Long-Lasting Income Shock and Adaptations: Evidence from Coral Bleaching in Indonesia

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Abstract

This paper 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. I also find evidence for declines in most consumption measures in the short run. Protein consumption dropped the most, and grain consumption almost did not change. This fall in consumption is due to both the decreases in income and protein availability.

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[2] For the latest version, please visit `https://dl.dropboxusercontent.com/u/13416847/JMP_Chaijaroen.pdf`.

1 Introduction

The world climate has been changing with the expectation that the temperature will continue to rise for the coming centuries. There is a robust debate about how 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 areas[2] and 16.7% of global animal protein consumption coming from fish (FAO, 2014), these impacts can be substantial.

This paper 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 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 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. 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

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[1] For 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.

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

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.

I have three main results. 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 2007[3]. 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. Third, 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. Protein consumption was one of the consumption measures with the largest drops. This, combined with results on fruit and vegetable consumption, suggests that the affected households received less nutrition relative to the control groups at least in the short run.

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). Taraz (2015) 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. Schlenker and Lobell (2010) 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 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.

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[3] The public version of the IFLS is currently available for 1993, 1997, 2000, and 2007.

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 findings in this paper have implications for policies that could alleviate adverse effects of coral bleaching as well as other long-lasting income shocks in general. Without fully-measured costs and benefits, we cannot make meaningful policy recommendations.

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.

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, our focus is 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) (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.

[Figure 1 about here.]

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 locations[4]. In general, coral depletion leads to a rapid decline in abundance of coral reef species in the short to medium 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 lagged 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).

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[4] For 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.

The impact of coral bleaching on human is at least three folds. 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).

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 an endowed factor of production– fish stock resource. The model is based on the agricultural household framework, in which a household engages in fishery 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.

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. The budget constraint then imposes a condition that total consumption expenditure must be less than or equal to the sum of fishery profits and wage incomes. 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

$$
\begin{aligned}
\max \quad & \log C_1 + \log l_1 + \phi(\log C_2 + \log l_2) \\
& \text{s.t. } C_1 + pC_2 + w_1 L_1^{In} + w_2 L_2^{In} \\
& \quad \le F(L_1, R(\delta, M_1)) - m_1 M_1 + pF(L_2, R(\delta, M_1, M_2)) - m_2 M_2 + w_1 L_1^{Out} + w_2 L_2^{Out} \\
& \xi = L_t^{HH} + L_t^{Out} + l_t; t = 1, 2 \\
& L_t = L_t^{HH} + L_t^{In}; t = 1, 2,
\end{aligned}
$$

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 ξ, so leisure and household labor supplies to fishery production and labor market must sum to ξ.

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 conditions. 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* $\frac{\partial R_1}{\partial M_2} = 0$*.*

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, $R(\delta, M_1, M_2)$. In a baseline model, I impose a constant elasticity of substitution (CES) functional form on the resource functions, so we can explore 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

$$R_1 = (\delta^\rho + M_1^\rho)^\rho,$$

$$R_2 = (\delta^\rho + M_1^\rho + M_2^\rho)^\rho.$$

3.2 Interior Solution

Figure 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 are different with different values of 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. 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 low. When only small increases in migration are required to alleviate the effect of fish stock reduction, migration rises when there is an initial fish endowment shock. Otherwise, migration falls as the initial fish stock decreases. Empirical results presented in the next section support the case of high substitutability between migration and initial fish stock.

[Figure 2 about here.]

These findings suggest time inconsistency 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 in models with positive relationship between migration and resource endowment. These time consistency patterns 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 discusses theoretical findings based on a more conventional function form, Cobb-Douglas, of the resource function. It also outlines the closed-form interior solution based on a linear resource function.

4 Empirical Framework

4.1 Data

The main sources of data in this paper are the Indonesian Family Life Survey (IFLS)[5], reported coral bleaching spots from Goreau et al. (2000), and SST anomaly from National Oceanic and

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[5] Frankenberg and Karoly (1995), Frankenberg and Duncan (2000), Strauss et al. (2004), and Strauss et al. (2009)

Atmospheric Administration (NOAA) remote-sensing map. The IFLS is a panel that has been tracking around 7,000 Indonesian households since 1993. The survey includes detailed information on socioeconomic status, consumption, labor market history, migration, and so on.

The public-use version of 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. 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. Table 1 illustrates the numbers of households by coral bleaching and control areas in each wave.

[Figure 3 about here.]

[Table 1 about here.]

Identification is based on variations of the difference-in-difference technique. The treated households are defined as households that engaged in fishery and lived in the affected areas in 1997. This treatment status is held constant across all waves of data. Table 2 shows the number of households who were affected by coral bleaching based on the 1997 wave of data. Of the 7,516 households, 2,191 households lived in the areas with reported coral bleaching spots, and 196 engaged in fishing. Among these households, 76 of them fished and lived in the coral bleaching area and hence constitute our treated group. 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 test[6] indicates that attrition is not significantly different between the treated and the control groups.

[Table 2 about here.]

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

The binary treatment status based on reported bleaching spots is subject to under reporting. This can result in significant measure errors. As a result, 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 (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 province[7], 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.

The SST anomaly days measure does not suffer from under-reporting, but it is not perfectly correlated with the actual bleaching events. Even though the SST anomaly is the most important cause of mass coral bleaching, light, currents, and water salinity could also adversely affect the coral reefs. Moreover, the SST threshold can vary by locations and coral species (Hughes et al., 2003). Despite these possible measurement errors, both measures of coral bleaching yield statistically significant and similar empirical results.

4.2 Methodology

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.

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[7] The exception to this rule is Bali and West Nusa Tengara 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.

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 variation of a difference-in-difference model where 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, coral bleaching may adversely affect income only in the short run when households have limited adaptation options. With more flexibility in the long run, people may find ways to mitigate the income shock, and the long run income effect maybe minimal.

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

$$Y_{ht} = \alpha + \delta_1 Treat_h + \delta_2 Post_t + \sum_{\tau=2000,2007} \beta_\tau I(wave = \tau) * Treat_h + \boldsymbol{X_{ht}\gamma} + \mu_h + \lambda_t + \epsilon_{ht}, \quad (1)$$

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 $\boldsymbol{X_{ht}}$ 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 factors that are constant within households, any particular wave, and provinces of residence prior to the shock.

Similar to (1), the estimating equation under the SST anomaly days specification takes the form

$$Y_{ht} = \alpha + \delta_1 SSTdays_h + \delta_2 Post_t + \sum_{\tau=2000,2007} \beta_\tau I(wave = \tau) * SSTdays_h + \boldsymbol{X_{ht}\gamma} + \mu_h + \lambda_t + \epsilon_{ht}, \quad (2)$$

where $SSTdays_h$ denotes the number of SST anomaly days household h faced during the 1998 coral bleaching.

The treatment status is specified as households who engaged in fishery and lived in the coral bleaching area in 1997. Consequently, 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 these non-observables that are constant within the fishery sector. One drawback of using the fishery control group is the small sample size as illustrated in Table 2.

[Table 3 about here.]

Table 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 4 and 5 help validate this assumption by comparing the treatment group's and the control groups' trends of log of real household income over time[8]. Log real household income is quite similar among the three groups prior to the 2000 wave. In 2000 the treatment group's income dropped before increasing in 2007.

[Figure 4 about here.]

[Figure 5 about here.]

One limitation of using the difference-in-difference specification with two control groups is that an unobservable that is controlled for in one control group specification might not be controlled for when using another control group. For example, if there is a change in fishery regulations, then all fishery households are affected, and the treatment effect can be identified using the fishery control group. However, identification fails if we use the geographic control group because fishery

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[8] Similar graphs for other outcome variables are available upon request.

regulations do not affect non-fishery households. One way to better control for the common factors is the triple difference approach. The triple difference specification allows for identification even when there exist both the unobservables that affect all fishery households and the unobservables that affect all households in coral bleaching areas. For instance, if there exist both a change in a fishery regulation at a country level and a geographical price shock common to every household in coral bleaching area, then the treatment effect cannot be identified using the double difference specifications. However, the treatment effect can be identified using the triple difference specification as this specification simultaneously controls for both changes in mean outcomes of the fishery group in non-coral bleaching area and changes in mean outcomes of the non-fishery households in coral bleaching area. The estimating question based on the triple difference specification can be written as

$$Y_{ht} = \alpha + \delta_p Post_t + \delta_f Fish_h + \delta_b Bleach_h + \phi_1 Post_t * Fish_h + \phi_2 Post_t * Bleach_h + \phi_3 Fish_h * Bleach_h + ...$$

$$... + \sum_{\tau=2000,2007} \beta_\tau I(wave = \tau) * Fish_h * Bleach_h + \boldsymbol{X_{ht}}\boldsymbol{\gamma} + \mu_h + \lambda_t + \epsilon_{ht}. \quad (3)$$

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 weaker than those from the double difference specifications and are presented in the next section as a robustness check.

The second identification concern is measurement errors. The current measures of coral bleaching in this paper contain varying extents of measurement errors. 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. In either case, the measurement errors bias the OLS estimates towards zero. Despite these measurement errors, I find significant impacts of coral bleaching on various outcomes using both measures of coral bleaching and both definitions of control groups.

The rest of the empirical section 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 and consumption. The labor market decisions include decisions to migrate, supply labor, and switch to another industry. For consumption, I look into both the changes in consumption expenditures and whether the affected households substitute between different consumption categories.

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. In terms of consumption, a number of consumption measures change in tandem with income. The largest drop in consumption in 2000 is the fall in overall protein consumption. In contrast, food staple consumption almost did not change in response to the change in income. These findings suggest that coral bleaching and income shock could result in a decline in nutrition intake among the affected households. This section explains all empirical results in details. First, the results on income are discussed. Then, labor-related adaptations and changes in consumption are deliberated.

5.1 Income shock

Tables 4-5 show the estimates of the key coefficients from equations (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. As the affected households adjusted, their income increased. Consequently, their income was at a level comparable to the control groups' in 2007, nine years after coral bleaching.

Columns 2 in Tables 4-5 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 that the income shock is averaged 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 affirmed under the SST anomaly specifications– the coefficients on $I(2000) * SSTdays_h$ are also negative and translated into large percentage declines in income relative to both control groups. 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. To ensure that this exclusion is not systematically different between the treatment and the control groups, I estimate equation (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.

[Table 4 about here.]

[Table 5 about here.]

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 should also investigate if the affected households adjusted another factor of fishery production, labor supply, as well as other labor-related behaviors that could have alleviated the income shock. The most important take away among many labor-related findings is that labor market options became more flexible 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 to a possible lack of skills. 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 skill acquisition over time.

[Table 6 about here.]

Table 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 to migrate. The 2007 effect on migration is not statistically significant. These estimates imply that the affected households are more likely to migrate right after the shock than much later in time. 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 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 0.34[9].

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

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[9] Full spillover results are available upon request.

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 15 in appendix B.

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. 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 for the affected households.

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 change 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 hypothesis. Another reasonable explanation is that the treated households might not have skills to work outside of fishery in the short run, 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. 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. This increase in migration, however, could not fully compensate for the resource shock. The affected households still experienced a drop in income in 2000. In addition, there is no statistically significant evidence for an increase in labor supply or industry switching in the short run. Nonetheless, labor market adaptations were more flexible 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 and households' skill acquisition took time. As a result, policies that help households transition into other industries would be useful.

5.3 Consumption

Given the income shock in 2000, I find evidence for a fall in consumption in various consumption measures. 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 micronutrients 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.

[Table 7 about here.]

[Table 8 about here.]

The regression results in Tables 7-8 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 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, 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'. Detailed results on food consumption in Table 9 and Table 16 in appendix B 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. 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 are an evidence for 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 substitution pattern is particularly troublesome when the affected households were in fishery, and their protein source was closely tied with their income source.

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 might 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. 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.

[Table 9 about here.]

Columns 4 in Tables 7-8 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 protein after coral bleaching in the affected area. Market could have been efficient enough to handle a supply shock that was limited to only some areas. 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 9 and 16 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 in some model specifications. The drop in consumption of caught fish could have resulted from a substitution of household consumption for sales of fish. However, the simultaneous fall in income and the fact that the affected households still engaged in fishery in 2000 rule out this substitution. Moreover, fishing effort, as proxied by working hours or working weeks, did not statistically change in 2000. All these findings imply that fish stock declined and that protein from fish became less available at least in 2000. 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 10 illustrates the differences in protein and other food consumption among non-fishery households who live in and outside of coral bleaching areas. The results suggest a weak evidence for a spill over 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, 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 and both meat and fish were equally available, the households would have increased both meat and fish consumption. This hypothesis also reinforces the argument that fish protein became less available after coral bleaching. Alternatively, market might have reallocated the fish supply so that coral bleaching had no effects on fish available for purchases.

[Table 10 about here.]

All the empirical results so far imply that protein is a luxury good. The estimates 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 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 7), 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. 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 consumption types as equivalent as they might be able to sell their production output at a 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, protein purchase will give a more direct inference on the luxury good argument. Further evidence suggests that the latter might be true.

Table 9 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. 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 9. 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 18 in appendix B). However, the double difference specifications using the geographical control group yield slightly different results as the non-fishery households in coral bleaching areas increased their consumption of many household-produced goods in 2000. Detailed results are included in appendix B.

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 possible 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 or the Asian Crisis, so the risk-sharing mechanisms were not feasible. These prospects should be explored in future work.

5.3.1 Robustness Checks

This section examines the robustness of the empirical via a triple difference specification and a false 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. 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 (3) and show that most empirical findings hold. Table 11 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.

[Table 11 about here.]

Results on labor market outcomes and consumption based on the triple difference model also share the same key characteristics 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.

[Table 12 about here.]

In terms of consumption, the triple difference models also affirm 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} 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.

[Table 13 about here.]

The second robustness check is whether there are false 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 14 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 sector[10].

[Table 14 about here.]

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[10] There is an evidence for labor market and consumption spillovers to non-fishery households in coral bleaching areas. Details are still under investigation. Full results are available upon request.

6 Conclusion

In this paper 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 paper include labor activities and consumption.

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 perspectives, the findings in this paper provide insights into ways to alleviate impacts of unexpected, long-lasting income shocks. From the environmental perspectives, 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 terms of consumption, I find evidence for a decline in almost every consumption measure with the largest negative effect on protein consumption. Food staple consumption is largely unaffected by changes in income. Moreover, evidence also suggests that protein from fish became less available after coral bleaching and that protein was a luxury good for these households. These results imply that policies that could help smooth consumption would be useful. Quick-fix policies can be, for example, consumption subsidy and nutrition supplements. However, policies that could solve the problem from its root causes should promote safety nets such as savings and insurance.

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A 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 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

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

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:

$$\begin{aligned}
[C_1] \quad & \frac{1}{C_1} = \lambda, \\
[C_2] \quad & \frac{\phi}{C_2} = p\lambda, \\
[L_1^D] \quad & \frac{1}{\xi - L_1 + L_1^D} = \lambda w_1,
\end{aligned}$$

$$
\begin{aligned}
[L_2^D] &\quad \frac{\phi}{\xi - L_2 + L_2^D} = \lambda w_2, \\
[L_1] &\quad \frac{1}{\xi - L_1 + L_1^D} = \lambda \alpha L_1^{\alpha-1}(\delta + \gamma M_1)^{\beta}, \\
[L_2] &\quad \frac{\phi}{\xi - L_2 + L_2^D} = \lambda p \alpha L_2^{\alpha-1}(\delta + \gamma M_1 + \gamma M_2)^{\beta}, \\
[M_1] &\quad \beta\gamma L_1^{\alpha}(\delta + \gamma M_1)^{\beta-1} + p\beta\gamma L_2^{\alpha}(\delta + \gamma M_1 + \gamma M_2)^{\beta-1} = m_1, \\
[M_2] &\quad p\beta\gamma L_2^{\alpha}(\delta + \gamma M_1 + \gamma M_2)^{\beta-1} = m_2, \\
[\lambda] &\quad L_1^{\alpha}(\delta + \gamma M_1)^{\beta} - m_1 M_1 + pL_2^{\alpha}(\delta + \gamma M_1 + \gamma M_2)^{\beta} - m_2 M_2 = C_1 + pC_2 + w_1 L_1^D + w_2 L_2^D.
\end{aligned}
$$

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

$$
\begin{aligned}
&L_1 = \Big(\frac{\alpha}{w_1}\Big)^{\frac{1-\beta}{1-\alpha-\beta}} \Big(\frac{\beta\gamma}{m_1 - m_2}\Big)^{\frac{\beta}{1-\alpha-\beta}}, \\
&L_2 = p^{\frac{-\beta}{\alpha}} \Big(\frac{\alpha}{w_2}\Big)^{\frac{1-\beta}{1-\alpha-\beta}} \Big(\frac{\beta\gamma}{m_2}\Big)^{\frac{\beta}{1-\alpha-\beta}}, \\
&M_1 = \frac{1}{\gamma}\left[\Big(\frac{\alpha}{w_1}\Big)^{\frac{\alpha}{1-\alpha-\beta}} \Big(\frac{\beta\gamma}{m_1 - m_2}\Big)^{\frac{1-\alpha-\beta+\alpha\beta}{(1-\alpha-\beta)(1-\beta)}} - \delta\right], \\
&M_2 = \frac{1}{\gamma}\left[p\Big(\frac{\alpha}{w_2}\Big)^{\frac{\alpha}{1-\alpha-\beta}} \Big(\frac{\beta\gamma}{m_2}\Big)^{\frac{1-\alpha}{1-\alpha-\beta}} - \Big(\frac{\alpha}{w_1}\Big)^{\frac{\alpha}{1-\alpha-\beta}} \Big(\frac{\beta\gamma}{m_1 - m_2}\Big)^{\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} = \xi - \frac{1}{w_1}\left[\frac{\delta m_1}{\gamma(\phi+3)} + \Omega\right], \\
&L_2^{HH} + L_2^{Out} = \xi - \frac{\phi}{w_2}\left[\frac{\delta m_1}{\gamma(\phi+3)} + \Omega\right], \\
&l_1 = \frac{1}{w_1}[\frac{\delta m_1}{\gamma(\phi+3)} + \Omega], \\
&l_2 = \frac{1}{w_2}[\frac{\phi\delta m_1}{\gamma(\phi+3)} + \Omega] \\
&where \quad \Omega = \Big(\frac{\alpha\gamma\beta}{w_1(m_1 - m_2)}\Big)^{\frac{1}{1-\alpha-\beta}} \left[\Big(\frac{\alpha}{w_1}\Big)^{\alpha}\Big(\frac{\beta\gamma}{m_1 - m_2}\Big)^{\beta} - \frac{m_1}{\gamma}\Big(\frac{\alpha}{w_1}\Big)^{\alpha}\Big(\frac{\beta\gamma}{m_1 - m_2}\Big)^{\frac{1-\alpha-\beta+\alpha\beta}{(1-\beta)}} - ...\right. \\
&\qquad\qquad \left. ... - w_1\Big(\frac{\alpha}{w_1}\Big)^{1-\beta}\Big(\frac{\beta\gamma}{m_1 - m_2}\Big)^{\beta}\right] + \Big(\frac{\alpha\gamma\beta}{w_2 m_2}\Big)^{\frac{1}{1-\alpha-\beta}} \left[p^2\Big(\frac{\alpha}{w_2}\Big)^{\alpha}\Big(\frac{\beta\gamma}{m_1 - m_2}\Big)^{\beta} - pm_2\Big(\frac{\alpha}{w_2}\Big)^{\alpha} - ...\right.
\end{aligned}
$$

$$\ldots - \left(\frac{\beta\gamma}{m_1 - m_2}\right)^{1-\alpha} - w_2 p^{\frac{-\beta}{\alpha}} \left(\frac{\alpha}{w_2}\right)^{1-\beta} \left(\frac{\beta\gamma}{m_2}\right)^{\beta} \Bigg] + w_1 + w_2.$$

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 consistency 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, $L_t^{HH} + L_t^{Out} = \xi - l_t$, 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.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 6 illustrates the results from numerical optimization for the linear and Cobb-Douglas resource specifications.

[Figure 6 about here.]

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.

B Additional Empirical Results

Table 15 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.

[Table 15 about here.]

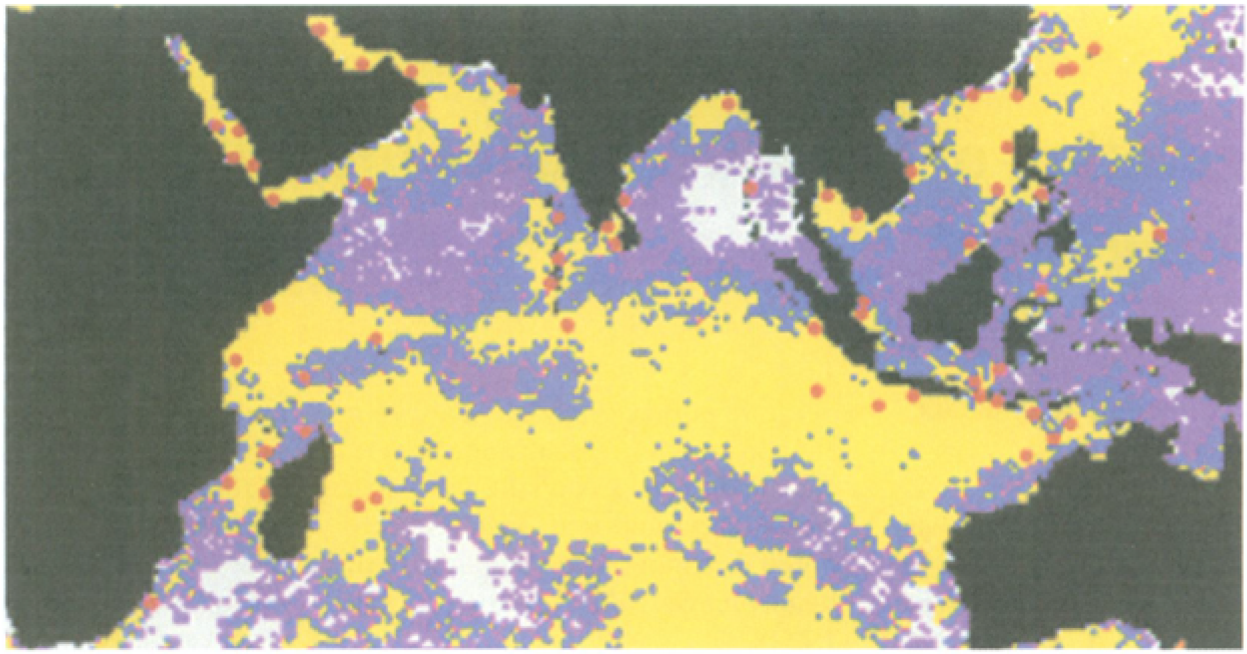
Table 16 shows the results on purchased and produced consumption using the double difference specification with non-fishery households as a control group, and Table 17 contains the double-difference splillover results. Specifically, the models in Table 17 compare consumption among non-fishery households in coral bleaching and control areas. Table 18 exhibits the results using the triple difference specification.

[Table 16 about here.]

[Table 17 about here.]

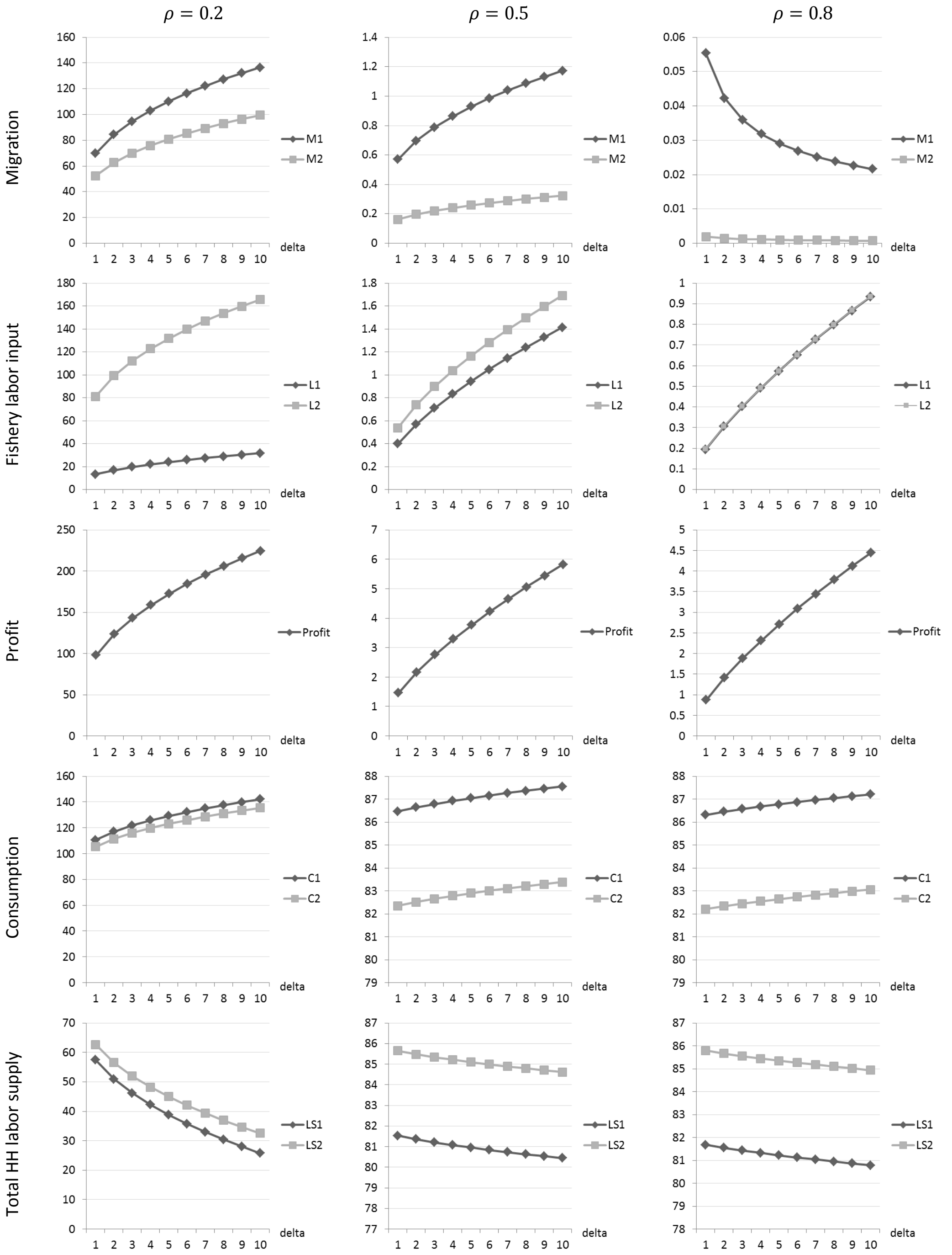
[Table 18 about here.]

Figure 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)

Figure 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 $\xi = 168$.

Figure 3: IFLS provinces and treated area

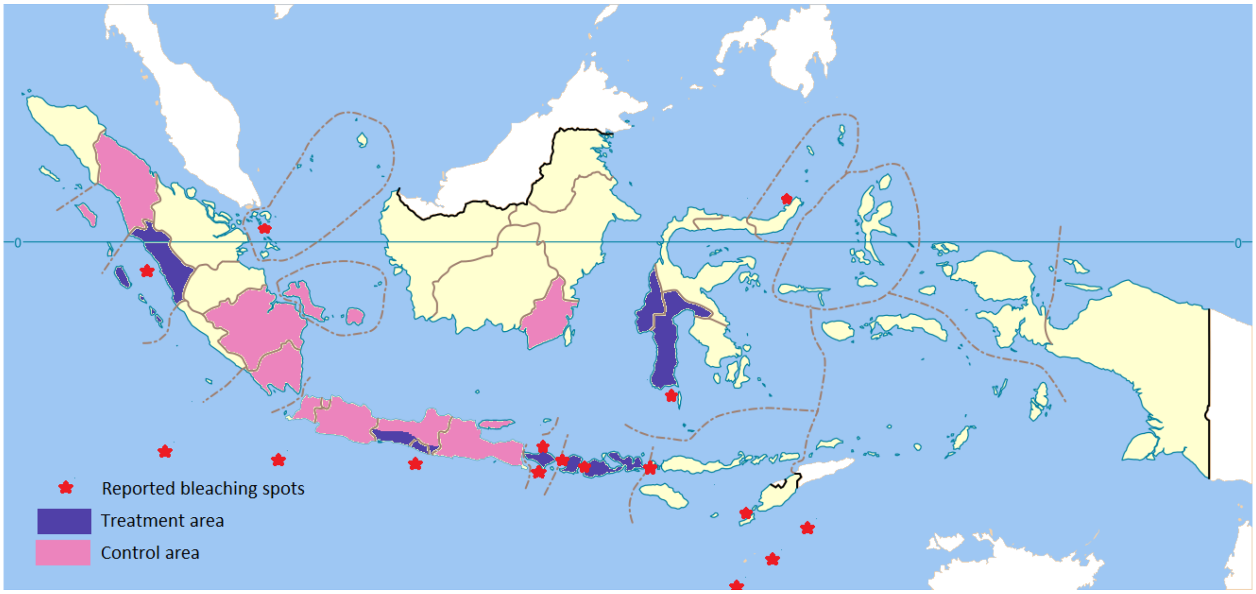
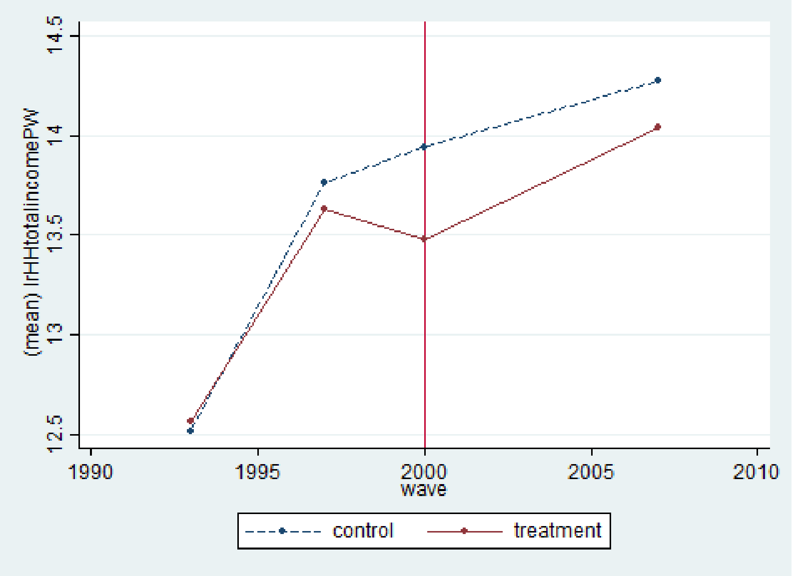


Figure 4: log(real household income per worker) of fishery households and other households in bleaching area

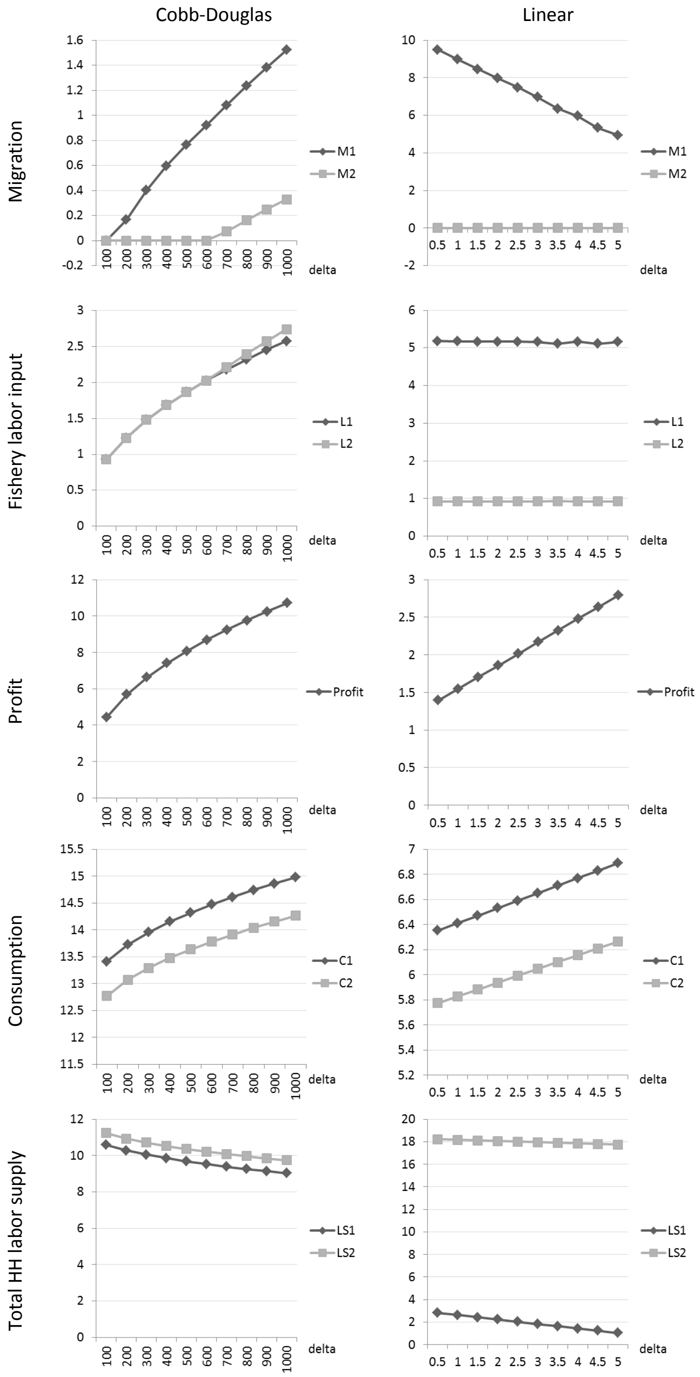


Averages are calculated from households with positive income

Figure 5: log(real household income per worker) among fishery households in bleaching and non-bleaching areas

Averages are calculated from households with positive income

Figure 6: 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 $R_1 = \delta^{\gamma} M_1^{\gamma} M_2^{\gamma}$. These results are obtained from numerical optimization with the following parameters: $\alpha = 0.3, \beta = 0.5, \eta = 0.5, \gamma = 0.3. ForCobb - Douglas : w_1 = 1, w_2 = 1.05, p = 1.05, m_1 = 1.08$, and $m_2 = 1.08$. For linear: $w_1 = .3, w_2 = .33, p = .33, m_1 = .31$, and $m_2 = .31$.

Table 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 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

Table 3: Summary statistics by treatment status, 1997 wave

	Treated group			Geographic control				Fishery control			
	Mean	SD	N	Mean	SD	N	p-value	Mean	SD	N	p-value
HH head's age	43.25	12.27	72	48.98	33.74	1,948	0.1511	43.91	11.91	112	0.7171
Male HH head	0.972	0.165	72	0.805	0.396	1,948	0.0004	0.929	0.259	112	0.2045
Number of members in fishery	1.184	0.647	76	0.000	0.000	2,115	1.0000	1.183	0.580	120	0.9921
Fraction of labor in fishery	0.421	0.212	76	0.000	0.000	2,115	1.0000	0.431	0.185	120	0.7226
SST anomaly days	58.39	32.90	76	0.00	0.00	2,115	1.0000	8.66	20.45	120	0.0000
Real HH income	1,413,430	2,124,524	73	1,884,484	7,467,620	1,777	0.5907	2,847,497	7,248,134	112	0.1020
Second job	0.539	0.871	76	0.356	0.601	2,115	0.0102	0.192	0.473	120	0.0004
Fraction of female labor	0.201	0.201	76	0.273	0.292	2,115	0.0325	0.112	0.184	120	0.0018
Working weeks per year	38.63	20.09	76	32.85	21.16	2,110	0.0192	27.76	12.19	120	0.0000
Working hours per week	33.22	17.54	76	27.62	18.85	2,112	0.0107	27.97	15.95	120	0.0320
Total food consumption expdt	6,128	4,134	76	8,324	17,927	2,110	0.2862	8,116	7,169	120	0.0293
Protein consumption expdt	1,444	1,457	76	2,096	5,815	2,110	0.3288	1,828	1,831	120	0.1238
Nonfood consumption expdt	39,347	60,296	76	102,742	257,106	2,052	0.0319	71,509	118,671	116	0.0302

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

Table 4: Effects of coral bleaching on income - geographic control group

	(1) log(income)	(2) Has zero or negative income
A: Binary treatment		
2000*Fish	-0.3236*	-0.0034
	(0.1821)	(0.0294)
2007*Fish	-0.0012	0.0165
	(0.2)	(0.0322)
F-Test p-value	0.0886	0.3381
B: SST anomaly days		
2000*SSTdays	-0.0046*	0.0005
	(0.0027)	(0.0003)
2007*SSTdays	0.0001	0.0006
	(0.0029)	(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), and panel B contains selected coefficients from equation (2). 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. Dependent variables are a dummy indicator for zero or negative household income and log of real household income per worker.

Table 5: Effects of coral bleaching on income - fishery control group

	(1) log(income)	(2) Has zero or negative income
A: Binary treatment		
2000*Fish	-0.6213**	0.0068
	(0.2562)	(0.0414)
2007*Fish	-0.0616	0.0071
	(0.2849)	(0.044)
F-Test p-value	0.0187	0.9898
B: SST anomaly days		
2000*SSTdays	-0.0062*	0.0004
	(0.0036)	(0.0006)
2007*SSTdays	0.0008	0.0004
	(0.0039)	(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), and panel B contains selected coefficients from equation (2). 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. Dependent variables are a dummy indicator for zero or negative household income and log of real household income per worker.

Table 6: Effects of coral bleaching on labor market outcomes - geographic control group

	(1) Migration	(2) Work hours	(3) Work weeks	(4) Second jobs	(5) Fishermen
A: Binary treatment					
I(2000)*Fish	0.1121**	1.1372	3.8924	-0.1205	-0.0807
	(0.0445)	(3.1596)	(3.5959)	(0.0837)	(0.1311)
I(2007)*Fish	-0.0584	5.7516*	13.7718***	0.1865**	-0.3874***
	(0.0703)	(3.0533)	(3.8307)	(0.0748)	(0.1301)
F-Test p-value	0.0442	0.1320	0.0156	0.0003	0.0244
B: SST anomaly days					
I(2000)*SSTdays	0.0007***	-0.0141	0.0317	-0.0023*	-0.0018
	(0.0002)	(0.047)	(0.0585)	(0.0013)	(0.0019)
I(2007)*SSTdays	0.0005	0.0786*	0.2317***	0.0028**	-0.0056***
	(0.0009)	(0.0463)	(0.0586)	(0.0012)	(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), and panel B contains selected coefficients from equation (2). 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.

Table 7: Effects of coral bleaching on consumption - geographic control group

	(1) Non-food	(2) Total Food	(3) All protein	(4) Fish	(5) Fruit/Veg	(6) Grain
A: Binary treatment						
I(2000)*Fish	-0.1407	-0.165	-0.4113***	-0.1634	-0.201*	-0.1312
	(0.1588)	(0.1361)	(0.129)	(0.1344)	(0.1181)	(0.1365)
I(2007)*Fish	0.225	0.0123	-0.1422	-0.254**	0.1909*	0.0824
	(0.1486)	(0.1186)	(0.105)	(0.1106)	(0.1091)	(0.1179)
F-Test p-value	0.049	0.277	0.035	0.488	0.003	0.079
B: SST anomaly days						
I(2000)*SST	-0.0042*	-0.0047**	-0.0067***	-0.0041**	-0.0039**	-0.0036*
	(0.0022)	(0.0019)	(0.002)	(0.0021)	(0.0018)	(0.002)
I(2007)*SST	0.0029	0.0006	-0.0024	-0.0035**	0.0004	0.0003
	(0.0019)	(0.0015)	(0.0015)	(0.0015)	(0.0014)	(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 (1), and panel B contains selected coefficients from equation (2). 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 expenditures per household member.

Table 8: 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
A: Binary treatment						
I(2000)*Bleach	-0.3704	-0.3416	-0.5514***	-0.4088**	-0.2725	-0.1032
	(0.247)	(0.2076)	(0.1912)	(0.1954)	(0.1721)	(0.1884)
I(2007)*Bleach	0.2868	0.0114	-0.2882*	-0.2641	0.1356	0.0635
	(0.2237)	(0.1547)	(0.157)	(0.1762)	(0.1386)	(0.1513)
F-Test p-value	0.004	0.076	0.137	0.441	0.013	0.331
B: SST anomaly days						
I(2000)*SST	-0.0059*	-0.0061**	-0.0067**	-0.0061**	-0.0041*	-0.0031
	(0.0032)	(0.0028)	(0.0027)	(0.0027)	(0.0024)	(0.0024)
I(2007)*SST	0.0028	0.001	-0.0029	-0.0026	-0.0007	0.0001
	(0.0028)	(0.0019)	(0.002)	(0.0022)	(0.0017)	(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 (1), and panel B contains selected coefficients from equation (2). 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 expenditures per household member.

Table 9: Effects of coral bleaching on consumption purchases and consumption of household production - fishery control

	Purchases						
	(1) Total food	(2) All protein	(3) Fish	(4) Meat	(5) Other protein	(6) Fruit/veg	(7) Grain
A: Binary treatment							
2000*Bleach	-0.2995	-0.5509***	-0.133	0.0775	-0.7439***	-0.3629**	-0.0796
	(0.2029)	(0.2068)	(0.2512)	(0.1878)	(0.2078)	(0.1803)	(0.2401)
2007*Bleach	0.1372	-0.1137	0.2543	0.1375	-0.1528	0.1625	0.1493
	(0.1623)	(0.155)	(0.1948)	(0.1645)	(0.1656)	(0.1517)	(0.1854)
F-Test p-value	0.019	0.017	0.103	0.775	0.001	0.006	0.323
B: SST anomaly days							
2000*SST	-0.0054**	-0.0065**	-0.0004	0.0017	-0.0064**	-0.0053**	-0.0037
	(0.0027)	(0.0028)	(0.0035)	(0.0027)	(0.003)	(0.0025)	(0.0031)
2007*SST	0.002	-0.0021	0.001	0.0014	-0.0031	-0.001	0.0002
	(0.0019)	(0.0021)	(0.0025)	(0.0022)	(0.0022)	(0.0019)	(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) Total food	(2) All protein	(3) Fish	(4) Meat	(5) Other protein	(6) Fruit/veg	(7) Grain
A: Binary treatment							
I(2000)*Bleach	-0.3307	-0.418*	-0.3408	-0.1975*	0.049	-0.04	0.2272
	(0.2189)	(0.2342)	(0.2187)	(0.1156)	(0.1428)	(0.1912)	(0.18)
I(2007)*Bleach	-0.2981	-0.3353*	-0.3917*	0.0389	0.0832	-0.0859	-0.0176
	(0.2097)	(0.2011)	(0.2082)	(0.0931)	(0.1351)	(0.1627)	(0.1596)
F-Test p-value	0.894	0.705	0.826	0.045	0.836	0.806	0.211
B: SST anomaly days							
I(2000)*SST	-0.0073**	-0.0077**	-0.0072**	-0.0016	0.0017	0.0013	0.0032
	(0.0028)	(0.0033)	(0.003)	(0.0015)	(0.0019)	(0.0027)	(0.0025)
I(2007)*SST	-0.0023	-0.0046*	-0.0031	-0.0003	-0.0005	0.0008	0.0021
	(0.0026)	(0.0026)	(0.0026)	(0.0012)	(0.0017)	(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 (1), and panel B contains selected coefficients from equation (2). 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. Dependent variables are log of purchased consumption expenditures and log of consumption of household production (expenditure-equivalent).

Table 10: Effects of coral bleaching on consumption - spillover

	(1) Total Food	(2) All protein	(3) Fish	(4) Meat	(5) Other protein	(6) Fruit/Veg	(7) Grain
A: Binary treatment							
I(2000)*Bleach	-0.0197	0.0666	0.012	0.1718***	-0.0608	0.0354	0.0483
	(0.0566)	(0.0552)	(0.0509)	(0.0557)	(0.0568)	(0.0481)	(0.0558)
I(2007)*Bleach	0.0448	0.0119	0.016	0.0309	-0.076	0.0402	0.0024
	(0.0455)	(0.0452)	(0.042)	(0.0494)	(0.0478)	(0.0403)	(0.046)
F-Test p-value	0.15	0.2	0.924	0.005	0.723	0.904	0.313
B: SST anomaly days							
I(2000)*SST	-0.0008	0.0009	0.0007	0.0012**	0.0013**	0.0009	0.0009
	(0.0006)	(0.0006)	(0.0005)	(0.0006)	(0.0006)	(0.0005)	(0.0006)
I(2007)*SST	-0.0001	-0.0002	-0.0002	-0.0018***	0.0003	0.0004	-0.0005
	(0.0004)	(0.0004)	(0.0004)	(0.0005)	(0.0004)	(0.0004)	(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 (1), and panel B contains selected coefficients from equation (2). 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. Dependent variables are log of total consumption expenditures. Sample is all non-fishery households.

Table 11: Effects of coral bleaching on income - triple differences

	(1) log(income)	(2) Has zero or negative income
2000*Fish*Bleach	-0.2803	-0.0393
	(0.2448)	(0.0412)
2007*Fish*Bleach	-0.0315	-0.0265
	(0.2581)	(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 (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. Dependent variables are a dummy indicatory for zero or negative household income and log of real household income per worker.

Table 12: Effects of coral bleaching on labor market outcomes - triple differences

	(1) Migration	(2) Work hours	(3) Work weeks	(4) Second job	(5) Fishermen
I(2000)*Fish*Bleach	0.247***	0.3739	2.1668	-0.1694*	0.0139
	(0.0703)	(3.7405)	(4.0822)	(0.0948)	(0.1531)
I(2007)*Fish*Bleach	0.0877	5.9099	13.956***	0.1786**	-0.2857*
	(0.0868)	(3.6851)	(4.3599)	(0.0883)	(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 (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.

Table 13: 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	-0.1642	-0.5006***	-0.2637	-0.2506*	-0.1052
	(0.2283)	(0.1853)	(0.1607)	(0.1662)	(0.147)	(0.1576)
I(2007)*Fish*Bleach	0.2803	0.0413	-0.2817**	-0.3426**	0.1246	0.0691
	(0.2202)	(0.1726)	(0.1429)	(0.1527)	(0.1402)	(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 (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. All consumption measures are log of real consumption per household member.

Table 14: Robustness check - false treatment on control area

	Income		Labor Activities					Consumption			
	(1) Zero/neg. income	(2) Income	(3) Migration	(4) Work hours	(5) Work weeks	(6) Second job	(7) Fishermen	(8) Non-food	(9) Total food	(10) Protein	(11) Food staples
I(2000)*Fish	0.0347	0.1548	-0.0623	0.746	1.1195	0.0221	-0.0155	-0.0266	0.0028	0.1376	-0.0149
	(0.0306)	(0.1787)	(0.0621)	(2.5353)	(1.9889)	(0.051)	(0.0876)	(0.2033)	(0.1688)	(0.1384)	(0.1292)
I(2007)*Fish	0.0467	-0.1912	-0.2053***	-0.8809	-0.8393	0.0177	-0.2015**	-0.0906	-0.0472	0.0704	-0.0085
	(0.0308)	(0.1883)	(0.0658)	(2.3877)	(2.6265)	(0.0587)	(0.1022)	(0.1689)	(0.1181)	(0.0965)	(0.0811)
F-Test p-value	0.5115	0.0219	0.0179	0.5378	0.3927	0.9362	0.0512	0.6915	0.7153	0.6001	0.9611
N	21,700	17,426	17,000	21,668	21,743	21,776	20,888	21,308	21,700	21,700	21,700
Mean dep. variable	0.103	13.918	0.223	30.437	32.559	0.275	0.034	3.194	2.757	2.082	1.991

Remarks: Estimates based on (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 households in areas without coral bleaching. 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 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.

Table 15: Effects of coral bleaching on labor market outcomes - fishery control group

	(1) Migration	(2) Work hours	(3) Work weeks	(4) Second jobs	(5) Fishermen
A: Binary treatment					
2000*Fish	0.1596**	-1.253	-0.9271	-0.1752*	-0.0465
	(0.0724)	(4.1025)	(4.0757)	(0.0977)	(0.1601)
2007*Fish	0.0861	6.7686*	14.5637***	0.2161**	-0.1595
	(0.0922)	(3.756)	(4.5903)	(0.0929)	(0.1622)
F-Test p-value	0.4285	0.0389	0.0007	0.0001	0.4753
B: SST anomaly days					
2000*SSTdays	0.0012	-0.025	-0.0033	-0.002	-0.0013
	(0.0008)	(0.0579)	(0.0589)	(0.0014)	(0.0022)
2007*SSTdays	0.0037***	0.0741	0.2027***	0.0023*	-0.0011
	(0.0012)	(0.0538)	(0.0629)	(0.0013)	(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 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.

Table 16: 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
A: Binary treatment							
2000*Fish	-0.1441	-0.3721**	-0.017	-0.0723	-0.5292***	-0.1934	-0.0982
	(0.1304)	(0.1453)	(0.1738)	(0.1483)	(0.1473)	(0.134)	(0.1665)
2007*Fish	0.0504	0.0519	0.216	0.2424*	-0.025	0.0751	0.0633
	(0.1089)	(0.1266)	(0.1442)	(0.1379)	(0.1286)	(0.1229)	(0.1395)
F-Test p-value	0.170	0.003	0.201	0.054	0.001	0.065	0.364
B: SST anomaly days							
2000*SST	-0.0043**	-0.0066***	0.0004	0.0001	-0.0074***	-0.0039*	-0.0033
	(0.0019)	(0.0021)	(0.0027)	(0.0024)	(0.0023)	(0.002)	(0.0023)
2007*SST	0.0009	-0.001	0.002	0.0031*	-0.0024	-0.0014	-0.0002
	(0.0014)	(0.0018)	(0.002)	(0.0019)	(0.0018)	(0.0015)	(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
A: Binary treatment							
2000*Fish	-0.2816*	-0.5071***	-0.187	-0.178**	-0.2224**	-0.3193**	0.014
	(0.1605)	(0.1879)	(0.1805)	(0.0747)	(0.1079)	(0.1489)	(0.1403)
2007*Fish	-0.1832	-0.4266***	-0.4718***	-0.0419	0.1389	0.0736	0.0971
	(0.1531)	(0.1456)	(0.1506)	(0.0881)	(0.1042)	(0.1319)	(0.1349)
F-Test p-value	0.635	0.62	0.134	0.16	0.007	0.007	0.622
B: SST anomaly days							
2000*SST	-0.0063***	-0.0092***	-0.0061**	-0.0018	-0.0025	-0.0058***	-0.0001
	(0.0021)	(0.003)	(0.0028)	(0.0011)	(0.0017)	(0.0022)	(0.0021)
2007*SST	-0.0022	-0.0065***	-0.006***	-0.0001	0.0006	0.0007	0.0024
	(0.0017)	(0.0021)	(0.0021)	(0.0012)	(0.0013)	(0.0018)	(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 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. Dependent variables are log of purchased consumption expenditures and log of consumption of household production (expenditure-equivalent).

Table 17: Effects of coral bleaching on consumption purchases and consumption of household production - non-fishery households in coral bleaching vs control areas

	Purchases						
	(1) Total food	(2) All protein	(3) Fish	(4) Meat	(5) Other protein	(6) Fruit/veg	(7) Grain
A: Binary treatment							
2000*Fish	-0.0178	0.0354	-0.0262	0.1179**	-0.0843	0.0576	-0.0012
	(0.0566)	(0.0552)	(0.0511)	(0.0524)	(0.0569)	(0.053)	(0.0612)
2007*Fish	0.0278	-0.0281	-0.0268	-0.0412	-0.0648	0.0856*	-0.0004
	(0.046)	(0.0462)	(0.0429)	(0.0461)	(0.0494)	(0.0458)	(0.0521)
F-Test p-value	0.309	0.146	0.989	0	0.657	0.519	0.987
B: SST anomaly days							
2000*SST	-0.0006	0.0008	0.0006	0.0011*	0.001*	0.0012**	0.0014**
	(0.0006)	(0.0006)	(0.0005)	(0.0006)	(0.0006)	(0.0006)	(0.0006)
2007*SST	-0.0002	-0.0005	-0.0003	-0.0016***	0	0.0004	-0.0009*
	(0.0004)	(0.0004)	(0.0004)	(0.0005)	(0.0004)	(0.0004)	(0.0005)
F-Test p-value	0.5260	0.014	0.095	0	0.038	0.134	0
N	30363	30363	30363	30363	30363	30363	30363
Mean dep var	2.706	2.034	1.404	0.892	1.667	1.729	1.673

	Household production						
	(1) Total food	(2) All protein	(3) Fish	(4) Meat	(5) Other protein	(6) Fruit/veg	(7) Grain
A: Binary treatment							
2000*Fish	-0.0393	0.2119***	0.0556*	0.0749**	0.1906***	0.1674***	0.1549***
	(0.063)	(0.0504)	(0.0305)	(0.0327)	(0.0427)	(0.0507)	(0.0536)
2007*Fish	-0.0726	0.096**	0.0461*	0.067**	0.041	0.0042	0.0372
	(0.0558)	(0.0403)	(0.0238)	(0.0274)	(0.0328)	(0.0428)	(0.0455)
F-Test p-value	0.536	0.017	0.754	0.818	0	0	0.019
B: SST anomaly days							
2000*SST	-0.0007	0.0005	0.0002	0.0003	0.0001	0.0013**	0.0002
	(0.0007)	(0.0006)	(0.0003)	(0.0004)	(0.0005)	(0.0006)	(0.0006)
2007*SST	0.0001	-0.0001	0.0001	-0.0004	0.0002	0.0007*	0.0001
	(0.0005)	(0.0004)	(0.0002)	(0.0003)	(0.0003)	(0.0004)	(0.0004)
F-Test p-value	0.2110	0.284	0.753	0.08	0.772	0.319	0.838
N	30363	30363	30363	30363	30363	30363	30363
Mean dep var	1.499	0.523	0.166	0.185	0.31	0.738	0.747

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. Dependent variables are log of purchased consumption expenditures and log of consumption of household production (expenditure-equivalent).

Table 18: 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	-0.5101***	-0.0849	0.0176	-0.6236***	-0.2566	-0.0134
	(0.1726)	(0.1731)	(0.2078)	(0.1675)	(0.178)	(0.1573)	(0.1967)
2007*Bleach	0.0462	-0.1461	0.1533	0.2093	-0.1223	0.0159	0.1485
	(0.1572)	(0.1574)	(0.1863)	(0.1642)	(0.1638)	(0.1472)	(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	-0.4291**	-0.2237	-0.196**	-0.1323	-0.1718	0.0285
	(0.202)	(0.2107)	(0.2028)	(0.0891)	(0.123)	(0.1649)	(0.1602)
2007*Bleach	-0.0769	-0.434**	-0.5052***	-0.0764	0.1216	0.0802	0.0143
	(0.1953)	(0.1788)	(0.1798)	(0.0965)	(0.1226)	(0.1505)	(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 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. Dependent variables are log of purchased consumption expenditures and log of consumption of household production (expenditure-equivalent).