Firstly, the triple difference specification controls for a broader range of confounding factors than the double difference model. Specifically, the treatment effects are identified even when there are both time-varying unobservables that affect all fishery households and those that affect every household in the coral bleaching areas. In contrast, the double difference specification allows for only one kind of unobservables at a time. For instance, under the double difference when the regression sample is those in the coral bleaching area, the treatment effect will not be identified if there is a country-wide change in fishing regulations. The new regulations are likely to affect only the treated group but not the control group. Identification should then be based on the fishery control group. If there also exists location-specific shock that makes the treated fishery households' outcome trend different from that of the control fishery households, then the fishery control group will not be valid either. In this case, the treatment effect can still be identified using the triple difference approach provided that the location-

specific unobservable similarly affects all households in the area.

I utilize the triple difference estimator based on (1.3) and show that the results are broadly consistent with the main specifications. Table 1.7 shows the results from the triple difference model on income. The estimates still exhibit similar patterns as those in the main results. However, some coefficients cannot be precisely estimated due to the small treatment group size. In particular, the treated households are not statistically different from other households in terms of the ability to earn positive income. Even though triple difference estimate for 2000 in the income model is not statistically significant under traditional significant levels, it is negative and large in absolute value compared to the 2007 estimate. Specifically, the 2000 coefficient is estimated to be -0.2803 with a p-value of .252 and a 95% confidence interval that is mostly in the negative range, (-0.76, 0.2). The 2007 coefficient is estimated to be -0.0315 with a p-value of 0.903, in line with the adaptations suggested by the difference-in-difference specifications.

Table 1.7: Effects of coral bleaching on income - triple differences

	(1) log(income)	(2) Has zero or negative income
2000*Fish*Bleach	-0.2803 (0.2448)	-0.0393 (0.0412)
2007*Fish*Bleach	-0.0315 (0.2581)	-0.0265 (0.0438)
F-Test p-value	0.1802	0.5278
N	25,148	31,244
Mean dependent variable	13.875	0.100

Remarks: Estimates based on (1.3). Clustered standard errors are in parenthesis. *, **, *** denote statistical significance at 10%, 5%, and 1%, respectively. F-test $H_0 : \beta_{2000} = \beta_{2007}$. All models include household head's gender, age, and education as control covariates. Wave, province and household fixed effects are included in all specifications. Dependent variables are a dummy indicator for zero or negative household income and log of real household income per worker.

Results on labor market outcomes based on the triple difference model also show similar findings as the main results, despite some weaker estimates. The 2000 coefficient on migration is highly significant and large, and so does the 2007 coefficient on work weeks. The results on secondary jobs and industry switching are also similar to the main results.

The second robustness check is to use the instrumental variable approach to estimate

Table 1.8: Effects of coral bleaching on labor market outcomes - triple differences

	(1)	(2)	(3)	(4)	(5)
	Migration	Work hours	Work weeks	Second job	Fishermen
I(2000)*Fish*Bleach	0.247*** (0.0703)	0.3739 (3.7405)	2.1668 (4.0822)	-0.1694* (0.0948)	0.0139 (0.1531)
I(2007)*Fish*Bleach	0.0877 (0.0868)	5.9099 (3.6851)	13.956*** (4.3599)	0.1786** (0.0883)	-0.2857* (0.152)
F-Test p-value	0.0510	0.0671	0.0037	0.0000	0.0253
N	24,407	31,198	31,301	31,348	30,023
Mean dependent variable	0.220	30.713	33.458	0.296	0.036

Remarks: Estimates based on (1.3). Clustered standard errors are in parenthesis. *, **, *** denote statistically significance at 10%, 5%, and 1%, respectively. F-test $H_0 : \beta_{2000} = \beta_{2007}$. All models include household head's gender, age, and education as control covariates. Wave, province and household fixed effects are included in all specifications. Work hours is per week and per worker. Work weeks is per year and per worker. Second job is equal to one if at least one worker in a household has a secondary job. Fishermen is the number of household workers in fishery.

the treatment effects. When there are two possible treatment variables, it is possible to instrument one treatment variable with the other. In our case, I instrument the binary treatment variable with SST anomaly days because the SST anomaly days is used for coral bleaching prediction. Table 1.9 exhibits the IV results and shows that the key findings also hold under this specification. In fact, most of the treatment coefficients are larger in magnitude in the IV models compared to the similar coefficients under the OLS binary treatment models.

The third robustness check is whether there are placebo treatment effects. In particular, among households that lived outside of coral bleaching areas, fishery and non-fishery households should not exhibit differences in outcomes post-treatment. Table 1.10 illustrates results from the models where the sample is all households that lived in control areas. These results indicate that fishery and non-fishery households were similar in terms of labor market outcomes and consumption in absence of coral bleaching. This reassures that the treatment effects presented earlier were not driven by unobservables inherent in the fishery sector¹⁵.

¹⁵There is an evidence for labor market and consumption spillovers to non-fishery households in coral bleaching areas based on the specification that compares non-fishery households in coral bleaching areas to non-fishery households in the control area. Details are still under investigation. Full results are available upon request.

Table 1.9: Robustness check - IV estimation

	Income		Labor Activities			
	(1) Income	(2) Migration	(3) Work hours	(4) Work weeks	(5) Second job	(6) Fishermen
2000*Bleach	-0.6791** (0.2834)	0.0987 (0.0777)	-4.4111 (5.2444)	-2.0651 (5.3629)	-0.2507** (0.1255)	-0.1478 (0.1964)
2007*Bleach	0.057 (0.3053)	0.3971*** (0.1073)	8.645* (4.8111)	21.9853*** (5.8903)	0.2623** (0.1202)	-0.1531 (0.1937)
F-Test p-value	0.0150	0.0071	0.0172	0.0002	0.0003	0.9807
N	692	628	848	848	849	792
Mean dependent variable	13.673	0.164	29.703	33.042	0.320	0.819

Remarks: Clustered standard errors are in parenthesis. *, **, *** denote statistical significance at 10%, 5%, and 1%, respectively. F-test $H_0 : \beta_{2000} = \beta_{2007}$. Sample is all fishery households. The binary treatment variables are instrumented with SST anomaly days variables. All models include household head's gender, age, and education as control covariates. Wave, province and household fixed effects are included in all specifications. Income is log of real household income per worker. Work hours is per week and per worker. Work weeks is per year and per worker. Second job is equal to one if at least one worker in a household has a secondary job. Fishermen is the number of household workers in fishery. All consumption measures are log of real consumption per household member.

Table 1.10: Robustness check - placebo treatment on control area

	Income		Labor Activities				
	(1) Zero/neg. income	(2) Income	(3) Migration	(4) Work hours	(5) Work weeks	(6) Second job	(7) Fishermen
I(2000)*Fish	0.0347 (0.0306)	0.1548 (0.1787)	-0.0623 (0.0621)	0.746 (2.5353)	1.1195 (1.9889)	0.0221 (0.051)	-0.0155 (0.0876)
I(2007)*Fish	0.0467 (0.0308)	-0.1912 (0.1883)	-0.2053*** (0.0658)	-0.8809 (2.3877)	-0.8393 (2.6265)	0.0177 (0.0587)	-0.2015** (0.1022)
F-Test p-value	0.5115	0.0219	0.0179	0.5378	0.3927	0.9362	0.0512
N	21,700	17,426	17,000	21,668	21,743	21,776	20,888
Mean dep. variable	0.103	13.918	0.223	30.437	32.559	0.275	0.034

Remarks: Estimates based on (1.1). Clustered standard errors are in parenthesis. *, **, *** denote statistical significance at 10%, 5%, and 1%, respectively. F-test $H_0 : \beta_{2000} = \beta_{2007}$. Sample is all households in areas without coral bleaching. Wave, province and household fixed effects are included in all specifications. Dependent variable in Column (1) is whether a household has zero or negative income. Income is log of real household income per worker. Work hours is per week and per worker. Work weeks is per year and per worker. Second job is equal to one if at least one worker in a household has a secondary job. Fishermen is the number of household workers in fishery. All consumption measures are log of real consumption per household member.

1.6 Conclusion

In this chapter I study relationships between a long-lasting income shock and several adaptation mechanisms. The source of an exogenous income shock is coral bleaching, which occurs as a result of abnormally high sea surface temperature. Using the IFLS, I empirically show that fishery households that were affected by coral bleaching had lower income compared to other households two years after coral bleaching. The income shock was mitigated over time as these households adapted. The adaptation mechanisms considered in this chapter include labor activities.

As the world climate changes, long-lasting income shocks are more likely to occur. The results from this paper have interesting policy implications from both development and environmental perspectives. From the development perspective, the findings in this paper provide insights into ways to alleviate impacts of unexpected, long-lasting income shocks. From the environmental perspective, this paper sheds some lights on how climate change affects people, especially those in the vulnerable coastal communities.

I find that the affected households responded to the income shock by migration in the short run. This result suggests that policies that help facilitate migration might be useful. For example, in the case of fishery households who faced a decline in fish stock, a policy that directs them to an area with a healthy fish stock might be useful. Nonetheless, there could be several problems with migration. For example, the locals might reject migrants who try to come in and share the resource, and the migrants have a high cost of adapting to a new area. In a broader perspective, migration may not be feasible for every household in every situation. For instance, agricultural households who own or rely on land face a high cost of migration and may be better off not migrating. Additionally, if a shock is widespread, the cost of migration will be high as households will be required to migrate a long distance. Subsidizing migration in these situations can make migration feasible for the households, but the cost of the subsidy could be very high.

The results also indicate that the affected households increased labor supply, took second jobs, and switched to another industry in the long run but not in the short run. Consequently, skill acquisition policy might help mitigate the income shock. If these households had acquired new skills, they might have been able to work in other industries sooner, and the income shock could have been less severe in the short run. In addition, labor market frictions might have prevented the affected households from supplying labor to other industries in the short run. In this case, policies that reduce the frictions, such as those that reduce

search costs and facilitate information flow, can be useful.

Chapter 2

CHANGES IN CONSUMPTION AMONG FISHERY HOUSEHOLDS

Abstract

This paper explores how people adjusted their consumption after coral bleaching. Using a household panel survey and scientific data on coral bleaching, I find evidence for declines in most consumption measures in the short run among fishery households that were exposed to coral bleaching. Protein consumption dropped the most, and grain consumption almost did not change. These results, combined with an evidence for a decline in fruits and vegetables consumption, imply that the affected households might have received less nutrition. Further analysis on home-grown consumption suggests that this fall in consumption is due mostly to the decreases in income, but the fall in protein availability cannot be ruled out.

2.1 Introduction

Even though the literature on the economic impacts of climate change is well-established, little is known about the potential impacts of climate change on food security, especially on the nutrition aspect. Most of the current economic literature on climate change focuses on the impacts on yields and income from staple crops. However, climate change could also affect human's nutrition intakes through either changes in income or direct impacts of climate change on productions of important nutrition sources.

The goal of this chapter is to fill in this literature gap by examining impacts of a climate shock, coral bleaching, on various consumption categories. Coral bleaching is found to cause a large income shock among Indonesian fishery households that were exposed to the massive bleaching event in 1998. This substantial decrease in income could have led to a fall in consumption in absence of sufficient savings or risk sharing mechanisms.

Additionally, coral bleaching is also associated with a fall in fish stock in the medium to the long run. As a result, areas with coral bleaching might have experienced a shock to fish supply. This supply shock can have a devastating effect on protein intakes because fish is

the main protein source for many developing countries, including Indonesia.

The empirical study in this chapter mimics that in the first chapter. The setting is the fishery sector in Indonesia, the fourth largest country in terms of population and the country with the second longest coastline in the world. The main sources of data include the household panel survey from the Indonesian Family Life Survey, and the data on coral bleaching from [Goreau et al. \[2000\]](#) and remote sensing maps. Identification in this chapter also relies on the premises that coral bleaching is exogenous to household behaviors and that its effects are long-term. Consequently, the income shock from coral bleaching is unexpected, and it allows us to study effects of long-term unexpected income shocks on consumption, in addition to the effects of climate change.

The empirical results suggest a large fall in consumption two years after coral bleaching. I find evidence for decreases in various consumption measures with an exception of food staple consumption. This decline in consumption was due to both the income shock and the fall in fish availability. As a result, protein consumption was one of the consumption measures with the largest drops. This, combined with results on declined fruit and vegetable consumption, suggests that the affected households might have received less nutrition relative to the control groups at least in the short run.

These findings are consistent with the literature on income elasticity of food consumption. For example, [Subramanian and Deaton \[1996\]](#) estimate the elasticity of calorie consumption with respect to total expenditure in India to be around 0.3–0.5, suggesting that calorie intake is a normal good. In the context of Indonesia, [Skoufias et al. \[2012\]](#) estimate the similar elasticity to range from 0.12–0.25. In addition, they find that the income elasticity of starchy staple to total calorie ratio ranges from -0.21– -0.31 implying that households consume less starchy staples as their income increases.

In addition to the literature on income elasticity of food consumption, this chapter is also related to the literature on consumption smoothing and consumption response to income changes, a large and well-established research area. For example, [Morduch \[1995\]](#) and [Jappelli and Pistaferri \[2010\]](#) provide traditional and current surveys of this literature. A large number of works postulate imperfect consumption smoothing, especially in the cases with liquidity constraints and/or unexpected shocks. This paper provides another evidence for a large decline in consumption following an unexpected income shock.¹

¹Note that the main goal of this chapter is not to test the permanent income hypothesis, so the methods used here are not the traditional rigorous ones such as in [Paxson \[1993\]](#).

Most importantly, the findings in this chapter help filling in the large literature gap in the climate change literature. Most of the current literature is contributed to the production of main staple crops such as corn and soybean in the U.S. The literature on developing countries is quite sparse, but the impacts of climate change can be larger in these countries due to the severity of the changes as well as the inadequate social safety nets and risk sharing mechanisms. This chapter offers a unique opportunity to investigate the consumption side of the picture and to understand how households in developing countries adapt to climate change.

A couple of policy implications arise from results in this chapter. First, the results suggest that a climate shock that happens within the ocean can adversely affect protein consumption through the fall in protein availability. Thus, policies should target not only at smoothing total consumption but also at maintaining adequate nutrition intake. This implication is also applicable to other recent and future climate shocks within the ocean, for example, ocean acidification and changes in phytoplankton concentration. Second, the results shed some lights on how policies can help households smooth their consumption after long-term unexpected income shocks. In particular, cash transfer might be an effective policy device to increase consumption of normal/luxury goods such as protein and other nutrition-rich food.

The rest of the chapter proceeds as follows. Section 2 provides further insights into how coral bleaching affects fish stock and income in the Indonesian fishery sector. Section 3 describes the empirical framework, including data and methodology. Section 4 presents empirical results, and section 5 discusses policy implications and concludes.

2.2 Background on Effects of Coral Bleaching in Indonesia

The previous chapter outlines the effects of coral bleaching on income and labor-related outcomes among the Indonesian fishery households. The decrease in income is estimated to be at least 27% in 2000, two years after coral bleaching in 1998. However, there was no detectable change in income in 2007. This fall in income can be interpreted as an unexpected long-term income shock because 1. coral bleaching is exogenous to household behaviors, and 2. marine resources take at least 5-10 years to recover [e.g. [Graham et al., 2007](#), [Wilkinson and Hodgson, 1999](#)]. The literature on consumption smoothing postulates that consumption smoothing is less likely when the income shock is unexpected than when the shock is expected [[Jappelli and Pistaferri, 2010](#)]. Thus, households that were exposed a large income shock due to coral bleaching might have to cut down their consumption, particularly in the cases

where liquidity constraint is binding.

Coral bleaching is exogenous to household behaviors because it is mainly caused by abnormally high sea surface temperature (SST). This study is based on the massive coral bleaching event that followed the severe El Niño in 1998, a completely natural process. In addition, this income shock is unlikely to be expected because even scientists could predict this bleaching event just a few weeks in advance [Hoegh-Guldberg, 1999].

In addition to the changes in income, the fall in fish availability after coral bleaching might have affected household consumption. Since corals are at the bottom of the food chain in the ocean ecosystem and coral reefs are a habitat for many species, deteriorating coral reefs can adversely impact fish stock [Pratchett et al., 2008]. For instance, coral reef degradation leads to a decrease in abundance of coral reef species within three years after coral bleaching [van Oppen and Lough, 2008]. Fishing of coral reef species is usually for exports as live fish as well as for local consumption [Kruger, 2014, ?], so the decline in the abundance of reef species can affect both income and consumption. In addition to the effects on reef species, coral bleaching can adversely impact non-reef species through ecological relationships, such as the impacts on species that rely on coral reefs for reproduction. This kind of effects takes time to manifest. For this reason, in the long run, fish composition changes, and overall abundance and diversity decline [van Oppen and Lough, 2008]. Therefore, the long-run effects of coral bleaching on fishery are not limited to only reef fishery in the long run.

For the bleaching event in 1998, coral mortality rate was estimated to be around 50% in Bali [Goreau et al., 2000], the area where most of the fishery households in the IFLS lived. To the best of my knowledge, there was no official study of changes in fish stock due to the 1998 coral bleaching in Indonesia due to sparse data. Studies in other countries indicate slow recoveries of fish stock from this bleaching event (5-10 years) as well as failures to recover in some locations [e.g. Graham et al., 2007, 2015, Garpe et al., 2006, Booth and Beretta, 2002]. Consequently, if coral bleaching affects consumption through the fall in fish availability, this consumption shock is likely to be intermediate to long term.

2.3 Empirical Framework

2.3.1 Data

The empirical framework in this chapter is similar to that in the first chapter. The sources of data include household panel survey from the IFLS, reported coral bleaching spots from

Goreau et al. [2000], and SST anomaly from satellite maps.

The IFLS is a panel dataset that consists of household and community surveys. The surveys started in 1993 with 7,224 households, and the 312 communities where these households lived. These households and communities were resurveyed in 1997, 2000, and 2007. The household survey contains information on demographics, labor market history, consumption, among others. The community survey comprises of information on schools, health facilities, prices of common commodities, and so on.

The consumption section in the IFLS was interviewed at a household level. The questions ask how much each household spent on different types of consumption. The questionnaire also distinguishes between consumption of goods that were produced within the households and those that were bought. The price data are collected at the community level and contain prices of key commodities such as beef and rice. However, the price of fresh fish is not available.

Similar to the first chapter, there are two measures of coral bleaching in this chapter. First, reported coral bleaching spots from Goreau et al. [2000] define a binary exposure to coral bleaching. This study gathered information from long-term observers, so the chance of misreporting is relatively small. Nonetheless, there could be unreported spots as some areas might not be covered by these observers. For this reason, I also use SST anomaly days as a second measure of coral bleaching² and show that both measure yield similar results. The SST anomaly days is constructed from remote sensing maps, so it does not suffer from under reporting. These SST anomaly maps were reported by the Nation Oceanic and Atmospheric Administration (NOAA) every 1-7 days during the first half of 1998.

2.3.2 Identification and Methodology

The identification strategies in this chapter follow those in the first chapter very closely. The estimating equation is based on the difference-in-difference framework with time-varying treatment effects. Identification also relies on the premises that coral bleaching is exogenous, so the effects on consumption can be interpreted as the effects of an income shock as well as a climate shock. The previous section discussed the reasons why coral bleaching is likely to be exogenous.

²This measure follows from a popular mass coral bleaching model by Hoegh-Guldberg [1999]. The model postulates that the temperature threshold for coral bleaching is 1 degree Celsius above the normal summer average, and coral bleaching is likely to occur when a coral reef is exposed to this temperature anomaly for at least 3-4 weeks.

The treatment group based on reported coral bleaching spots is defined as households that engaged in fishery and lived in areas with coral bleaching according to the 1997 wave of data. Following this treatment status definition, there are two possible control groups: fishery households that did not live in coral bleaching areas, and non-fishery households that lived in coral bleaching areas. The massive coral bleaching event occurred in 1998, so the pretreatment period include 1993 and 1997. The 2000 wave represents the short-run post-treatment period, and the 2007 wave is considered the long-run. Tables 1.1–1.2 contain the number of households in each group, and table 1.3 exhibits summary statistics for each group based on the data in the 1997 wave.

Let Y_{ht} be the dependent variable of interest. Similar to the main specification in the first chapter, the main estimating equation is given by

$$Y_{ht} = \alpha + \delta_1 Treat_h + \delta_2 Post_t + \sum_{\tau=2000,2007} \beta_\tau I(wave = \tau) * Treat_h + X'_{ht}\gamma + \mu_h + \lambda_t + \epsilon_{ht}, \quad (2.1)$$

where the subscript h is for household, and t is for time. The dummy variable $Treat_h$ is equal to 1 for households that engaged in fishery and lived in coral bleaching areas. $I(wave = \tau)$ is an indicator function for each of the post-treatment waves. The vector of control covariates, X_{ht} , comprises of household head's demographic characteristics, and a set of dummy variables for provinces of residences in 1997. This model also contains household fixed effects, μ_h , and wave fixed effects, λ_t . Hence, any factors that are constant within a province or a wave are controlled for, and identification is based on within-household variations. Also, note that δ_1 and δ_2 are not identified as the model contains wave and province fixed effects.

The estimating equation using SST anomaly days as a treatment take the similar form:

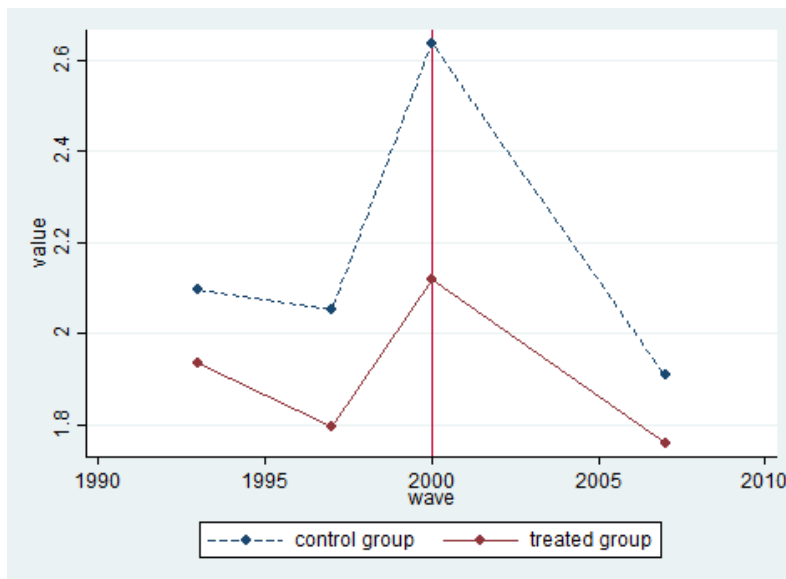
$$Y_{ht} = \alpha + \delta_1 SSTdays_h + \delta_2 Post_t + \sum_{\tau=2000,2007} \beta_\tau I(wave = \tau) * SSTdays_h + X'_{ht}\gamma + \mu_h + \lambda_t + \epsilon_{ht}, \quad (2.2)$$

where $SSTdays_h$ is household h 's exposure to coral bleaching as measure by the number of SST anomaly days. $SSTdays_h$ is equal to zero for all non-fishery households and is equal to the actual anomaly days in the household's coastal area for all fishery households.

The technical concerns on identification include the violation of the parallel trend assumption and measurement errors. Even though table 1.3 indicates some differences in

consumption between the treatment and the control groups, these differences are not a concern if the pre-treatment trends are similar between the treatment and the control groups. Figures 2.1 - 2.2 help validating this assumption by plotting log of protein consumption expenditure for each group over time.

Figure 2.1: log(protein consumption expenditure per household member) of fishery households and other households in bleaching area



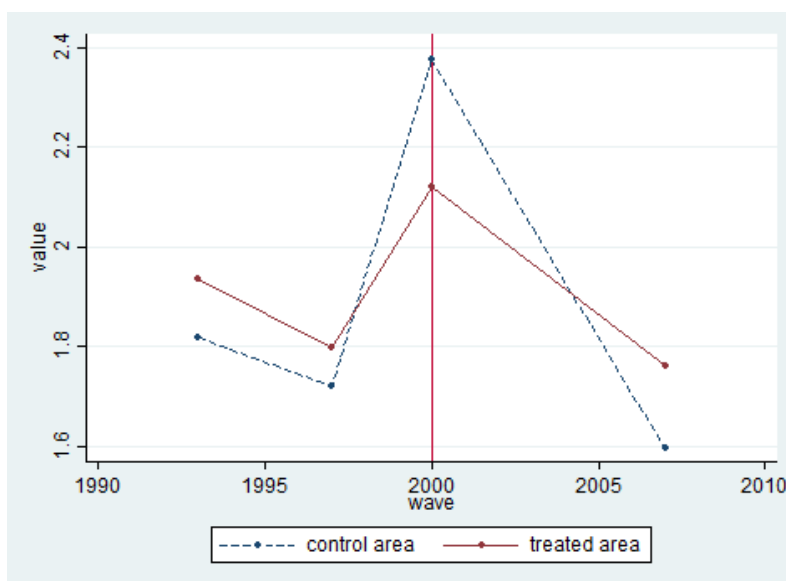
As mentioned in the first chapter, treatment effects in this setting can also be estimated using the triple differences framework which allows for a wider range of possible confounders.³ The results from the triple differences models are similar to those from the main specifications and are included as one of the robustness checks.

The second technical concern involves measurement errors in coral bleaching measures. First, reported coral bleaching spots might suffer from underreporting. Second, SST anomaly days is not perfectly correlated with the actual bleaching spots as there are other factors that affect the bleaching process. In the case of classic measurement error⁴, the treatment coefficients tend to be biased toward zero. However, I employ both measures of coral bleaching and show that they yield similar, statistically significant results. I also adopt the IV approach, where I instrument the binary treatment status with SST anomaly days, and

³See chapter 1 for detailed discussion of triple differences.

⁴See chapter 1 for the full discussion of measurement errors in this case.

Figure 2.2: $\log(\text{protein consumption expenditure per household member})$ of fishery households in and outside of bleaching areas



include the results as a robustness check.

2.4 Empirical Results

Given the income shock in 1998, I find evidence for a fall in consumption in various consumption measures in 2000. In particular, most of the treated households' consumption changed in tandem with their income. The households cut down on most consumption and probably received less nutrition in 2000 but not in 2007. Among all consumption measures, protein consumption fell the most in 2000, and some evidence suggests that it did not fully recover by 2007. On the other hand, food staple consumption almost did not change either in 2000 or 2007 relative to the pre-bleaching level. Plausible explanations for these results include changes in food availability, changes in income, changes in career, households viewing nutrient-rich food as a luxury good, as well as imperfect risk sharing and safety net mechanisms. My results indicate that most of the effects on consumption were driven by the income effect, but the decline in protein availability cannot be ruled out as well. To investigate these channels, I distinguish between consumption that is produced within the household and that is purchased from markets. These two types of consumption might not be perfect substitutes if the markets are imperfect. For instance, households may not be able to supply what they

produce at the market price due to transaction costs, or the transportation costs might deter the reallocation of supply from one area to the other.

Table 2.1: Effects of coral bleaching on consumption - geographic control group

	(1)	(2)	(3)	(4)	(5)	(6)
	Non-food	Total Food	All protein	Fish	Fruit/Veg	Grain
<i>A: Binary treatment</i>						
I(2000)*Fish	-0.1407 (0.1588)	-0.165 (0.1361)	-0.4113*** (0.129)	-0.1634 (0.1344)	-0.201* (0.1181)	-0.1312 (0.1365)
I(2007)*Fish	0.225 (0.1486)	0.0123 (0.1186)	-0.1422 (0.105)	-0.254** (0.1106)	0.1909* (0.1091)	0.0824 (0.1179)
F-Test p-value	0.049	0.277	0.035	0.488	0.003	0.079
<i>B: SST anomaly days</i>						
I(2000)*SST	-0.0042* (0.0022)	-0.0047** (0.0019)	-0.0067*** (0.002)	-0.0041** (0.0021)	-0.0039** (0.0018)	-0.0036* (0.002)
I(2007)*SST	0.0029 (0.0019)	0.0006 (0.0015)	-0.0024 (0.0015)	-0.0035** (0.0015)	0.0004 (0.0014)	0.0003 (0.0016)
F-Test p-value	0.0002	0.003	0.018	0.753	0.016	0.019
N	9464	9544	9544	9544	9544	9544
Mean dependent variable	3.271	2.82	2.168	1.522	1.979	2.088

Remarks: Panel A contains selected coefficients from equation (2.1), and panel B contains selected coefficients from equation (1.2). Clustered standard errors are in parenthesis. *, **, *** denote statistical significance at 10%, 5%, and 1%, respectively. F-test $H_0 : \beta_{2000} = \beta_{2007}$. All models include household head's gender, age, and education as control covariates. Wave, province and household fixed effects are included in all specifications. All consumption measures are log of real consumption expenditures per household member.

The regression results in Tables 2.1-2.2 generally indicate that changes in overall consumption mimic the income trend. Consumption measures explored here include non-food consumption expenditure during the past 12 months, and detailed food consumption expenditures during the past week. The non-food consumption measure consists of long-run consumption on clothing, household supplies, medical costs, and others. Most consumption measures in 2000 fell relative to the pre-bleaching level, but the changes in consumption in 2007 are mostly not statistically significant.

Among all consumption measures, the effect on protein consumption was the largest and the most prolonged. The treatment coefficients for log protein consumption expenditure in 2000 are negative, large in magnitude, and statistically significant across all model specifications. The drop in total protein consumption in 2007 was weaker than the effect in 2000. The 2007 coefficients for protein are all negative but smaller in magnitude than the 2000 coefficients. In addition, some of these estimates are not statistically significant. For example,

Table 2.2: Effects of coral bleaching on consumption - fishery control group

	(1) Non-food	(2) Total Food	(3) All protein	(4) Fish	(5) Fruit/Veg	(6) Grain
<i>A: Binary treatment</i>						
I(2000)*Bleach	-0.3704 (0.247)	-0.3416 (0.2076)	-0.5514*** (0.1912)	-0.4088** (0.1954)	-0.2725 (0.1721)	-0.1032 (0.1884)
I(2007)*Bleach	0.2868 (0.2237)	0.0114 (0.1547)	-0.2882* (0.157)	-0.2641 (0.1762)	0.1356 (0.1386)	0.0635 (0.1513)
F-Test p-value	0.004	0.076	0.137	0.441	0.013	0.331
<i>B: SST anomaly days</i>						
I(2000)*SST	-0.0059* (0.0032)	-0.0061** (0.0028)	-0.0067** (0.0027)	-0.0061** (0.0027)	-0.0041* (0.0024)	-0.0031 (0.0024)
I(2007)*SST	0.0028 (0.0028)	0.001 (0.0019)	-0.0029 (0.002)	-0.0026 (0.0022)	-0.0007 (0.0017)	0.0001 (0.0018)
F-Test p-value	0.0010	0.004	0.109	0.138	0.127	0.13
N	875	881	881	881	881	881
Mean dependent variable	2.705	2.396	1.874	1.617	1.653	1.875

Remarks: Panel A contains selected coefficients from equation (2.1), and panel B contains selected coefficients from equation (1.2). Clustered standard errors are in parenthesis. *, **, *** denote statistical significance at 10%, 5%, and 1%, respectively. F-test $H_0 : \beta_{2000} = \beta_{2007}$. All models include household head's gender, age, and education as control covariates. Wave, province and household fixed effects are included in all specifications. All consumption measures are log of real consumption expenditures per household member.

under the fishery control group specification, the coefficients for log total protein consumption expenditure model are -0.5514 and -0.2882 for 2000 and 2007, respectively. This implies that the affected households' total protein consumption expenditure dropped by 42.4% in 2000 and 25% in 2007 relative to other fishery households'. Under the geographic control group, the binary treatment coefficient in 2000 is -0.4113, but the 2007 coefficient is not statistically significant. Detailed results on food consumption in Table 2.3 and Table A.2.2 in appendix A.2 further reveal that this significant fall in protein consumption was largely driven by a substantial decline in consumption of eggs, dairy, and plant proteins.

In addition to a fall in protein consumption, the regression results also suggest that there was a drop in total food, non-food, and fruit and vegetable consumption expenditures in 2000 but not in 2007, suggesting the possibility of long-run health effects. Grain consumption is the only consumption measure that almost did not change with income. Most treatment coefficients for grain consumption expenditures are not statistically significant. These results suggest a substitution of grains for nutrient-rich food, and they imply that the affected households' nutrition intake might have fallen at least in 2000. This pattern is particularly

troublesome when the affected households were in fishery, and their protein source was closely tied with their income source. These households are constrained by both a decline in income and a fall in fish stock whereas the control households faced only a possible reduction in fish availability.

Since all of consumption measures here are log of consumption expenditures, the fall in consumption could result from a decrease in price and/or a decrease in quantity. The geographical control group specification controls for the price effect as people in the same geographical area should have faced similar prices. Therefore, the estimates from these specifications can be interpreted as the quantity effect. Additionally, since coral bleaching was associated with a fish supply shock, price of protein should have had increased in coral bleaching area. This implies that the estimates on protein consumption expenditure under the fishery control group specifications would be the lower bound for the quantity effect.

The significant fall in protein consumption can be due to a couple of factors. First, protein from fish became less available after coral bleaching as fish stock declined. Second, protein and micronutrients are normal/luxury goods for households. Empirical evidence suggests that both could be true. The former is true at least for a fall of fish stock available for fishing, and to a lesser extent, a fall in fish available in markets. Relative sizes of the estimates of income shock and fall in protein consumption imply about the latter. I can also further explore these factors as the IFLS distinguishes between consumption that is produced within the household and that is purchased from outside. Changes in fish consumption from household production among the treated group and changes of overall fish consumption in the treated area reflect availability of fish after coral bleaching. The treated group's purchases of other protein and nutrient-rich food given the income shock allow for a direct test of whether these nutrients are a luxury good.

Columns 4 in Tables [2.1-2.2](#) suggest that the treated group's fish consumption fell relative to both control groups'. This consumption measure contains consumption that came from both household production and purchases, so this measure might not fully reflect the availability of fish after coral bleaching in the affected area. Markets could have been efficient enough to clear a supply shock that was limited to only some areas by reallocation of supply. We can investigate the availability of fish protein by examining the treated group's consumption of their own catch. Columns 3 in the bottom panels of Tables [2.3](#) and [A.2.2](#) illustrate the effects of coral bleaching on own catch consumption. The results indicate that the own catch consumption fell in 2000 and 2007, albeit statistically insignificant estimates

Table 2.3: Effects of coral bleaching on consumption purchases and consumption of household production - fishery control

	Purchases						
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
	Total food	All protein	Fish	Meat	Other protein	Fruit/veg	Grain
<i>A: Binary treatment</i>							
2000*Bleach	-0.2995 (0.2029)	-0.5509*** (0.2068)	-0.133 (0.2512)	0.0775 (0.1878)	-0.7439*** (0.2078)	-0.3629** (0.1803)	-0.0796 (0.2401)
2007*Bleach	0.1372 (0.1623)	-0.1137 (0.155)	0.2543 (0.1948)	0.1375 (0.1645)	-0.1528 (0.1656)	0.1625 (0.1517)	0.1493 (0.1854)
F-Test p-value	0.019	0.017	0.103	0.775	0.001	0.006	0.323
<i>B: SST anomaly days</i>							
2000*SST	-0.0054** (0.0027)	-0.0065** (0.0028)	-0.0004 (0.0035)	0.0017 (0.0027)	-0.0064** (0.003)	-0.0053** (0.0025)	-0.0037 (0.0031)
2007*SST	0.002 (0.0019)	-0.0021 (0.0021)	0.001 (0.0025)	0.0014 (0.0022)	-0.0031 (0.0022)	-0.001 (0.0019)	0.0002 (0.0023)
F-Test p-value	0.0020	0.076	0.665	0.933	0.201	0.092	0.187
N	881	881	881	881	881	881	881
Mean dep var	2.315	1.609	0.944	0.484	1.308	1.528	1.672
	Household production						
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
	Total food	All protein	Fish	Meat	Other protein	Fruit/veg	Grain
<i>A: Binary treatment</i>							
I(2000)*Bleach	-0.3307 (0.2189)	-0.418* (0.2342)	-0.3408 (0.2187)	-0.1975* (0.1156)	0.049 (0.1428)	-0.04 (0.1912)	0.2272 (0.18)
I(2007)*Bleach	-0.2981 (0.2097)	-0.3353* (0.2011)	-0.3917* (0.2082)	0.0389 (0.0931)	0.0832 (0.1351)	-0.0859 (0.1627)	-0.0176 (0.1596)
F-Test p-value	0.894	0.705	0.826	0.045	0.836	0.806	0.211
<i>B: SST anomaly days</i>							
I(2000)*SST	-0.0073** (0.0028)	-0.0077** (0.0033)	-0.0072** (0.003)	-0.0016 (0.0015)	0.0017 (0.0019)	0.0013 (0.0027)	0.0032 (0.0025)
I(2007)*SST	-0.0023 (0.0026)	-0.0046* (0.0026)	-0.0031 (0.0026)	-0.0003 (0.0012)	-0.0005 (0.0017)	0.0008 (0.0021)	0.0021 (0.0022)
F-Test p-value	0.0800	0.274	0.16	0.458	0.319	0.851	0.672
N	881	881	881	881	881	881	881
Mean dep var	1.498	1.054	0.892	0.129	0.262	0.5	0.572

Remarks: Panel A contains selected coefficients from equation (2.1), and panel B contains selected coefficients from equation (1.2). Clustered standard errors are in parenthesis. *, **, *** denote statistical significance at 10%, 5%, and 1%, respectively. F-test $H_0 : \beta_{2000} = \beta_{2007}$. All models include household head's gender, age, and education as control covariates. Wave, province and household fixed effects are included in all specifications. Dependent variables are log of purchased consumption expenditures and log of consumption of household production (expenditure-equivalent).

in some model specifications. As the affected households were still in fishery and did not change their labor supply in 2000, these findings imply that fish stock declined and that protein from fish became less available at least in 2000. The drop in consumption of own catch could have resulted from a substitution of household consumption for sales of fish, but this substitution is incomplete as both the total fish consumption and household income fell. The implications from the 2007 results are not as clear since the affected households might have left fishery by 2007. The reduction in own catch consumption in 2007 could have also stemmed from the fact that these households no longer fished.

The next question to ask is whether non-fishery households in coral bleaching area were affected by this fish supply shock. Table 2.4 illustrates the differences in protein and other food consumption among non-fishery households who live in the coral bleaching areas and non-fishery households outside of coral bleaching areas. The results suggest a weak evidence for a spillover of fish supply shock to non-fishery households who lived in the same areas. Non-fishery households' fish consumption did not statistically change in the coral bleaching area relative to the control area. However, two reasons explain why there could have been a fall in fish available to the geographical control group. First, the result in column 4 suggests that there is an increase in meat consumption among non-fishery households in the coral bleaching areas in 2000. These households that did not directly experience fish supply or income shocks might have substituted meat for fish. If these households were to increase their protein consumption, both meat and fish were equally available, and the income elasticities for the two goods are similar, then the households would have increased both meat and fish consumption. Second, consumption here is measured as expenditure, so the fact that expenditure on fish consumption does not change could have stemmed from an increase in price combined with a fall in consumption quantity.

Alternatively, the insignificant spillover effect on fish suggests that markets might have allocated fish to coral bleaching areas, so that coral bleaching did not affect fish available for purchase. However, this hypothesis can only be true under the model of low transportation costs and absence of other impediments to reallocation, such as poor transportation infrastructure. In this case, both areas experienced similar prices and quantities, and market mechanisms help alleviate the spillover effect of coral bleaching on fish availability to the geographical control group.

All the empirical results so far imply that protein is a luxury good⁵. The estimates

⁵An income elasticity of demand for a luxury good is greater than one

Table 2.4: Effects of coral bleaching on consumption - spillover

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
	Total Food	All protein	Fish	Meat	Other protein	Fruit/Veg	Grain
<i>A: Binary treatment</i>							
I(2000)*Bleach	-0.0197 (0.0566)	0.0666 (0.0552)	0.012 (0.0509)	0.1718*** (0.0557)	-0.0608 (0.0568)	0.0354 (0.0481)	0.0483 (0.0558)
I(2007)*Bleach	0.0448 (0.0455)	0.0119 (0.0452)	0.016 (0.042)	0.0309 (0.0494)	-0.076 (0.0478)	0.0402 (0.0403)	0.0024 (0.046)
F-Test p-value	0.15	0.2	0.924	0.005	0.723	0.904	0.313
<i>B: SST anomaly days</i>							
I(2000)*SST	-0.0008 (0.0006)	0.0009 (0.0006)	0.0007 (0.0005)	0.0012** (0.0006)	0.0013** (0.0006)	0.0009 (0.0005)	0.0009 (0.0006)
I(2007)*SST	-0.0001 (0.0004)	-0.0002 (0.0004)	-0.0002 (0.0004)	-0.0018*** (0.0005)	0.0003 (0.0004)	0.0004 (0.0004)	-0.0005 (0.0004)
F-Test p-value	0.265	0.038	0.091	0	0.064	0.325	0.013
N	30363	30363	30363	30363	30363	30363	30363
Mean dependent variable	2.787	2.115	1.492	1.022	1.755	1.944	2.025

Remarks: Panel A contains selected coefficients from equation (2.1), and panel B contains selected coefficients from equation (1.2). Clustered standard errors are in parenthesis. *, **, *** denote statistical significance at 10%, 5%, and 1%, respectively. F-test $H_0 : \beta_{2000} = \beta_{2007}$. All models include household head's gender, age, and education as control covariates. Wave, province and household fixed effects are included in all specifications. Dependent variables are log of total consumption expenditures. Sample is all non-fishery households.

for the percentage decline in protein consumption expenditure in 2000 are larger than the comparable estimates for the income shock. As a result, the back of envelope calculation yields an income elasticity of protein consumption expenditure that is greater than one. For example, under the geographic control group and binary treatment specification, the coefficient on $I(2000) * Fish$ in the log income model is -0.3236 (see Table 1.4), which is equal to a decline in income of 27.65%. The coefficient on $I(2000) * Fish$ in the log protein consumption expenditure model is -0.4113 (see Table 2.1), or a 33.72% fall in protein consumption expenditure. Then, the income elasticity of protein consumption expenditure is equal to 1.22, indicating that protein consumption is a luxury good. Apart from the implication on a large magnitude of a fall in protein consumption after the income shock, this finding also implies that economic development might lead to a significant improvement in nutrition and health outcomes. Moreover, cash transfer might be an effective policy to mitigate the fall in protein consumption.

This elasticity estimate has one caveat—the consumption measure contains both household's own productions and purchases. On one hand, households might view the two con-

sumption types as equivalent as they might be able to sell their production output at the market price. In this case, it is valid to consider the elasticity that is derived from overall consumption expenditure. On the other hand, if households perceive purchased consumption as different from self-produced consumption or if transaction costs prevent the households from supplying their fish at a market price, then protein purchase will give a more direct inference on the luxury good argument. Further evidence suggests that the latter might be true.

Table 2.3 shows the regression results from models that distinguish between purchased and produced consumption expenditures using the fishery control group. These results suggest that households view the two consumption types as different. However, the coefficient on $I(2000) * Fish$ for protein purchase is similar to the coefficient in the total protein consumption expenditure model.

A closer look at the results on purchased and produced consumption also suggests that changes in home-produced consumption are related to jobs and household productions. In particular, the treatment group's consumption of their own catch fell in both 2000 and 2007, but fish purchases did not statistically change. Also, the changes in consumption of other household productions were mostly not statistically significant as shown in the lower panel of Table 2.3. In contrast, changes in purchased consumption imitated the changes in income. Bean/dairy products and fruit/vegetable purchased consumption fell in 2000 as the households experienced the drop in income. In 2007, the changes in purchased protein consumption were not statistically significant. This set of findings is also confirmed by the results from the triple difference specifications (see Table A.2.3 in appendix A.2). The double difference specifications using the geographical control group also yield similar results, but with more significant negative coefficients on consumption of household production. One reason for the stronger results is the geographical control group's increase in consumption of many household-produced goods relative to non-fishery households outside of coral bleaching areas. Detailed results are included in appendix A.2.

The results on consumption also have some other interesting implications. The treated households had to cut back on most consumption goods, including necessities such as food and medical care. One plausible implication from this finding is that risk-sharing and savings were minimal among these households. Another plausible explanation is that there had been some risk-sharing mechanisms. However, the whole economy was impacted by coral bleaching and/or the Asian Crisis, so the usual risk-sharing mechanisms were not feasible. The Asian

Crisis has impacted everyone in the economy, so social safety nets and risk sharing were already utilized in absence of coral bleaching. The interesting research question is then to ask whether the existing social safety nets and risk sharing mechanisms would have been sufficient had coral bleaching occurred at a different time period. These prospects shall be explored in future work.

Robustness checks

In the same spirit as the robustness checks in the first chapter, I perform three robustness checks to ensure the validity of the empirical results in this chapter. First, I estimate the treatment effects using the triple-difference specification. Second, I follow the common practice in dealing with measurement error by instrumenting the binary treatment variable with SST anomaly days. Finally, I impose a placebo treatment in the control area and show that there were no differences between fishery and non-fishery households in the control area.

The triple difference models also confirm the finding on protein consumption. The estimate for β_{2000} for protein is the largest in absolute term compared to other consumption. In addition, β_{2007} for protein is also negative and statistically significant. Other consumption measures have negative treatment coefficients in 2000 but not 2007; however, most of these coefficients are not statistically significant. This is plausibly due to the small size of the treatment group relative to other groups, and hence, the small power.

Table 2.5: Effects of coral bleaching on consumption - triple differences

	(1) Non-food	(2) Total Food	(3) All protein	(4) Fish	(5) Fruit/Veg	(6) Grain
I(2000)*Fish*Bleach	-0.118 (0.2283)	-0.1642 (0.1853)	-0.5006*** (0.1607)	-0.2637 (0.1662)	-0.2506* (0.147)	-0.1052 (0.1576)
I(2007)*Fish*Bleach	0.2803 (0.2202)	0.0413 (0.1726)	-0.2817** (0.1429)	-0.3426** (0.1527)	0.1246 (0.1402)	0.0691 (0.146)
F-Test p-value	0.024	0.188	0.069	0.533	0.003	0.133
N	30772	31244	31244	31244	31244	31244
Mean dependent variable	3.218	2.776	2.108	1.495	1.936	2.02

Remarks: Estimates based on (1.3). Clustered standard errors are in parenthesis. *, **, *** denote statistical significance at 10%, 5%, and 1%, respectively. F-test $H_0 : \beta_{2000} = \beta_{2007}$. All models include household head's gender, age, and education as control covariates. Wave, province and household fixed effects are included in all specifications. All consumption measures are log of real consumption per household member.

Table 2.6 exhibits the results from the IV approach. The IV framework yields similar

results as the main specifications with some larger coefficients.

Table 2.6: Effects of coral bleaching on consumption - IV

	(1) Non-food	(2) Total food	(3) Protein	(4) Food staples
2000*Bleach	-0.6624** (0.2839)	-0.6933*** (0.253)	-0.6828*** (0.2442)	-0.3833* (0.219)
2007*Bleach	0.4124* (0.247)	0.2157 (0.1663)	-0.2303 (0.179)	0.0569 (0.1653)
F-Test p-value	0.0002	0.0005	0.0521	0.0457
N	839	845	845	845
Mean dependent variable	2.681	2.379	1.875	1.874

Remarks: Clustered standard errors are in parenthesis. *, **, *** denote statistically significance at 10%, 5%, and 1%, respectively. F-test $H_0 : \beta_{2000} = \beta_{2007}$. All models include household head's gender, age, and education as control covariates. Wave, province and household fixed effects are included in all specifications. All consumption measures are log of real consumption per household member.

Table 2.7 contains results from the placebo treatment specification. In this specification, the sample is all households in the control area, and the treatment group is households that engaged in fishery in 1997. The results do not show any statistically significant differences between fishery and non-fishery households in absence of the direct exposure to coral bleaching.

Table 2.7: Results from placebo treatment test

	(1) Non-food	(2) Total food	(3) Protein	(4) Food staples
2000*Fish	-0.0266 (0.2033)	0.0028 (0.1688)	0.1376 (0.1384)	-0.0149 (0.1292)
2007*Fish	-0.0906 (0.1689)	-0.0472 (0.1181)	0.0704 (0.0965)	-0.0085 (0.0811)
F-Test p-value	0.6915	0.7153	0.6001	0.9611
N	21,308	21,700	21,700	21,700
Mean dependent variable	3.194	2.757	2.082	1.991

Remarks: Estimates based on (2.1). Clustered standard errors are in parenthesis. *, **, *** denote statistically significance at 10%, 5%, and 1%, respectively. F-test $H_0 : \beta_{2000} = \beta_{2007}$. All models include household head's gender, age, and education as control covariates. Wave, province and household fixed effects are included in all specifications. All consumption measures are log of real consumption per household member. Sample is all households in the control area.

2.5 Policy Implications and Conclusion

This chapter examines the effects of coral bleaching on consumption. I find evidence for a decline in almost every consumption measure with the largest negative effect on protein consumption. Staple grain consumption is largely unaffected by changes in income. Further investigation suggests that this decrease in consumption was largely driven by the income shock, but the decline in fish availability might have also accounted for the fall in protein consumption.

Coral bleaching is a climate shock that is brought about by abnormally high sea surface temperature. Due to the slow recovery process of marine resources, the effects of coral bleaching can be long-term. As the world climate changes, this kind of shocks could become more common than before. Yet, little is known about how people in developing countries, especially those in coastal communities, cope with these large and long-lasting shocks. The findings in this chapter have a couple of implications for policies that could help people smooth their consumption after such shocks.

First, some consumption categories, such as staple grains, were not responsive to changes in income. On the other hand, consumption of nutrition-rich food was very sensitive to a fall in income suggesting that households that experience an income shock might also receive less nutrition relative to other households. As a result, policies on consumption smoothing should consider both overall consumption amount and consumption composition.

Second, the results on protein and other nutrition-rich food indicate that income elasticities for these goods are relatively large. For example, the income elasticity of protein consumption expenditure is greater than one implying that protein consumption is a luxury good. Consequently, cash transfer might be an effective policy device for smoothing nutrition intakes.

Finally, a large drop in consumption after an idiosyncratic shock implies that risk sharing among these communities might not be perfect. Policies on social safety nets and risk sharing mechanisms might be helpful and sustainable in the long run. This aspect shall be explored in future works.

Chapter 3

BEYOND THE SEA: SPILLOVER EFFECTS OF CORAL BLEACHING TO NON-FISHERY SECTORS

Abstract

Coral bleaching has large adverse impacts on the Indonesian fishery sector. Fishery households in the affected areas experienced a large fall in income and responded to this income shock by increasing migration and labor supply. These changes could have affected non-fishery households who lived in the same area. I estimate these spillover effects and show that the adverse effects of coral bleaching were not limited to those who are directly affected. Compared to non-fishery households in other areas, non-fishery households in coral bleaching area had a lower likelihood to earn positive income. Evidence suggests that these changes in income were driven by a decline in labor supply in coral bleaching areas. This income change was not associated with a fall in consumption in most consumption categories.

3.1 Introduction

It is quite common for economic shocks, programs, and policies to affect people who were not directly exposed to such events. The economic literature provides extensive grounds for spillovers of numerous positive and negative shocks, but spillovers and general equilibrium effects of the future climate change are less known. Direct effects of climate change can be estimated based on historical data, then the impact of future climate change is extrapolated using projected climate conditions. However, it is challenging to accurately extrapolate the spillover effects to other sectors because the historical variations in temperature and rainfall are quite small compared to the future estimated changes. This paper offers a unique setting to explore the spillover effects of a large historical shock based on micro data, so we could get a better grasp of the overall impacts of the future climate change.

Coral bleaching has large effects on the fishery sector, but its overall effects are far beyond that. The goal of this paper is to estimate spillover effects of coral bleaching to other sectors. According to the previous chapters, coral bleaching in 1998 resulted in a 27% fall in income

and a 34% fall in protein consumption among the affected fishery households in the short run. As fishery is a small portion of the Indonesian formal economy as measured by GDP, but fish is the most common protein source for the country, it is natural to ask whether a shock to the fish stock has impacts on other households that did not directly engage in fishery. In a macroeconomic sense, an income shock to parts of the economy can affect other sectors as the whole economy is interconnected. First, a fall in income among some households is associated with a fall in demand for goods and services. Second, the demand for labor could also decline as a result of either less favorable fishing conditions or reduced demand for goods and services. Third, changes in labor-related outcomes among the affected fishery households, such as industry switching, might have affected other households in the same area. Fourth, the decline in fish stock might have caused a shock to fish supply which could affect everyone in the economy. Moreover, the processing sector might have experienced reduced businesses due to these shocks to the fish stock and the fishery sector.

Nonetheless, there are ways through which localized, idiosyncratic shocks can be mitigated. Efficient markets could reallocate resources and smooth out shocks on goods and services. Risk sharing and safety nets might help alleviate the effects of localized income shocks [e.g. [Townsend, 1994](#)]. Some of these aspects shall be investigated in this chapter.

Similar to the empirical study in the first two chapters, the spillover effects of coral bleaching are empirically tested using the Indonesian Family Life Survey (IFLS). I estimate the spillover effects to non-fishery sectors in terms of income, labor-related outcomes, and consumption. As coral bleaching was reported only for some of the IFLS provinces, I can compare non-fishery households in areas with coral bleaching to non-fishery households in other areas. However, there are a couple of empirical issues in identifying these spillover effects. First, coral bleaching might have directly affected non-fishery sectors such as tourism. This is not a particular concern if one's goal is to determine the overall impacts of coral bleaching, regardless of whether they are direct or indirect. Second, El Niño, the main cause of Coral Bleaching, affects weather patterns and might impact agricultural and living conditions. In this chapter, I first shut down some spurious channels and estimate the net spillover effects due to indirect exposure to coral bleaching. Then, I point out the possible direct effects on the tourism sector and show that the net spillover effects are robust to different measures of rainfall.

The empirical results suggest that there were effects of coral bleaching on non-fishery households in terms of labor outcomes, and to a lesser extent, consumption. Non-fishery

households in coral bleaching areas cut down on their labor supply after coral bleaching, and this fall in labor supply was associated with an decrease in the likelihood to have positive income. Conditioning on earning positive income, weak evidence suggests that households in coral bleaching areas earned less income relative to household in other areas only in the long run. The models on consumption suggest that there were no spillover effects as measured by most total consumption expenditures. However, there is an evidence for a substitution of goods for sale for consumption goods because home-grown food consumption increased while agricultural income fell.

In addition to the climate shock interpretation, the spillover effects in this paper can also be interpreted as spillovers of a long-lasting income shock because the coral bleaching event associated with this decline in income is exogenous to household behaviors. The massive coral bleaching event in 1998 was mainly caused by a severe El Niño, a natural shift in tropical weather, and evidence suggests that marine resources take at least 5-10 years to recover from this kind of events.

This paper is related to two strands of the economic literature. First, it contributes to the climate change literature by providing a micro-level evidence that effects of climate change are not limited to those who are directly affected such as the agricultural or the fishery sectors. Rather, interactions within the economy can lead to adverse effects on those that are not directly affected. The existing literature on the spillovers of an increase in temperatures is sparse and is mostly based on macro data. For example, a macro-level study by [Dell et al. \[2012\]](#) postulates that one of the reasons that a temperature shock could lead to shocks to industrial output growth is through the spillover from the negative impacts on agricultural output. Some macro analyses also investigate the spatial spillover of climate change through trade. For example, [Jones and Olken \[2010\]](#) find that effects of local weather shocks can have spillover effects to trading partners through exports.

Other related works in environmental economics deal with spillovers of natural disasters, which can usually be interpreted as spillovers of shocks. This leads us to the second strand of relevant literature, the studies of shocks. Similar shocks to coral bleaching include natural disasters, and other long-term income shocks such as a negative income shock from a health condition or a positive income shock from a long-term development program. In the literature related to natural disasters, the output decline due to natural disasters such as earthquakes and cyclones can be contributed to both directly-affected sectors and other sectors. For example, [Zylberberg \[2012\]](#) found that a \$1 direct loss from cyclones is associated with 40

cents of output losses from reduced economic activities.

The remaining of this chapter proceeds as follows. Section 2 describes coral bleaching and its primary cause, the El Niño-Southern Oscillation (ENSO), as well as how they impact humans. Section 3 discusses empirical strategies, including data and methodology. Section 4 presents empirical results. Section 5 concludes and discusses some policy implications.

3.2 ENSO, Coral bleaching, and Human

Coral bleaching is a natural phenomenon in which coral reefs turn white due to abnormally high sea surface temperature (SST). When SST is too high, corals release symbiotic algae which photosynthesize and feed the corals [Brown, 1997]. If the temperature anomaly is temporary, corals can usually recover, regain their colors, and survive. On the other hand, if the anomaly persists, corals usually die [Wilkinson and Hodgson, 1999, Hoegh-Guldberg, 1999], and it can take many years for the reef to recover. The recovery process would involve new coral larvae or polyps settling in the existing reef structure; then the corals regrow, usually at a very slow rate¹[Barnes and Hughes, 1999, Veron and Stafford-Smith, 2000].

Corals are at the bottom of the food chain in the ocean, and the reefs are a habitat for a vast number of species. Hence, weakening coral reefs can result in a deteriorated fish stock [Pratchett et al., 2008]. Scientific evidence suggests that coral bleaching adversely impacts the fish stock with the severity varying by species and locations². In general, coral reef exhaustion results in a fall in abundance of coral reef species within three years after coral bleaching. Coral bleaching can also affect other non-reef species through ecological relationships. In the long run, fish composition changes, and overall abundance and diversity fall [van Oppen and Lough, 2008].

These negative effects of coral bleaching on marine species can translate into adverse impacts on humans. In the first two chapters, I found the negative effects of the massive coral bleaching in 1998 on income, labor-related outcomes, and consumption among the Indonesian fishery households in 2000. These effects two years after coral bleaching were mostly interpreted as the short run effects of coral bleaching because the effects on fish stock

¹The rate of growth ranges between less than one inch to four inches per year, depending on species [NOAA].

²For example, Garpe et al. [2006] found that total abundance and taxonomic richness of species increased right after coral bleaching in Tanzania, but both measures significantly declined below the initial level six years after the bleaching. Booth and Beretta [2002] found a lower recruitment of fish at bleached southern Great Barrier Reef sites relative to unbleached sites one year after the bleaching.

take time to manifest, and marine resource recovery happens rather slowly. The scientific literature indicates that recovery from coral bleaching can take at least five years provided that the coral reefs are not permanently ruined [e.g. [Graham et al., 2007](#), [Wilkinson and Hodgson, 1999](#)].³

In addition to fishery, coral bleaching could impact humans via other channels. First, bleached corals are less attractive, so coral bleaching might have negative effects on tourism and related economic activities. These effects usually materialize immediately after corals lose their colors. Second, coral reefs play a crucial role in land preservation; consequently, deteriorated coral reefs might lead to land erosion. Among the three direct channels, land erosion happens at the slowest rate. It usually starts after corals are dead, and the reef structure is destroyed.

The estimation of coral bleaching spillover effects can be confounded by the effects of El Niño on non-fishery sectors. The main cause of coral bleaching in 1998, El Niño, might have impacted other sectors, such as agriculture, as it resulted in unusual weather patterns. Specifically, El Niño is a phase of El Niño-Southern Oscillation (ENSO), which is a fluctuating cycle in ocean temperatures in equatorial Pacific. A typical ENSO cycle usually consists of El Niño, neutral years, and La Niña. During the last couple of decades, El Niño years include 1991-2, 1997-98, 2002-3, 2009-10, and 2015-6; La Niña years include 1998-9, 1999-00, 2007-8, and 2010-11. Throughout the El Niño and La Niña periods, temperature and rainfall patterns in the Pacific ocean and coastal areas deviate from their usuals. For Indonesia, El Niño is associated with high ocean temperatures and droughts while La Niña usually leads to early wet seasons and abnormally high rainfalls. These unusual weather patterns have direct short-term effects on agriculture. Reduced or delayed rainfall during the El Niño years can lead to delayed planting, reduced cultivation, and low crop yields [[Kishore et al., 2000](#)]. The early wet seasons during the La Niña periods may allow for a second cultivation, but there is also an anecdotal evidence for bad harvesting conditions due to excess rainfall in 2010-11.

In addition to rainfall anomalies, droughts during the El Niño phase increase the risk of forest fires which could indirectly affect agriculture. During the 1997-8 El Niño, Indonesia experienced one of the most severe forest fires worldwide. Most of the burned areas were

³For example, in Seychelles in 2005, coral reefs did not completely recover, and fish reproduction was minimal [[Graham et al., 2007](#)]. [Graham et al. \[2015\]](#) conducted a follow-up study at the same sites in 2011 and found that 9 out of 21 reef sites were permanently ruined while 11 out of 21 reef sites recovered. Note that the evidence for recovery after coral bleaching in 1998 is quite sparse due to the lack of pre-bleaching data. This is because the event was the first one to be widely documented.

in Sumatra, Kalimantan, and West Papua. Forest fires might increase the amount of land available for agriculture and improve soil condition, or it could destroy the current agricultural land. The ambiguity and the long-run nature of the effects of forest fires on agriculture could confound our empirical estimates, and we will discuss the empirical strategies to deal with this issue in the next section.

3.3 Empirical Framework

3.3.1 Data

Similar to the data in the previous chapters, data in this chapter come from three main sources: household data from the IFLS, reported coral bleaching spots from [Goreau et al. \[2000\]](#), and SST data from remote sensing maps. The IFLS is a panel that covers a representative sample of the Indonesian population. It started with 7,224 households in 1993, and these households, together with their spilt-offs, were resurveyed in 1997, 2000, and 2007. The IFLS contains detailed information on labor market history, consumption, socioeconomic and demographic status, and so on. One attractive feature of the IFLS is the low attrition rate. This is important as migration is among our outcomes of interests. The recontact rate in 2007 among the original 1993 IFLS households is 93.6%, and this rate is 95.8% among fishery households. A simple test where a dummy indicator for failure to contact a household is regressed on all regressors in the main model indicates that attrition is not statistically different between the treated and the control groups.

The IFLS is then merged with two measures of coral bleaching, reported coral bleaching spots and SST anomaly days. The reported spots come from [Goreau et al. \[2000\]](#), a paper that gathers reef data from long-term observers. The experience of these long-term observers ensures that the spots reported were truly coral bleaching spots, not damages caused by other factors. However, reported data suffer from under-reporting as the network of observers might not be comprehensive.

To assure that under-reporting is not an identification threat, I used another comprehensive measure of coral bleaching, SST anomaly days, and showed that it led to similar results as reported coral bleaching spots in the previous chapters. In this chapter, I only use SST anomaly days in specifications that require a proxy for coral bleaching severity. Using SST anomaly days as a proxy for coral bleaching follows from a popular scientific model where coral bleaching is associated with an exposure to SST that is higher than 1 degree Cel-

sus above the normal summer average for at least 3-4 week [Hoegh-Guldberg, 1999]. The National Oceanic and Atmospheric Administration (NOAA) has been using days of SST anomaly to predict coral bleaching since the 1990's and it was successful in predicting massive bleaching events shortly before they happened [Hoegh-Guldberg, 1999]. In addition, the scientific literature suggests that the longer the corals are exposed to the high temperature, the higher the risk of coral mortality is.

The SST anomaly days in this chapter is also constructed based on satellite images from NOAA. These images are available every 1-7 days during the first six months of 1998. The calculation is done for each coastal area, defined as one ocean coastline in one province.⁴ The SST anomaly days is then merged with the household data at the coastal area level.

3.3.2 Methodology

The goal of this study is to identify the spillover effects of coral bleaching to non-fishery households that lived in coral bleaching areas. In addition to the interpretation as spillovers of a climate shock, the spillover effects here can also be interpreted as a spillover of an income shock because coral bleaching is exogenous to household behaviors. The 1998 coral bleaching event was mainly caused by El Niño; hence, it was beyond human control. Moreover, typical households should have not expected coral bleaching to occur; even scientists could only predict the 1998 coral bleaching just only days in advance [Hoegh-Guldberg, 1999].

The main identification strategy is based on a difference-in-difference framework where the treatment effect is allowed to vary by post-treatment periods. The sample is households that did not engaged in fishery in 1997. Non-fishery households in areas with coral bleaching are compared against non-fishery households in unaffected areas. This specification allows us to examine whether households outside of fishery are different due to their different exposures to coral bleaching and the communities that were affected by coral bleaching.

Let Y_{ht} denote a dependent variable of interest, then the main estimating equation can be written as

$$Y_{ht} = \alpha + \delta_1 Treat_h + \delta_2 Post_t + \sum_{\tau=2000,2007} \beta_\tau I(wave = \tau) * Treat_h + X'_{ht}\gamma + \mu_h + \lambda_t + \epsilon_{ht}, \quad (3.1)$$

⁴The exception is an area that covers Bali and West Nusa Tenggara where the two provinces are combined into one coastal area because they are small islands in one area with similar SST.

where h is a subscript for household and t is a subscript for time. $Treat_h$ is equal to 1 for households that lived in areas with reported coral bleaching spots in Goreau et al. [2000]. $I(wave = \tau)$ is an indicator function for each of the post-coral bleaching periods. X_{ht} is a vector of control covariates which include a set of dummy variables for provinces of residence in 1997, and household head's demographic characteristics such as age and education. This model also includes household fixed effects, μ_h , and wave fixed effects, λ_t . For these reasons, δ_1 and δ_2 are not identified.

The identification concerns in this chapter include 1. non-parallel pre-trends in outcomes, 2. possible confounding factors due to ENSO, and 3. direct effects of coral bleaching on non-fishery sectors. Table 3.1 shows summary statistics of key variables by treatment areas based on the 1997 wave of data. These statistics indicate that there were differences between non-fishery households in and outside of coral bleaching areas, mostly in terms of labor supply, before coral bleaching. Households in coral bleaching areas worked more, as measure by number of jobs and working time, compared to those in areas without coral bleaching. Similar to the identification concerns in the previous chapters, these differences prior to the treatment are not an identification concern as long as trends in outcomes are similar between the two groups prior to coral bleaching. Figure 3.1 illustrates means of log of income for non-fishery households in and outside of coral bleaching areas over time.⁵ Even though the difference in income in 1993 appears to be larger than the differences in other years, this difference is not statistically significant conditioning on the control covariates and fixed effects in (3.1).

The second concern involves possible confounding factors. First, ENSO, the main cause of massive coral bleaching, is correlated with rainfall and other agricultural conditions. SST is highly correlated with land surface temperature, so the SST anomaly measure of coral bleaching, and to a lesser extent coral bleaching spots, might be correlated with agricultural and living conditions that vary with geographic locations and different phases of ENSO. Due to the fluctuating and short-term nature of rainfall variations due to ENSO, the overall direct effects of El Niño on the agricultural sector cannot be estimated using the time frame for coral bleaching. A particular El Niño event only causes one or two years of abnormally low rainfall, then neutral and La Niña years follow. The usual timing of the IFLS data collection is from the end of the dry season to the beginning of the wet season, so agricultural profit in the data reflects the agricultural condition during the previous year's planting season.

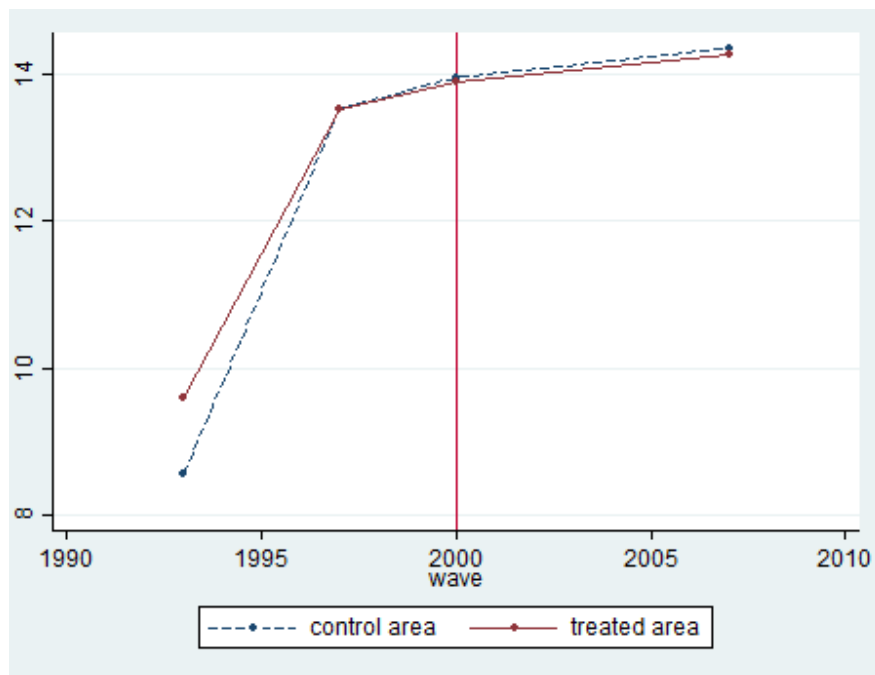
⁵Graphs for other outcomes are available upon request.

Table 3.1: Summary statistics by treatment area, 1997 wave

	Coral bleaching		Control Area		p-value
	Mean	SD	Mean	SD	
HH head's age	49.0	33.7	47.7	24.4	0.084
Male HH head	0.80	0.40	0.82	0.39	0.222
SST days	41.0	36.2	7.7	20.0	0.000
Real HH income	1,884,484	7,467,620	2,071,007	4,410,762	0.228
Second jobs	0.36	0.60	0.19	0.45	0.000
Working weeks	32.85	21.16	27.22	18.06	0.000
Working hours	27.62	18.85	25.89	18.59	0.000
Total food consn	8,324	17,927	9,035	17,357	0.116
Protein consn	2,096	5,815	2,351	7,612	0.168

Remarks: p-values from unpaired t-tests for difference in means between the treated and control areas.

Figure 3.1: Trends in log(real household income per worker) among non-fishery household in and outside of coral bleaching areas



The IFLS 1997 captured the farm profit in 1996, prior to the 1997-98 El Niño, while the agricultural outcomes observed in 2000 were caused by a subsequent mild La Niña event. On the other hand, 2000 is considered the short run for the impacts of coral bleaching and El Niño on the fishery sector as shocks to marine resources take time to manifest. Similarly, even though 2007 is interpreted as the long run for the impacts on marine resources, 2007 corresponds to another round of La Niña for agriculture. The estimating equation (3.1) compares the effects in 2000 and 2007 to the average outcome in 1993 and 1997. Because 1992 was a mild El Niño year, 1996 was a neutral year, and 1999 and 2006 were neutral to mild La Niña years, the empirical model compares the outcomes in weak La Niña years to the average outcomes in weak El Niño/neutral years. These different phases of ENSO might have caused inferior agricultural conditions in the coral bleaching areas relative to other areas after coral bleaching. Specifically, rainfall east of Sumatra Island was delayed for about one month in 2006.⁶ Additionally, the eastern part of Indonesia experienced unusually high rainfall during the harvest season in 2000. However, these patterns were induced by ENSO, rather than the 1997-98 El Niño.

To ensure that the spillover effects are not driven by different variations in rainfall due to ENSO across different areas, I control for short-term rainfall variations in one of robustness checks and show that the spillover effects are similar to those in the main specifications.

Even though the effects of rainfalls are short-run, forest fires during El Niño years can have long-term effects on the agricultural sector, and the time frame can be similar to the coral bleaching time frame. However, the scientific literature on direct effects of forest fires on agriculture is sparse, and there is no clear indication for either a positive or a negative effect. These effects should be controlled for in specifications with province fixed effects under the assumption that the effects of forest fires are constant overtime. However, it is possible that the effects of forest fires were mitigated overtime, so I exclude provinces with reported forest fires from the main specifications. I also include these provinces as a robustness check and show that the main results are not sensitive to omitting these areas.

The third empirical challenge lies within disentangling direct effects of coral bleaching on non-fishery sectors from the spillover effects. Investigating the direct effects of coral bleaching on tourism is not straightforward because the occupation code in the IFLS does not explicitly outline the tourism sector. As a result, I omit provinces with famous beaches and diving spots, Bali and West Nusa Tenggara, from the main specifications, so the estimates

⁶See figure 1.3 for the distribution of coral bleaching spots across islands

from these specifications can be interpreted as pure spillover effects.

I also directly examine effects of coral bleaching on tourism by testing if the effects are larger in provinces with famous beaches and recreational diving spots. In this case, the two provinces are added back to the sample. Those areas were also exposed to severe coral bleaching, so I use SST anomaly days as a treatment specification to capture the difference in bleaching severity. I then add interaction terms between the treatment terms and a dummy indicator for 1997 provinces of residence in Bali or West Nusa Tenggara. This specification is given by

$$Y_{ht} = \alpha + \delta_1 SSTdays_h + \delta_2 Post_t + \sum_{\tau=00,07} \beta_\tau I(wave = \tau) * SSTdays_h + \sum_{\tau=00,07} \eta_\tau I(wave = \tau) * SSTdays_h * Tour_h + X'_{ht}\gamma + \mu_h + \lambda_t + \epsilon_{ht}, \quad (3.2)$$

where $Tour_h$ is equal to one if household h lived in Bali or West Nusa Tenggara in 1997. We can then imply about the direct effects of coral bleaching on the tourism sector by multiplying β_τ in this specification by the mean SSTdays in the positive SST group and comparing them to those in (3.1).

3.4 Empirical Results

I find evidence for spillover effects of coral bleaching to non-fishery households that lived in coral bleaching areas. The spillover was most apparent in labor market outcomes, and it was also detectable in terms of income and consumption changes.

3.4.1 Labor market outcomes

There are a couple of channels through which coral bleaching and a shock to the fishery sector can affect the overall labor market. First, deterioration of coral reefs and fish stock might affect marginal product of labor in fishery and other related sectors. Second, shocks to fishery might have resulted in a fall in labor demand in other closely-related sectors, such as the processing sector. Third, reduced demand from goods and services from the income shock in the fishery sector might have led to a fall in labor demand. Finally, coral bleaching resulted in industry switching and migration among fishery households, and these changes can impact other households in non-fishery labor markets.

Table 3.2: Spillovers of coral bleaching to non-fishery households–labor market outcomes

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	Wages	Work hours	Work weeks	Second jobs	Total workers	Formal workers	Fishermen	Migration
2000*Bleach	-0.0918 (0.0809)	-0.6559 (0.9508)	-2.4476*** (0.883)	0.0075 (0.0231)	0.0063 (0.0545)	-0.076** (0.0344)	-0.0118*** (0.0045)	-0.0198 (0.0178)
2007*Bleach	-0.1323 (0.0974)	0.0535 (1.2586)	-0.5173 (1.0603)	0.0325 (0.0251)	-0.0121 (0.071)	0.0116 (0.0417)	-0.0022 (0.0071)	-0.0609*** (0.0219)
F-Test p-value	0.6374	0.5159	0.0600	0.3062	0.7394	0.0243	0.1730	0.0648
N	12,236	24,236	24,323	24,361	24,271	24,361	24,358	19,095
Cluster N	6,280	9,021	9,056	9,064	9,048	9,064	9,063	8,761
Mean dep var	12.685	30.985	33.038	0.278	2.262	0.728	0.012	0.216

Remarks: This table contains β_r from (3.1). Clustered standard errors are in parenthesis. *, **, *** denote statistical significance at 10%, 5%, and 1%, respectively. F-test $H_0 : \beta_{2000} = \beta_{2007}$. Sample is all non-fishery households in the IFLS, except those in provinces with reported forest fires in 1997 (West Sumatra, South Sumatra, and West Kalimantan), and those with substantial tourism (Bali and West Nusa). All models include household head's gender, age, and education as control covariates. Wave, province and household fixed effects are included in all specifications. Wages is log of wages per wage earner. Work hours is per week and per worker. Work weeks is per year and per worker. Second jobs is the number of household members with secondary jobs. Total workers is the number of household members who are reported to be working, either within or outside of the household. Formal workers is the number of household members that were formally employed either in the public or the private sector according to the individual survey module. Fishermen is the number of household workers in fishery. Migration is a dummy variable that is equal to one if the household's location changes from the prior round of survey.

Table 3.2 shows regression results from models with a sample that contains all non-fishery households in areas without substantial tourism or forest fires. The result in column 1 suggests that non-fishery households' marginal product of labor as measured by log of wages per wage earner did not statistically change after coral bleaching. This finding makes intuitive sense as coral bleaching should not affect the marginal product of labor in sectors that are not directly related to the ocean in absence of industry switching and the subsequent changes in labor skills.⁷

The results in columns 2-6 of table 3.2 exhibit the spillover effects in terms of labor supply. They indicate that coral bleaching negatively affects non-fishery labor supply both at the intensive and extensive margins. At the intensive margin, non-fishery households in coral bleaching areas, on average, worked 2.45 fewer weeks per worker-year relative to those outside of coral bleaching areas in 2000. The spillover effects in terms of working hours is not statistically detectable. At the extensive margin, households that were indirectly exposed to coral bleaching had fewer members with formal employment compared to those in the control area only in 2000. Nonetheless, the effect on the total number of workers, including both formal and informal employment, is not statistically significant. This fall in labor supply can be due to a fall in labor demand in sector closely related to fishery or from the reduced demand for goods and services.

Taken together, the results on labor-related outcomes indicate no significant changes in marginal product of labor among those who were indirectly exposed to coral bleaching, but the non-fishery labor market seemed to experienced a fall in labor demand in 2000. Without a fall in labor demand, it is unlikely that we observed a fall in labor supplied by non-fishery households. It is possible that fishery households supplied their labor in the non-fishery labor market, but it is also unlikely because we did not observe a lower likelihood to be in fishery in 2000 in the first chapter.

The result in column 7 of Table 3.2 indicates that non-fishery households in areas with coral bleaching were less likely to engage in fishery in 2000 compared to the households in unaffected areas. Similar to the findings in the first chapter, this implies that coral bleaching might have adversely affected fishing conditions, and this effect is larger in the short run relative to the long run. This result also serves as another evidence for fish stock recovery

⁷Since the non-fishery status is defined based on occupation prior to coral bleaching, the sample in this model does not contain households that used to be in fishery but switched to other industries after coral bleaching. Moreover, the results from chapter 1 suggest that the affected fishery households did not switch to a new sector until 2007.

over time.

Table 3.3 exhibits the spillovers effects of coral bleaching in terms of total household income and farm profit. The decrease in labor supply in coral bleaching areas is associated with a decrease in the likelihood to have positive total household income in these areas as shown in column 1. Among households that earned positive income, there was no statistical difference in income between those in and outside of coral bleaching areas.

Table 3.3: Spillovers of coral bleaching to non-fishery households–income

	(1)	(2)	(3)	(4)
	Pos income	log(income)	Farm business	log(farm profit)
2000*Bleach	-0.0621*** (0.0133)	-0.0085 (0.1078)	-0.0474*** (0.0166)	-0.0208 (0.1)
2007*Bleach	-0.0529*** (0.0135)	-0.1956 (0.1435)	-0.0629*** (0.0199)	-0.2045* (0.1118)
F-Test p-value	0.3350	0.1238	0.3818	0.1001
N	24,271	20,536	24,269	7,561
Cluster N	9,048	8,562	9,047	3,481
Mean dependent variable	0.895	13.899	0.348	13.452

Remarks: This table contains β_τ from (3.1). Clustered standard errors are in parenthesis. *, **, *** denote statistical significance at 10%, 5%, and 1%, respectively. F-test $H_0 : \beta_{2000} = \beta_{2007}$. Sample is all non-fishery households in the IFLS, except those in provinces with reported forest fires in 1997 (West Sumatra, South Sumatra, and West Kalimantan), and those with substantial tourism (Bali and West Nusa). All models include household head's gender, age, and education as control covariates. Wave, province and household fixed effects are included in all specifications. Dependent variables are a dummy indicator for positive household income, log of real household income per worker, a dummy indicator for the presence of farm business, and log of farm profit. Samples in columns 2 and 4 include only households with positive income/farm profit.

In general, these observed effects on labor supply and income could have resulted from a couple of channels. First, it can be spillover effects from the fishery sector to other closely related sectors, such as the processing sector, or the whole economy. For instance, a decrease in income among the fishery households leads to a fall in their consumption, and hence, a reduction in income to other households who supply goods and services to the affected households. Second, these effects are not a spillover of coral bleaching, but they are other effects of El Niño/La Niña on non-fishery sectors such as agriculture. Finally, parts of these effects could be direct effects of coral bleaching on other non-fishery sectors such as tourism.

To investigate coral bleaching spillover to other sectors, I add the interactions between treatment variables and dummy variables for food processing sector, and for shop keepers and salespersons to the original specifications. The results in table 3.4 indicate no statistical

differences between households in food processing/trade and other non-fishery households. These results suggest that the spillover effects are quite homogeneous across the sample. Yet, one caveat of this finding is insufficient power due to the small size of the food processing sector in the sample.

Table 3.4: Spillovers of coral bleaching to non-fishery households—interactions with sectors

	(1) Work hours	(2) Work weeks	(3) Second jobs	(4) Fishermen	(5) Pos income	(6) log(income)
2000*Bleach	-0.593 (1.041)	-2.696** (0.955)	-0.00609 (0.0248)	-0.0123** (0.00499)	-0.0573*** (0.0143)	0.00425 (0.0645)
2007*Bleach	-0.425 (1.390)	-0.812 (1.155)	0.0295 (0.0268)	-0.00180 (0.00822)	-0.0529*** (0.0143)	-0.114 (0.0724)
2000*Bleach*Sale	-1.073 (1.216)	-0.704 (1.059)	0.0135 (0.0278)	0.00134 (0.00411)	-0.0125 (0.0143)	0.0258 (0.0668)
2007*Bleach*Sale	-0.200 (1.667)	-1.069 (1.466)	-0.0345 (0.0352)	0.00189 (0.00766)	-0.00860 (0.0148)	-0.00146 (0.0872)
2000*Bleach*Process	-1.654 (2.097)	0.604 (2.128)	0.0209 (0.0588)	0.00608 (0.00760)	-0.0321 (0.0269)	0.0386 (0.134)
2007*Bleach*Process	0.934 (3.200)	0.738 (3.321)	0.0307 (0.0912)	-0.0103 (0.0156)	0.0135 (0.0349)	-0.0420 (0.233)
N	24236	24323	24361	24358	24271	20237
N (HH)	9021	9056	9064	9063	9048	8523

Remarks: This table contains β_r from (3.1) as well as the coefficients on the interactions between the treatment terms and dummy indicators for processing and trade sectors. Clustered standard errors are in parenthesis. *, **, *** denote statistical significance at 10%, 5%, and 1%, respectively. F-test $H_0 : \beta_{2000} = \beta_{2007}$. Sample is all non-fishery households in the IFLS, except those in provinces with reported forest fires in 1997 (West Sumatra, South Sumatra, and West Kalimantan), and those with substantial tourism (Bali and West Nusa). All models include household head's gender, age, and education as control covariates. Wave, province and household fixed effects are included in all specifications. Dependent variables are working hours per week per worker, working weeks per year per worker, the number of household members with secondary jobs, the number of fishermen in HH, a dummy indicator for positive household income, and log of real household income per worker. The sample in column 6 includes only households with positive income.

To evaluate whether effects of El Niño on non-fishery sector drive the results from the main specifications, I explore spillovers in the agricultural sector, a large sector that is most likely to be directly affected by weather conditions. The results on farming show a very weak evidence for poorer agriculture conditions in the coral bleaching areas relative to the unaffected areas in 2000 and 2007. Columns 3-4 in table 3.3 illustrate that non-fishery households in coral bleaching areas farmed less and had lower farm income relative to other non-fishery households. After coral bleaching, households in coral bleaching areas were 4-6

percentage points less likely to engage in a farm business. Among those who earned positive farm profit, households in coral bleaching areas earned 20.5% less farm income relative to those outside of coral bleaching areas in 2007. Nonetheless, these results cannot be directly interpreted as the effects of El Niño because the effect of the 1997 El Niño on rainfall should not have lasted into 2000 or 2007. To formally check whether rainfall, either transitory or in 1997, drives these spillover effects in agriculture, I add rainfall deviations to the main specifications and show that the results remain similar to those in tables 3.2 and 3.3 (see table 3.9). However, transitory rainfall deviations seem to have effects on income and farm profit. After controlling for rainfall, the difference in these two outcomes between coral bleaching and other areas are not statistically significant.

Additionally, these effects on agriculture were not driven by the long-term effects of forest fires during the 1997 El Niño as provinces with reported forest fires in 1997 were omitted from the sample. Moreover, similar results can be obtained when provinces with forest fires are included in the sample as one of the robustness checks (see table 3.8).

A plausible scenario is the one where consumption substitution and sectoral shifts within coral bleaching areas affect income and farm profit. In the former scenario, the fall in farm income could have resulted from a substitution of goods between sale and household consumption. This model is supported by an increase in consumption of home-grown produce, grains, and protein. In addition, the result on the fallen likelihood of farming could stem simply from sectoral shifts within coral bleaching areas. Compared to non-fishery households in coral bleaching areas and fishery households in unaffected areas, the fishery households in coral bleaching areas were more likely to have a farm business both in 2000 and 2007. Moreover, the non-fishery households tend to shift to other sectors such as becoming salesmen/shop assistant.

Table 3.5 contains key estimates from (3.2) and provides some evidence for direct effects of coral bleaching on the tourism sectors. The results indicate that the effects on labor outcomes and income are larger in magnitude in areas with substantial tourism than in other coral bleaching areas. Specifically, when multiplying the coefficients by mean of SST anomaly days calculated based on the non-zero SST days sample, the magnitudes of the overall changes calculated based on the terms $I(2000) * SSTdays$, and $I(2007) * SSTdays$ are mostly smaller than the corresponding coefficients in tables 3.2-3.3. In addition, a number of coefficients on the interaction terms in table 3.5 are statistically significant and relatively large in size. This implies that there could be direct effects of coral bleaching on the tourism sector; hence,

areas with substantial tourism are excluded from the main specifications. Nonetheless, the possibility of these direct effects and the imperfect measure of tourism do not hinder the validity of the specifications based on (3.1) if the ultimate goal is to examine the general equilibrium effects of coral bleaching. Additionally, if coral bleaching had direct effects on the tourism sectors, then the large effects of coral bleaching estimated using the area control group in the first chapter could, if anything, have been underestimated. This aspect shall be further investigated using a dataset where the tourism sector can be properly identified.

These spillover effects can be mitigated in a couple of ways. For example, social safety nets might play a role in smoothing household income, and trade and labor mobility might help smooth shocks in labor market as well as good and services markets. To investigate if trade and labor mobility might have taken parts in smoothing labor market and fish supply shocks, I estimate (3.1) using only households in remote areas⁸ as a sample, and compare the estimates with those in tables 3.2-3.3.

Figure 3.2 compares spillover coefficients between remote area samples and the baseline sample. The two remote area samples include 1. the communities that are considered remote in all four waves of data, and 2. those that are considered remote in at least three waves of data. The former definition of remote areas is more consistent across all waves of data, but these areas do not contain any fishery households that were exposed to coral bleaching, as defined by reported bleaching spots. The latter definition of remote areas consists of all treatment and control groups, but some communities might not be remote in all waves of data. In general, the confidence intervals for the remote area specifications are larger than those for the baseline models due to smaller sample sizes in remote area specifications. In addition, most of the confidence intervals for the baseline sample lie within those for the corresponding remote area cases.

Nevertheless, these results indicate some differences between remote and non-remote areas. First, wages seemed to have slightly increased but decreased in 2007 only in remote areas. Second, households in remote areas were less likely to be in fishery in both the short run and the long run, but this effect is observed only in the short run in the baseline sample. Finally, the magnitudes of the coefficients for a dummy indicator for positive household income are larger than those in the baseline, and the confidence intervals based on the

⁸A community is considered remote during a particular wave if at least one of the followings is true: 1. there is no public transportation, 2. main roads are not paved, 3. motor vehicles cannot travel on main roads/waterways, 4. commute time to the nearest market is greater than 30 minutes, 5. commute time to the nearest bus stop is greater than 30 minutes.

Table 3.5: Spillovers of coral bleaching to non-fishery households—interactions with tourism areas

	(1)	(2)	(3)	(4)	(5)	(6)		
	Wages	Wages	Work hours	Work hours	Work weeks	Work weeks		
2000*SSTdays	0.00145 (0.00105)	0.000294 (0.00170)	-0.0228** (0.0104)	-0.000556 (0.0145)	-0.0523*** (0.0109)	-0.00334 (0.0156)		
2007*SSTdays	0.000641 (0.00119)	-0.000604 (0.00177)	-0.00442 (0.0152)	0.0347* (0.0199)	-0.0216 (0.0133)	0.0322* (0.0182)		
2000*SSTdays*TourismArea		0.00198 (0.00194)		-0.0390** (0.0181)		-0.0859*** (0.0195)		
2007*SSTdays*TourismArea		0.00214 (0.00214)		-0.0673** (0.0266)		-0.0928*** (0.0234)		
N	13410	13410	26913	26913	27003	27003		
N (HH)	6792	6792	9752	9752	9787	9787		
	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)
	Second jobs	Second jobs	Fishermen	Fishermen	Pos income	Pos income	log(income)	log(income)
2000*SSTdays	-0.000559* (0.000285)	0.000464 (0.000411)	0.0000593 (0.0000799)	0.000183 (0.000125)	-0.000329** (0.000158)	0.0000884 (0.000217)	0.000443 (0.000699)	0.00191* (0.00110)
2007*SSTdays	0.000213 (0.000298)	0.00125** (0.000425)	0.000183* (0.0000942)	0.000425** (0.000164)	-0.000432** (0.000153)	-0.0000716 (0.000220)	-0.0000839 (0.000753)	0.000925 (0.00116)
2000*SSTdays*Tour		-0.00180*** (0.000513)		-0.000217 (0.000155)		-0.000733** (0.000270)		-0.00253** (0.00127)
2007*SSTdays*Tour		-0.00179*** (0.000526)		-0.000416** (0.000194)		-0.000623** (0.000260)		-0.00168 (0.00136)
N	27043	27043	27040	27040	26952	26952	22574	22574
N (HH)	9795	9795	9794	9794	9779	9779	9243	9243

Remarks: This table contains β_τ and η_τ from (?). Clustered standard errors are in parenthesis. *, **, *** denote statistical significance at 10%, 5%, and 1%, respectively. F-test $H_0 : \beta_{2000} = \beta_{2007}$. Sample is all non-fishery households in the IFLS, except those in areas with reported forest fires in 1997 (West Sumatra, South Sumatra, and West Kalimantan). All models include household head's gender, age, and education as control covariates. Wave, province and household fixed effects are included in all specifications. Dependent variables are log of wages per wage earner, working hours per week, working weeks per year, the number of household members with secondary jobs, the number of fishermen in HH, a dummy indicator for positive household income, and log of real household income per worker. The sample in columns 13-14 includes only households with positive income.

3-wave remote sample mostly do not overlap with those for the baseline. These results indicate that labor mobility and trade might be important for risk mitigation. For example, the decrease in wages indicated that there might have been a decrease in demand for labor and an increase in competition in remote areas, and this decrease was not observed in the baseline specification because labor mobility might have smoothed labor market shocks in non-remote areas. The larger magnitudes of the effects on the ability to earn positive income in remote areas provides another evidence for this hypothesis.

3.4.2 Consumption

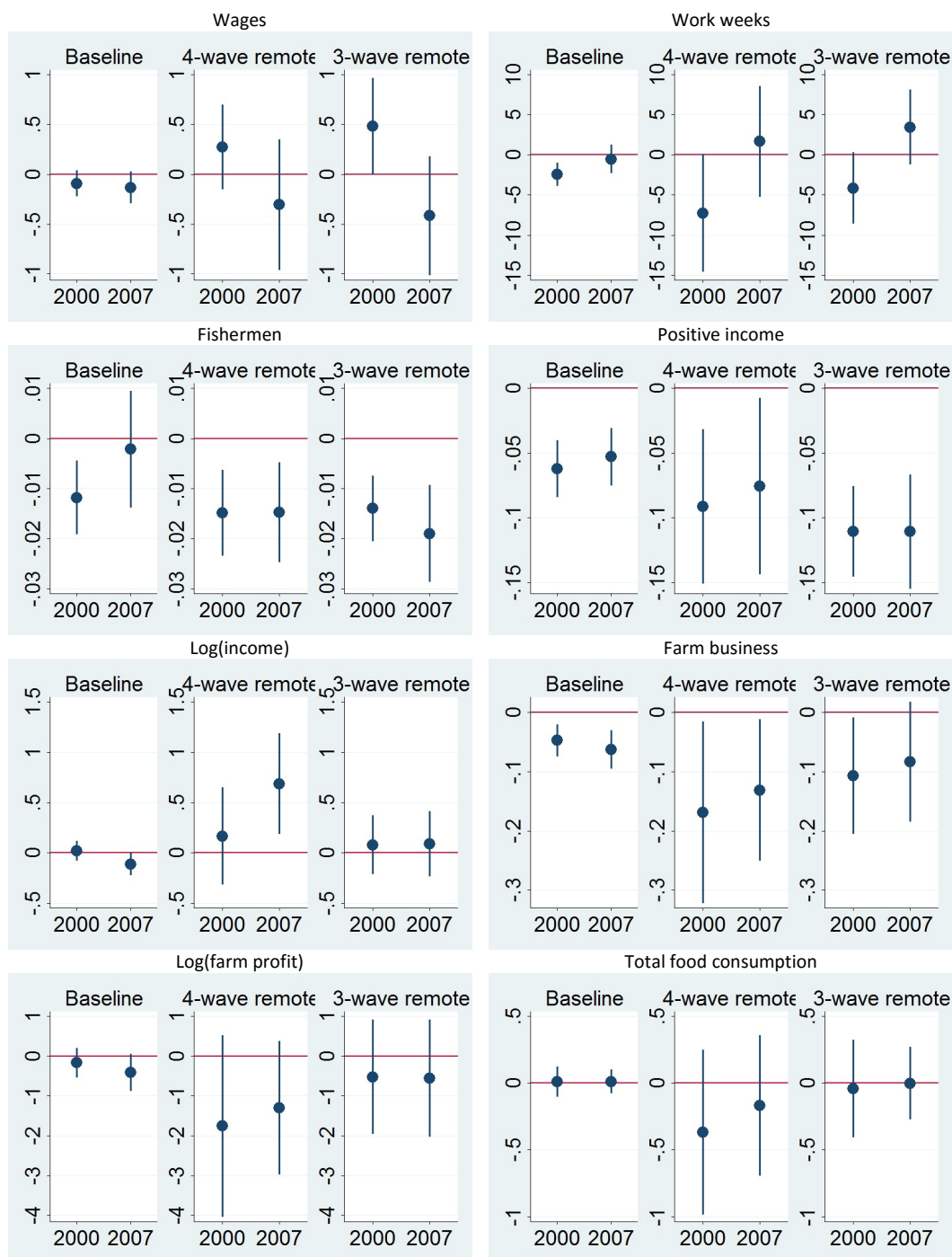
At a first glance, there is almost no consumption spillover resulted from coral bleaching. Non-fishery households in coral bleaching areas did not change their overall consumption relative to non-fishery households in unaffected areas. Table 3.6 shows the regression results with consumption expenditures in various consumption categories as dependent variables, and most of the treatment coefficients are not statistically significant. One caveat of the results here is the expenditure nature of consumption measures in the IFLS. Even when the coefficient is not statistically significant, the consumption quantity might have decreased if prices increased.

The result in column 3 indicates a positive and statistically significant treatment coefficient for protein consumption in 2000. This increase in protein consumption expenditure was largely driven by an increase in meat consumption expenditure, and a non-statistically significant fall in fish consumption expenditure. Since meat is generally more expensive than fish, especially in coastal areas, this increase in protein consumption might have been due to a substitution of meat for fish. In addition, a fish supply shock might have caused an increase in fish prices.

Despite minimal changes in various overall consumption expenditures, there is an evidence for a consumption pattern shift from purchased consumption to home-grown consumption in some food categories. Table 3.7 illustrates the spillover effects on home-grown consumption. These results suggest that there were increases in home-grown consumption of protein, fruits and vegetables, and grains.

In the case where prices increased, the statistically insignificant coefficients in table 3.6 implied that overall consumption quantities declined, and the results in table 3.7 imply that the households could have consumed the same amount of home-grown protein, fruits and vegetables, and grains. On the other hand, the results in table 3.6 indicate that there

Figure 3.2: Comparison of spillover effects: all areas vs remote areas



Notes: Point estimates and 90% confidence intervals of β_τ based on (3.1). Confidence intervals are constructed based on clustered standard errors. Baseline sample contains all non-fishery households in the IFLS, except those in areas with reported forest fires in 1997 (West Sumatra, South Sumatra, and West Kalimantan) ($N = 24,361$; 9,064 HHs). Remote areas are those considered remote in all four waves of data (4-wave remote; $N = 3,572$; 1,108 HHs), and those considered remote in at least three waves (3-wave remote; $N = 6,339$; 1,991 HHs). All models include household head's gender, age, and education as control covariates. Wave, province and household fixed effects are included in all specifications. Dependent variables are log of wages per wage earner, working weeks per year, the number of fishermen in HH, a dummy indicator for positive household income, and log of real household income per worker, a dummy indicator for presence of farm business, log of farm profit, and log of total food consumption expenditure.

Table 3.6: Spillovers of coral bleaching to non-fishery households–consumption

	(1) Non-Food	(2) Total Food	(3) Protein	(4) Fruits/Vegs	(5) Grains
2000*Bleach	-0.0005 (0.0851)	0.0103 (0.0685)	0.1443** (0.067)	0.0102 (0.0593)	0.0599 (0.0667)
2007*Bleach	-0.0461 (0.0686)	0.0117 (0.0534)	0.0817 (0.0516)	0.0203 (0.0483)	0.0463 (0.0507)
F-Test p-value	0.5476	0.9809	0.2815	0.8523	0.8227
N	23,903	24,271	24,271	24,271	24,271
Cluster N	9,027	9,048	9,048	9,048	9,048
Mean dependent variable	3.333	2.862	2.140	1.978	2.044

Remarks: Clustered standard errors are in parenthesis. *, **, *** denote statistical significance at 10%, 5%, and 1%, respectively. F-test $H_0 : \beta_{2000} = \beta_{2007}$. Sample is all non-fishery households in the IFLS, except those in provinces with reported forest fires in 1997 (West Sumatra, South Sumatra, and West Kalimantan), and those with substantial tourism (Bali and West Nusa). All models include household head's gender, age, and education as control covariates. Wave, province and household fixed effects are included in all specifications. All consumption measures are log of real consumption expenditures per household member.

was no difference in overall consumption quantities between households in and outside of coral bleaching areas under the assumption that the changes in prices were similar in both areas. In this case, the results in table 3.7 imply an increase in home-grown consumption quantities. In either case, an increase in home-grown consumption expenditure together with the decrease in farm income supports the model where households chose to consume agricultural goods rather than selling them, and provides an evidence for similar agricultural conditions between coral bleaching and control areas.

The changes in prices can be tested by regressing prices on key covariates from (3.1)⁹. These tests were done on prices of rice, beef, and dried fish. The results indicate a fall in a price of rice in 2000, and a fall in a price of beef in both 2000 and 2007 in coral bleaching areas relative to other areas. The results on the price of dried fish is not robust. As rice is the main staple crop in Indonesia, we may conclude that households in coral bleaching area consumed more grains in 2000, and a large part of this increase was driven by an increase in home-grown consumption.

⁹Since price data is available at a community level, these regressions are at a community level and do not contain household characteristics or household fixed effects. Full results are available upon requests.

Table 3.7: Spillovers of coral bleaching to non-fishery households–homegrown consumption

	(1)	(2)	(3)	(4)
	Total food	Protein	Fruits/Vegs	Grains
2000*Bleach	-0.0385 (0.0744)	0.227*** (0.0642)	0.1402** (0.0626)	0.1784*** (0.0671)
2007*Bleach	-0.1243* (0.0648)	0.1092** (0.0512)	-0.046 (0.053)	-0.0433 (0.0582)
F-Test p-value	0.2408	0.0708	0.0023	0.0010
N	24,271	24,271	24,271	24,271
Cluster N	9,048	9,048	9,048	9,048
Mean dep var	1.513	0.517	0.733	0.759

Remarks: This table contains β_T from (3.1). Clustered standard errors are in parenthesis. *, **, *** denote statistical significance at 10%, 5%, and 1%, respectively. F-test $H_0 : \beta_{2000} = \beta_{2007}$. Sample is all non-fishery households in the IFLS, except those in provinces with reported forest fires in 1997 (West Sumatra, South Sumatra, and West Kalimantan), and those with substantial tourism (Bali and West Nusa). All models include household head's gender, age, and education as control covariates. Wave, province and household fixed effects are included in all specifications. All consumption measures are log of real homegrown consumption (expenditure-equivalent) per household member.

3.4.3 Robustness Checks

A couple of checks were done to ensure the robustness of the results from the main specifications. I exclude areas with famous beach/diving attractions and areas with forest fires in 1997-98 from the main sample to allow for net spillover effect interpretation of the coefficients. However, adding areas with forest fires to the sample yields quite similar results implying that forest fires were not likely to be correlated with coral bleaching. These results are presented in table 3.8.

Additionally, rainfall deviation during the wet season preceding each survey year is included to the main specification to ensure that the spillover effects are not driven by the effects of ENSO on rainfall and agricultural conditions. The data on rainfall are from the Global Historical Climatology Network (GHCN), and the rainfall variable is constructed as a deviation of wet-season rainfall from the long-term average in each province.¹⁰ This variable

¹⁰The data from GHCN is available at a station level. To compute averages for each province, I first computed the median across all stations in each province in each period of time. Then, for each wave and province, the average rainfall during each wet season is calculated by averaging the monthly medians over the 5-6 months of the wet season, which varies by provinces. Then, the deviation is calculated by subtracting the long-term average from the current year's average rainfall in the wet months.

Table 3.8: Spillovers of coral bleaching to non-fishery households—forest fire areas included

	(1)	(2)	(3)	(4)	(5)	(6)
	Work hours	Work weeks	Second jobs	Fishermen	Pos Income	log(income)
2000*Bleach	-1.1129 (0.8082)	-3.0455*** (0.7735)	-0.0084 (0.0203)	-0.0114*** (0.0039)	-0.0559*** (0.012)	-0.0952 (0.1042)
2007*Bleach	0.6315 (1.0877)	-0.8038 (0.926)	0.0348 (0.0219)	-0.0041 (0.006)	-0.0417*** (0.0117)	-0.2706** (0.1341)
F-Test p-value	0.0766	0.0147	0.0482	0.2297	0.1044	0.1225
N	27,719	27,809	27,853	27,850	27,751	23,445
Cluster N	10,034	10,069	10,077	10,076	10,061	9,537
Mean dep var	30.793	33.046	0.289	0.013	0.897	13.893

Remarks: This table contains β_τ from (3.1). Clustered standard errors are in parenthesis. *, **, *** denote statistical significance at 10%, 5%, and 1%, respectively. F-test $H_0 : \beta_{2000} = \beta_{2007}$. Sample is all non-fishery households in the IFLS including those in Sumatra and Kalimantan, but excluding those in tourism area (Bali and West Nusa Tenggara). All models include household head's gender, age, and education as control covariates. Wave, province and household fixed effects are included in all specifications. Dependent variables are working hours per week per worker, working weeks per year per worker, the number of HH members with secondary job, number of fishermen in HH, a dummy indicator for positive household income, and log of real household income per worker. The sample in column 6 includes only households with positive income.

is included in the model to capture differences in short-term rainfall variations that might have resulted from ENSO and affected the agricultural sector. Note, however, that the rainfall during 1997 might be correlated with SST and coral bleaching measures. Consequently, these specifications are not chosen as the main specifications.

Table 3.9 illustrates the key coefficients from specifications that control for transitory rainfall. The coefficients here are similar to those in tables 3.2-3.3 suggesting that the spillover effects in the main results were not driven by short-run effects of ENSO. The only case where the result in table 3.9 is substantially different from those in the main specifications are the model with farm profit as the dependent variable. After controlling for rainfall, the results indicate no differences in farm profit between coral bleaching and other areas. This finding is consistent with the literature on rainfall shocks where rainfall can affect agricultural income. In addition to controlling for transitory rainfall deviation, I also control for rainfall deviation in 1997 and use different functional forms of the transitory rainfall. These additional results are similar to those presented here and are included in appendix A.2.

Table 3.9: Spillovers of coral bleaching to non-fishery households—controlling for rainfall

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	Work hours	Work weeks	Second jobs	Fishermen	Pos income	log(income)	Farm business	log(farm profit)
2000*Bleach	-0.6915 (0.9538)	-2.6036*** (0.8832)	0.0046 (0.0231)	-0.012*** (0.0045)	-0.0569*** (0.0132)	-0.0045 (0.1074)	-0.0468*** (0.0167)	-0.0298 (0.1001)
2007*Bleach	0.0205 (1.2602)	-0.6007 (1.0596)	0.0303 (0.0251)	-0.0023 (0.0071)	-0.0509*** (0.0134)	-0.1837 (0.1433)	-0.0628*** (0.0199)	-0.1279 (0.1126)
F-Test p-value	0.5147	0.0507	0.2906	0.1714	0.5389	0.1424	0.3671	0.3882
N	19,095	24,323	24,361	24,358	24,271	20,536	24,269	7,561
Cluster N	8,761	9,056	9,064	9,063	9,048	8,562	9,047	3,481
Mean dep var	0.22	33.04	0.28	0.01	0.90	13.90	0.35	13.45

Remarks: This table contains β_T from (3.1). Clustered standard errors are in parenthesis. *, **, *** denote statistically significance at 10%, 5%, and 1%, respectively. F-test $H_0 : \beta_{2000} = \beta_{2007}$. Sample is all non-fishery households in the IFLS, except those in provinces with reported forest fires in 1997 (West Sumatra, South Sumatra, and West Kalimantan), and those with substantial tourism (Bali and West Nusa). All models include household head's gender, age, and education as control covariates. Wave, province and household fixed effects are included in all specifications. All specifications also include a transitory wet-season rainfall deviation as a control variable. Dependent variables are working hours per week per worker, working weeks per worker, the number of HH members with secondary jobs, the number of fishermen in HH, a dummy indicator for positive household income, and log of real household income per worker, presence of farm business, and log of farm profit. The sample in columns 6 and 8 includes only households with positive income/profit.

3.5 Policy Implications and Conclusion

In this chapter, I estimate the spillover effects of coral bleaching to non-fishery sectors. The spillover effects are detectable in labor-related outcomes and consumption patterns. Specifically, non-fishery households in coral bleaching areas supplied less labor after coral bleaching relative to non-fishery households in other areas. This fall in labor is associated with a decrease in the likelihood to have positive household income in both the short run and the long run. Conditioning on earning positive income, there is no significant income difference between households in and outside of coral bleaching areas. Detailed analysis suggests that the labor market spillover was plausibly due to a fall in labor demand from reduced economic activities. Even though the fishery households in treatment area switched out of fishery, the sectoral shift did not significantly impact the non-fishery labor market.

In terms of consumption, there is no evidence for spillover effect as measured by consumption expenditures in most consumption categories. However, consumption pattern changed after coral bleaching as non-fishery households consumed rather than sold their agricultural products.

The empirical results also indicate that there could be direct effects of coral bleaching on the tourism sector, but it is unlikely that coral bleaching has direct effects on agriculture. The main cause of coral bleaching, ENSO, might have directly affected the agricultural sector both in the short and long run. However, tests indicate that the spillover effects estimated in the main specifications are robust to the possible short-run effects of transitory rainfall variations through out the ENSO cycle, and long-run effects of forest fires induced by El Niño in 1997.

Taken together, these results imply that a climate shock such as coral bleaching can have effects on the whole economy, not only through direct channels, but also through reduced economic activities. The spillover effects are smaller in magnitude than the direct effects, but they could affect a larger proportion of the population. As a result, it is important for studies of climate change to take into account general equilibrium effects.

Additionally, while fishery households were able to adapt and improve their income, non-fishery households in coral bleaching area were less likely to have positive household income relative to their peers in the control area even in the long run. This finding suggests that mitigation of spillovers might not be as effective as that for the actual shock, and that policy makers should also pay attention to those who were not directly affected by the shock.

BIBLIOGRAPHY

- RSK Barnes and RN Hughes. *An Introduction to Marine Ecology*. John Wiley & Sons, 1999.
- David J Booth and Giglia A Beretta. Changes in a fish assemblage after a coral bleaching event. *Marine Ecology Progress Series*, 245:205–212, 2002.
- BE Brown. Coral bleaching: causes and consequences. *Coral reefs*, 16(1):S129–S138, 1997.
- Pasita Chaijaroen. Long-lasting income shocks and adaptations: Evidence from coral bleaching in indonesia, 2016.
- Melissa Dell, Benjamin F Jones, and Benjamin A Olken. Temperature shocks and economic growth: Evidence from the last half century. *American Economic Journal: Macroeconomics*, pages 66–95, 2012.
- Melissa Dell, Benjamin F Jones, and Benjamin A Olken. What do we learn from the weather? the new climate–economy literature. *Journal of Economic Literature*, 52(3):740–798, 2014.
- Anil Deolalikar and Elaina Rose. Gender and savings in rural india. *Journal of Population Economics*, 11(4):453–470, 1998.
- Olivier Deschênes and Michael Greenstone. The economic impacts of climate change: evidence from agricultural output and random fluctuations in weather: reply. *The American Economic Review*, 102(7):3761–3773, 2012.
- Food and Agriculture Organization of the United Nations (FAO). The state of world fisheries and aquaculture. <http://www.fao.org/3/a-i3720e.pdf>, 2014. Accessed: 2015-10-16.
- E Frankenberg and L Karoly. The 1993 indonesian family life survey: Overview and field report, RAND. Technical report, DRU-1195/1-NICHD/AID, 1995.
- Elizabeth Frankenberg and Thomas Duncan. The indonesia family life survey (IFLS): study design and results from waves 1 and 2. Technical report, DRU-2238/1-NIA/NICHD, 2000.

- Kajsa C Garpe, Saleh AS Yahya, Ulf Lindahl, and Marcus C Ohman. Long-term effects of the 1998 coral bleaching event on reef fish assemblages. *Marine Ecology Progress Series*, 315:237–247, 2006.
- Tom Goreau, Tim McClanahan, Ray Hayes, and AL Strong. Conservation of coral reefs after the 1998 global bleaching event. *Conservation Biology*, 14(1):5–15, 2000.
- Nicholas AJ Graham, Shaun K Wilson, Simon Jennings, Nicholas VC Polunin, JAN Robinson, Jude P Bijoux, and Tim M Daw. Lag effects in the impacts of mass coral bleaching on coral reef fish, fisheries, and ecosystems. *Conservation biology*, 21(5):1291–1300, 2007.
- Nicholas AJ Graham, Simon Jennings, M Aaron MacNeil, David Mouillot, and Shaun K Wilson. Predicting climate-driven regime shifts versus rebound potential in coral reefs. *Nature*, 518(7537):94–97, 2015.
- Ove Hoegh-Guldberg. Climate change, coral bleaching and the future of the world’s coral reefs. *Marine and freshwater research*, 50(8):839–866, 1999.
- Terry P Hughes, Andrew H Baird, David R Bellwood, Margaret Card, Sean R Connolly, Carl Folke, Richard Grosberg, Ove Hoegh-Guldberg, JBC Jackson, Janice Kleypas, et al. Climate change, human impacts, and the resilience of coral reefs. *science*, 301(5635):929–933, 2003.
- Tullio Jappelli and Luigi Pistaferri. The consumption response to income changes. *Annu. Rev. Econ.*, 2(1):479–506, 2010.
- Benjamin F Jones and Benjamin A Olken. Climate shocks and exports. *American Economic Review: Papers & Proceedings*, pages 454–459, 2010.
- Kamal Kishore, A.R. Subbiah, Tien Sribimawati, Ir. Sri Diharto, Sutarto Alimoeso, Peter Rogers, and Adang Setiana. Indonesia country study. Technical report, Asian Disaster Preparedness Center, 2000.
- Anjini Kochar. Smoothing consumption by smoothing income: hours-of-work responses to idiosyncratic agricultural shocks in rural india. *Review of Economics and Statistics*, 81(1):50–61, 1999.

- Vivienne L. Kruger. *Balinese food : the traditional cuisine food culture of Bali*. Tuttle Publishing, 2014.
- Jonathan Morduch. Income smoothing and consumption smoothing. *The journal of economic perspectives*, 9(3):103–114, 1995.
- National Oceanic and Atmospheric Administration (NOAA). Corals: How do coral reefs form? http://oceanservice.noaa.gov/education/kits/corals/coral04_reefs.html. Accessed: 2015-02-16.
- Christina H Paxson. Consumption and income seasonality in thailand. *Journal of political Economy*, pages 39–72, 1993.
- Morgan S Pratchett, P Munday, Shaun K Wilson, Nicholas AJ Graham, Joshua E Cinner, David R Bellwood, Geoffrey P Jones, Nicholas VC Polunin, and TR McClanahan. Effects of climate-induced coral bleaching on coral-reef fishes. *Ecological and economic consequences. Oceanography and Marine Biology: An Annual Review*, 46:251–296, 2008.
- Elaina Rose. Ex ante and ex post labor supply response to risk in a low-income area. *Journal of Development Economics*, 64(2):371–388, 2001.
- Wolfram Schlenker and David B Lobell. Robust negative impacts of climate change on african agriculture. *Environmental Research Letters*, 5(1):014010, 2010.
- Wolfram Schlenker, W Michael Hanemann, and Anthony C Fisher. The impact of global warming on us agriculture: an econometric analysis of optimal growing conditions. *Review of Economics and Statistics*, 88(1):113–125, 2006.
- Emmanuel Skoufias, Sailesh Tiwari, and Hassan Zaman. Crises, food prices, and the income elasticity of micronutrients: estimates from indonesia. *The World Bank Economic Review*, 26(3):415–442, 2012.
- Statistics Indonesia. Agriculture and mining statistics - fishery. http://www.bps.go.id/eng/menutab.php?tabel=1&kat=3&id_subyek=56. Accessed: 2015-01-30.

- John Strauss, Kathleen Beegle, Bondan Sikoki, Agus Dwiyanto, Yulia Herawati, and Firman Witoelar. The third wave of the indonesia family life survey (IFLS3): overview and field report. Technical report, WR-144/1-NIA/NICHD, 2004.
- John Strauss, Firman Witoelar, Bondan Sikoki, and Anna Marie Wattie. The 4th wave of the indonesian family life survey (IFLS4): Overview and field report. Technical report, WR-675/1-NIA/NICHD, 2009.
- Shankar Subramanian and Angus Deaton. The demand for food and calories. *Journal of political economy*, pages 133–162, 1996.
- Vis Taraz. Adaptation to climate change: Historical evidence from the indian monsoon, 2015.
- Robert M Townsend. Risk and insurance in village india. *Econometrica: Journal of the Econometric Society*, pages 539–591, 1994.
- United Nations Environment Programme (UNEP). Marine and coastal ecosystems and human well-being. http://www.unep.org/pdf/Completev6_LR.pdf, 2006. Accessed: 2015-10-16.
- Madeleine JH van Oppen and Janice M Lough. *Coral bleaching: patterns, processes, causes and consequences*, volume 205. Springer Science & Business Media, 2008.
- J.E.N. Veron and M. Stafford-Smith. *Corals of the world*. Number v. 3 in Corals of the World. Australian Institute of Marine Science, 2000. URL <https://books.google.com/books?id=Np3wAAAAMAAJ>.
- Clive Wilkinson. *Status of coral reefs of the world 2000*. Australian Institute of Marine Science Townsville, 2000.
- Clive Wilkinson and Gregor Hodgson. Coral reefs and the 1997-1998 mass bleaching and mortality. *Nature & Resources*, 35(2):16–25, 1999.
- Kenneth I Wolpin. A new test of the permanent income hypothesis: the impact of weather on the income and consumption of farm households in india. *International Economic Review*, pages 583–594, 1982.

Yanos Zylberberg. Natural natural disasters and economic disruption, 2012.

Appendix A

DETAILS ON THEORETICAL MODEL AND ADDITIONAL EMPIRICAL RESULTS

A.1 *Theoretical Framework– Further Details*

This appendix discusses alternative specifications for the theoretical model. Specifically, I outline the interior solutions when the resource function takes two extreme functional forms—linear and Cobb-Douglas. The findings in this appendix support the main theoretical results: adaptations to a shock in fish resource are different between the short run and the long run, and the changes in migration depend on the substitutability between migration and initial fish stock in the resource function.

A.1.1 *Linear resource function*

The linear resource function, $R_1 = \delta + \gamma M_1$ and $R_2 = \delta + \gamma M_1 + \gamma M_2$, is the extreme case of the CES resource function where a shock to the initial fish resource can be flexibly compensated with migration. Under this assumption, it is possible to solve for closed-form solutions with or without the separation of fishery production decisions from the rest of the model. Without the separation property, the theoretical setup can be rewritten as

$$\begin{aligned} \max \quad & \log C_1 + \log (E^L - L_1 + L_1^{In} - L_1^{Out}) + \phi(\log C_2 + \log (E^L - L_2 + L_2^{In} - L_2^{Out})) \\ \text{s.t.} \quad & C_1 + pC_2 + w_1 L_1^{In} + w_2 L_2^{In} \leq L_1^\alpha (\delta + \gamma M_1)^\beta - m_1 M_1 + pL_2^\alpha (\delta + \gamma M_1 + \gamma M_2)^\beta - m_2 M_2 + w_1 L_1^{Out} + w_2 L_2^{Out} \\ & L_t = L_t^{HH} + L_t^{In}; t = 1, 2. \end{aligned}$$

Let λ be the Lagrange multiplier and $L_t^D = L_t^{In} - L_t^{Out}$. The following first order conditions must hold for the interior solution:

$$\begin{aligned}
[C_1] \quad & \frac{1}{C_1} = \lambda, \\
[C_2] \quad & \frac{\phi}{C_2} = p\lambda, \\
[L_1^D] \quad & \frac{1}{E^L - L_1 + L_1^D} = \lambda w_1, \\
[L_2^D] \quad & \frac{\phi}{E^L - L_2 + L_2^D} = \lambda w_2, \\
[L_1] \quad & \frac{1}{E^L - L_1 + L_1^D} = \lambda \alpha L_1^{\alpha-1} (\delta + \gamma M_1)^\beta, \\
[L_2] \quad & \frac{\phi}{E^L - L_2 + L_2^D} = \lambda p \alpha L_2^{\alpha-1} (\delta + \gamma M_1 + \gamma M_2)^\beta, \\
[M_1] \quad & \beta \gamma L_1^\alpha (\delta + \gamma M_1)^{\beta-1} + p \beta \gamma L_2^\alpha (\delta + \gamma M_1 + \gamma M_2)^{\beta-1} = m_1, \\
[M_2] \quad & p \beta \gamma L_2^\alpha (\delta + \gamma M_1 + \gamma M_2)^{\beta-1} = m_2, \\
[\lambda] \quad & L_1^\alpha (\delta + \gamma M_1)^\beta - m_1 M_1 + p L_2^\alpha (\delta + \gamma M_1 + \gamma M_2)^\beta - m_2 M_2 = C_1 + p C_2 + w_1 L_1^D + w_2 L_2^D.
\end{aligned}$$

Solving all first order conditions simultaneously leads to this interior solution:

$$\begin{aligned}
L_1 &= \left(\frac{\alpha}{w_1} \right)^{\frac{1-\beta}{1-\alpha-\beta}} \left(\frac{\beta \gamma}{m_1 - m_2} \right)^{\frac{\beta}{1-\alpha-\beta}}, \\
L_2 &= p^{\frac{-\beta}{\alpha}} \left(\frac{\alpha}{w_2} \right)^{\frac{1-\beta}{1-\alpha-\beta}} \left(\frac{\beta \gamma}{m_2} \right)^{\frac{\beta}{1-\alpha-\beta}}, \\
M_1 &= \frac{1}{\gamma} \left[\left(\frac{\alpha}{w_1} \right)^{\frac{\alpha}{1-\alpha-\beta}} \left(\frac{\beta \gamma}{m_1 - m_2} \right)^{\frac{1-\alpha-\beta+\alpha\beta}{(1-\alpha-\beta)(1-\beta)}} - \delta \right], \\
M_2 &= \frac{1}{\gamma} \left[p \left(\frac{\alpha}{w_2} \right)^{\frac{\alpha}{1-\alpha-\beta}} \left(\frac{\beta \gamma}{m_2} \right)^{\frac{1-\alpha}{1-\alpha-\beta}} - \left(\frac{\alpha}{w_1} \right)^{\frac{\alpha}{1-\alpha-\beta}} \left(\frac{\beta \gamma}{m_1 - m_2} \right)^{\frac{1-\alpha-\beta+\alpha\beta}{(1-\alpha-\beta)(1-\beta)}} \right], \\
C_1 &= \frac{\delta m_1}{\gamma(\phi + 3)} + \Omega, \\
C_2 &= \frac{\phi \delta m_1}{p \gamma(\phi + 3)} + \frac{\Omega}{p}, \\
L_1^{HH} + L_1^{Out} &= E^L - \frac{1}{w_1} \left[\frac{\delta m_1}{\gamma(\phi + 3)} + \Omega \right], \\
L_2^{HH} + L_2^{Out} &= E^L - \frac{\phi}{w_2} \left[\frac{\delta m_1}{\gamma(\phi + 3)} + \Omega \right],
\end{aligned}$$

$$l_1 = \frac{1}{w_1} \left[\frac{\delta m_1}{\gamma(\phi + 3)} + \Omega \right],$$

$$l_2 = \frac{1}{w_2} \left[\frac{\phi \delta m_1}{\gamma(\phi + 3)} + \Omega \right]$$

$$\begin{aligned} \text{where } \Omega = & \left(\frac{\alpha\gamma\beta}{w_1(m_1 - m_2)} \right)^{\frac{1}{1-\alpha-\beta}} \left[\left(\frac{\alpha}{w_1} \right)^\alpha \left(\frac{\beta\gamma}{m_1 - m_2} \right)^\beta - \frac{m_1}{\gamma} \left(\frac{\alpha}{w_1} \right)^\alpha \left(\frac{\beta\gamma}{m_1 - m_2} \right)^{\frac{1-\alpha-\beta+\alpha\beta}{(1-\beta)}} - \dots \right. \\ & \dots - w_1 \left(\frac{\alpha}{w_1} \right)^{1-\beta} \left(\frac{\beta\gamma}{m_1 - m_2} \right)^\beta \left. \right] + \left(\frac{\alpha\gamma\beta}{w_2 m_2} \right)^{\frac{1}{1-\alpha-\beta}} \left[p^2 \left(\frac{\alpha}{w_2} \right)^\alpha \left(\frac{\beta\gamma}{m_1 - m_2} \right)^\beta - p m_2 \left(\frac{\alpha}{w_2} \right)^\alpha - \dots \right. \\ & \dots - \left. \left(\frac{\beta\gamma}{m_1 - m_2} \right)^{1-\alpha} - w_2 p^{\frac{-\beta}{\alpha}} \left(\frac{\alpha}{w_2} \right)^{1-\beta} \left(\frac{\beta\gamma}{m_2} \right)^\beta \right] + w_1 + w_2. \end{aligned}$$

Similar to the result under the CES resource function with $\rho = 0.8$, the interior solution from the linear resource function implies that a shock to the initial fish stock is associated with an increase in migration in the short run. However, migration in the long run does not change in response to this shock. This time inconsistency pattern stems from the implicit assumption that migration cannot affect the marginal product of initial fish stock resource, $\frac{\partial R_t^2}{\partial \delta \partial M_t} = 0$, in addition to the difference between marginal benefits of migration in the two periods.

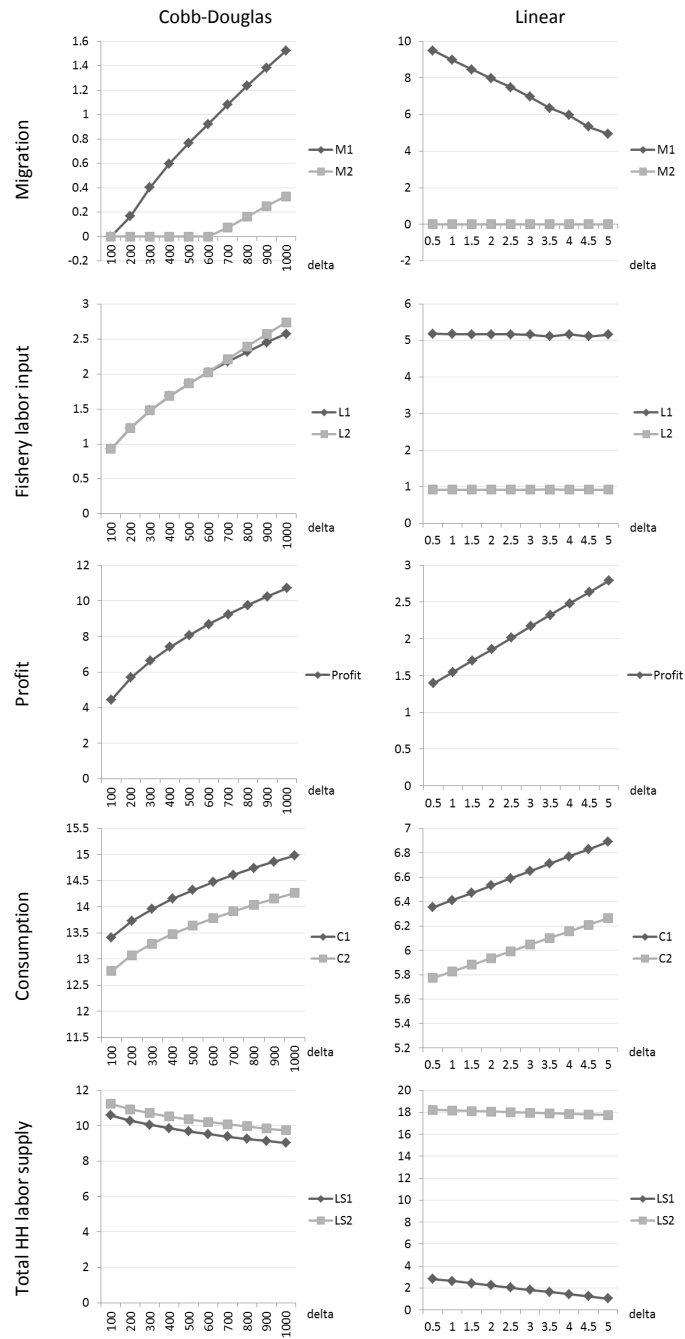
Changes in total household labor supply, $L_t^{HH} + L_t^{Out} = E^L - l_t$, also exhibit the time inconsistency pattern. The household tends to increase their total household labor supply after a shock to the fish stock resource only in the short run. The model also implies that the shock to the initial resource endowment does not affect total fishery labor input, $L_t^{HH} + L_t^{In}$, due partly to the functional form assumption. These changes imply that household's net labor supply to the labor market, $L_t^{Out} - L_t^{In}$, rises after the shock in the short run.

These changes in fishery production and labor market activities fail to prevent a fall in fishery profit after the shock to initial resource endowment. As consumption depends on total household income, consumption also declines after the shock, with a larger fall in the short run relative to the long run.

A.1.2 Cobb-Douglas Resource Function

Another extreme of the CES resource function is when the elasticity of substitution between migration and fish stock is one, the Cobb-Douglas function. Figure A.1.1 illustrates the results from numerical optimization for the linear and Cobb-Douglas resource specifications.

Figure A.1.1: Theoretical relationships between initial fish resource endowment (δ), inputs, and fishery profit obtained from Cobb-Douglas and linear resource functions



Fishery production function takes the form $F_t(L_t, R_t) = L_t^\alpha R_t^\beta$. Cobb-Douglas resource functions are written as $R_1 = \delta^\gamma M_1^\gamma$, and $R_2 = \delta^\gamma M_1^\gamma M_2^\gamma$. These results are obtained from numerical optimization with the following parameters: $\alpha = 0.3, \beta = 0.5, \eta = 0.5, \gamma = 0.3$. For Cobb-Douglas: $w_1 = 1, w_2 = 1.05, p = 1.05, m_1 = 1.08$, and $m_2 = 1.08$. For linear: $w_1 = .3, w_2 = .33, p = .33, m_1 = .31$, and $m_2 = .31$.

Table A.2.1: Effects of coral bleaching on labor market outcomes - fishery control group

	(1)	(2)	(3)	(4)	(5)
	Migration	Work hours	Work weeks	Second jobs	Fishermen
<i>A: Binary treatment</i>					
2000*Fish	0.1596** (0.0724)	-1.253 (4.1025)	-0.9271 (4.0757)	-0.1752* (0.0977)	-0.0465 (0.1601)
2007*Fish	0.0861 (0.0922)	6.7686* (3.756)	14.5637*** (4.5903)	0.2161** (0.0929)	-0.1595 (0.1622)
F-Test p-value	0.4285	0.0389	0.0007	0.0001	0.4753
<i>B: SST anomaly days</i>					
2000*SSTdays	0.0012 (0.0008)	-0.025 (0.0579)	-0.0033 (0.0589)	-0.002 (0.0014)	-0.0013 (0.0022)
2007*SSTdays	0.0037*** (0.0012)	0.0741 (0.0538)	0.2027*** (0.0629)	0.0023* (0.0013)	-0.0011 (0.0023)
F-Test p-value	0.0124	0.0745	0.0013	0.0023	0.9303
N	673	882	882	883	829
Mean dependent variable	0.177	29.682	32.926	0.313	0.812

Remarks: Clustered standard errors are in parenthesis. *, **, *** denote statistical significance at 10%, 5%, and 1%, respectively. F-test $H_0 : \beta_{2000} = \beta_{2007}$. All models include household head's gender, age, and education as control covariates. Wave, province and household fixed effects are included in all specifications. Work hours is per week and per worker. Work weeks is per year and per worker. Second job is equal to one if at least one worker in a household has a secondary job. Fishermen is the number of household workers in fishery.

In the Cobb-Douglas case, migration and fishery labor inputs fall with the initial fish stock endowment, which contrasts with the finding based on the linear functional form. As migration incurs costs while there is no cost to the resource endowment, it might not be optimal for the household to increase migration in response to the resource endowment shock when the elasticity of substitution between the two factors is relatively low. When the cost of migration is zero, a fall in resource endowment is associated with increases in migration in both periods under the Cobb-Douglas resource function specification.

A.2 Additional Empirical Results

Table A.2.1 exhibits the effects of coral bleaching on labor outcomes using the fishery control group. Most results are similar to the results presented in the main empirical section in chapter 1.

Table A.2.2 shows the results on purchased and produced consumption using the double difference specification with non-fishery households as a control group. Table A.2.3 exhibits

the consumption results using the triple difference specification.

Table [A.2.4](#) contains spillover results in specifications that control for the rainfall deviation in 1997. These results are similar to the results from the main specifications as well as those from the robustness checks with transitory rainfall deviations in chapter 3.

Figure [A.2](#) illustrates that the spillover effects in chapter 3 are robust to different functional forms of transitory rainfall, including lags and polynomials. Most of the coefficients do not change under various forms of transitory rainfall. The top panel of each graph exhibits β_τ from (3.1) with their respective 90% confidence intervals under different specifications of rainfall (models a-g), and under the main specification that does not control for rainfall (model h). The bottom panel contains model selection criteria, including AIC, BIC, and adjusted R^2 , for all the models. The details on specifications in models a-g are in table [A.2.5](#)

Table A.2.2: Effects of coral bleaching on consumption purchases and consumption of household production - geographical control

	Purchases						
	(1) Total food	(2) All protein	(3) Fish	(4) Meat	(5) Other protein	(6) Fruit/veg	(7) Grain
<i>A: Binary treatment</i>							
2000*Fish	-0.1441 (0.1304)	-0.3721** (0.1453)	-0.017 (0.1738)	-0.0723 (0.1483)	-0.5292*** (0.1473)	-0.1934 (0.134)	-0.0982 (0.1665)
2007*Fish	0.0504 (0.1089)	0.0519 (0.1266)	0.216 (0.1442)	0.2424* (0.1379)	-0.025 (0.1286)	0.0751 (0.1229)	0.0633 (0.1395)
F-Test p-value	0.170	0.003	0.201	0.054	0.001	0.065	0.364
<i>B: SST anomaly days</i>							
2000*SST	-0.0043** (0.0019)	-0.0066*** (0.0021)	0.0004 (0.0027)	0.0001 (0.0024)	-0.0074*** (0.0023)	-0.0039* (0.002)	-0.0033 (0.0023)
2007*SST	0.0009 (0.0014)	-0.001 (0.0018)	0.002 (0.002)	0.0031* (0.0019)	-0.0024 (0.0018)	-0.0014 (0.0015)	-0.0002 (0.0018)
F-Test p-value	0.0030	0.004	0.567	0.265	0.01	0.242	0.172
N	9544	9544	9544	9544	9544	9544	9544
Mean dep var	2.731	2.066	1.394	0.874	1.648	1.709	1.655
	Household production						
	(1) Total food	(2) All protein	(3) Fish	(4) Meat	(5) Other protein	(6) Fruit/veg	(7) Grain
<i>A: Binary treatment</i>							
2000*Fish	-0.2816* (0.1605)	-0.5071*** (0.1879)	-0.187 (0.1805)	-0.178** (0.0747)	-0.2224** (0.1079)	-0.3193** (0.1489)	0.014 (0.1403)
2007*Fish	-0.1832 (0.1531)	-0.4266*** (0.1456)	-0.4718*** (0.1506)	-0.0419 (0.0881)	0.1389 (0.1042)	0.0736 (0.1319)	0.0971 (0.1349)
F-Test p-value	0.635	0.62	0.134	0.16	0.007	0.007	0.622
<i>B: SST anomaly days</i>							
2000*SST	-0.0063*** (0.0021)	-0.0092*** (0.003)	-0.0061** (0.0028)	-0.0018 (0.0011)	-0.0025 (0.0017)	-0.0058*** (0.0022)	-0.0001 (0.0021)
2007*SST	-0.0022 (0.0017)	-0.0065*** (0.0021)	-0.006*** (0.0021)	-0.0001 (0.0012)	0.0006 (0.0013)	0.0007 (0.0018)	0.0024 (0.0017)
F-Test p-value	0.0350	0.287	0.962	0.326	0.086	0.002	0.265
N	9544	9544	9544	9544	9544	9544	9544
Mean dep var	1.697	0.668	0.221	0.213	0.418	0.906	0.883

Remarks: Clustered standard errors are in parenthesis. *, **, *** denote statistical significance at 10%, 5%, and 1%, respectively. F-test $H_0 : \beta_{2000} = \beta_{2007}$. All models include household head's gender, age, and education as control covariates. Wave, province and household fixed effects are included in all specifications. Dependent variables are log of purchased consumption expenditures and log of consumption of household production (expenditure-equivalent).

Table A.2.3: Effects of coral bleaching on consumption purchases and consumption of household production - triple differences

	Purchases						
	(1) Total food	(2) All protein	(3) Fish	(4) Meat	(5) Other protein	(6) Fruit/veg	(7) Grain
2000*Bleach	-0.1666 (0.1726)	-0.5101*** (0.1731)	-0.0849 (0.2078)	0.0176 (0.1675)	-0.6236*** (0.178)	-0.2566 (0.1573)	-0.0134 (0.1967)
2007*Bleach	0.0462 (0.1572)	-0.1461 (0.1574)	0.1533 (0.1863)	0.2093 (0.1642)	-0.1223 (0.1638)	0.0159 (0.1472)	0.1485 (0.1781)
F-Test p-value	0.114	0.007	0.183	0.229	0	0.05	0.347
N	31244	31244	31244	31244	31244	31244	31244
Mean dep var	2.695	2.022	1.391	0.88	1.657	1.723	1.673

	Household production						
	(1) Total food	(2) All protein	(3) Fish	(4) Meat	(5) Other protein	(6) Fruit/veg	(7) Grain
2000*Bleach	-0.1267 (0.202)	-0.4291** (0.2107)	-0.2237 (0.2028)	-0.196** (0.0891)	-0.1323 (0.123)	-0.1718 (0.1649)	0.0285 (0.1602)
2007*Bleach	-0.0769 (0.1953)	-0.434** (0.1788)	-0.5052*** (0.1798)	-0.0764 (0.0965)	0.1216 (0.1226)	0.0802 (0.1505)	0.0143 (0.1567)
F-Test p-value	0.800	0.975	0.13	0.17	0.047	0.066	0.93
N	31244	31244	31244	31244	31244	31244	31244
Mean dep var	1.499	0.538	0.186	0.184	0.309	0.731	0.742

Remarks: Clustered standard errors are in parenthesis. *, **, *** denote statistical significance at 10%, 5%, and 1%, respectively. F-test $H_0 : \beta_{2000} = \beta_{2007}$. All models include household head's gender, age, and education as control covariates. Wave, province and household fixed effects are included in all specifications. Dependent variables are log of purchased consumption expenditures and log of consumption of household production (expenditure-equivalent).

Table A.2.4: Spillovers of coral bleaching to non-fishery households—controlling for 1997 rainfall

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	Work hours	Work weeks	Second jobs	Fishermen	Pos income	log(income)	Farm business	log(farm profit)
2000*Bleach	-0.5757 (0.9445)	-2.0561** (0.893)	0.0151 (0.0233)	-0.012*** (0.0045)	-0.062*** (0.0135)	0.0161 (0.107)	-0.0459*** (0.0166)	0.0026 (0.1022)
2007*Bleach	0.1918 (1.2438)	-0.0733 (1.0686)	0.0405 (0.0253)	-0.0023 (0.0069)	-0.0517*** (0.0137)	-0.1683 (0.1417)	-0.0614*** (0.0198)	-0.1815 (0.1136)
F-Test p-value	0.4817	0.0531	0.2977	0.1711	0.2858	0.1289	0.3799	0.0995
N	24,236	24,323	24,361	24,358	24,271	20,536	24,269	7,561
Cluster N	9,021	9,056	9,064	9,063	9,048	8,562	9,047	3,481
Mean dependent variable	30.99	33.04	0.28	0.01	0.90	13.90	0.35	13.45

Remarks: This table contains β_τ from (3.1). Clustered standard errors are in parenthesis. *, **, *** denote statistical significance at 10%, 5%, and 1%, respectively. F-test $H_0 : \beta_{2000} = \beta_{2007}$. Sample is all non-fishery households in the IFLS, except those in provinces with reported forest fires in 1997 (West Sumatra, South Sumatra, and West Kalimantan), and those with substantial tourism (Bali and West Nusa). All models include household head's gender, age, and education as control covariates. Wave, province and household fixed effects are included in all specifications. All specifications also include the wet-season rainfall deviation in 1997 as a control variable. Dependent variables are working hours per week per worker, working weeks per year per worker, the number of HH members with secondary jobs, the number of fishermen in HH, a dummy indicator for positive household income, and log of real household income per worker, presence of farm business, and log of farm profit. The sample in columns 6 and 8 includes only households with positive income/profit.

Figure A.2.1: Robustness of spillover effects to different functional forms of transitory rainfall

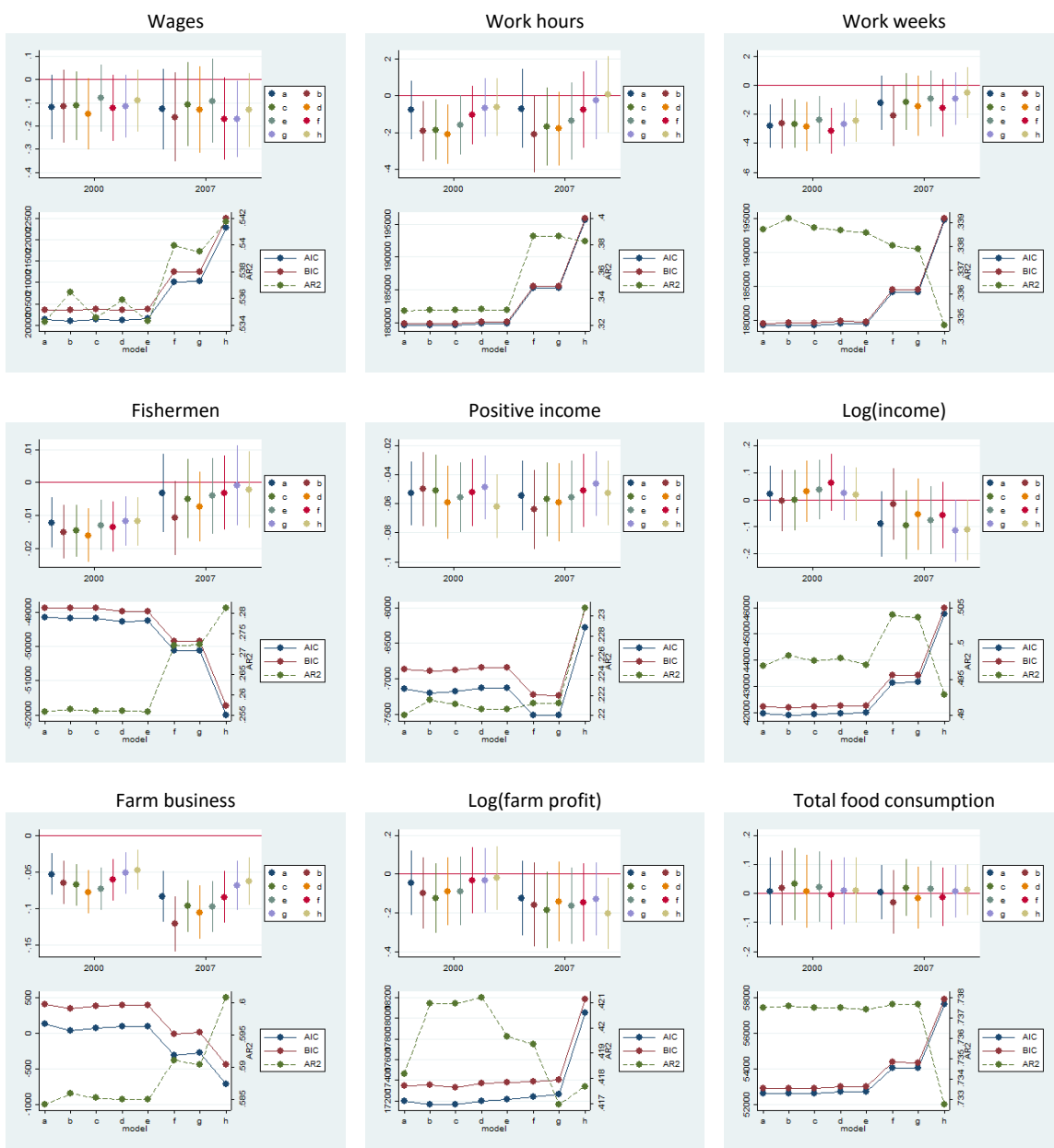


Table A.2.5: Model specifications for rainfall

Model	Specification
a	$rain_t + rain_{t-1} + rain_{t-2}$
b	$\sum_{q=1}^3 (rain_t^q + rain_{t-1}^q + rain_{t-2}^q)$
c	$\sum_{q=1}^2 (rain_t^q + rain_{t-1}^q + rain_{t-2}^q)$
d	$\sum_{q=1}^3 (rain_t^q + rain_{t-1}^q)$
e	$\sum_{q=1}^3 rain_t^q$
g	$rain_t$
h	na

Note: $rain_t$ denotes transitory rainfall deviation in year t .